A COMPARATIVE STUDY OF ELECTRICITY PRODUCTION IN CANADA

by Pauline K.S. Chung

Thesis presented to the Department of Economics of the University of Ottawa as partial fulfilment of the requirements for the degree of Master of Arts

Ottawa, Ontario, 1972

ACKNOWLEDGMENTS

The author thanks staff members of the Department of Energy, Mines and Resources, National Energy Board, Statistics Canada, Ontario Hydro, and Hydro Quebec for their valuable information and advice.

The author acknowledges the encouragement and constructive criticisms of Professors in the Department of Economics of the University of Ottawa especially Professors Dagum, Spry and Zerbinis.

The author wishes to give special thanks to Prof. J. Kuiper for the use of his MATOP Computer Program.

Last but not least, the author is grateful to Prof. P.J. Crabbé of the Department of Economics, for his patient advice and guidance. Without his initial and continuous encouragement and support this thesis could never have been carried out and completed.

CURRICULUM STUDIORUM

Pauline K.S. Chung was born on September 14, 1939 in Canton, China. She received a Honours Bachelor of Arts degree (Economics and Statistics) in 1965 from the University of Hong Kong.

TABLE OF CONTENTS

LIST OF TABLES IN THE TEXT

LIST OF DIAGRAMS IN THE TEXT

INTRODUCTION

In the United States, many studies have found that there are increasing returns to scale in the electricity industry but one study found that the long run average cost curve beyond a certain production level is a horizontal straight line.[1] In Canada, there is little published work about this problem.

Chapter I presents a survey of the technology and production of the industry. We study the broad engineering features of electricity generation from hydro electric-power plants, thermal electric-power plants and nuclear electric-power plants, and transmission and distribution. The allocation of production among the various generation processes from 1956 to 1968 in Canada as a whole as well as in each province is worked out.

Chapter II presents a study of the cost and market structure of the industry. It is a qualitative study of investment, production costs and financing of hydro electric-power plants and steam electric-power plants and distribution costs. The peculiar demand pattern for electricity and the allocation of large capacity costs lead to an interesting study of price determination in this industry. Average revenues from different groups of consumers from 1956 to 1968 in Canada and in each province are also worked out.

---

1 See Appendix III.6, Johnston, p.140 below.

Chapter III is an econometric study of the production function for electricity generation. It begins with a review of the necessary theoretical background for building the model including a study of the Neoclassical production functions and the duality principle of production and cost functions. A generalized Cobb-Douglas production function reduced to a cost function is used in this study. A moving cross section of thirteen observations (from 1956 to 1968) for each province on total cost, output, wage rates, rental rate of capital equipment and fuel price is used to test the selected model. Increasing returns to scale are found to prevail in the generation of electricity in Canada.

CHAPTER I

ELECTRICITY INDUSTRY IN CANADA - TECHNOLOGY AND PRODUCTION

Electricity has to be produced and delivered to the final consumers. The process of production is called generation and its transportation is referred to as transmission and distribution.

In Canada, broadly speaking two kinds of generation processes are used : hydro and thermal. In the process of hydro-electric generation water-wheels and turbines are used. Thermal generation can be broken into three types of engines and turbines - steam, internal combustion engines (using oil) and gas turbines (using gas). Conventionally coal or oil or gas is used in steam plants,[1] but since the announcement of the approved construction of the large-scale CANDU plant (Canadian-Deuterium Uranium) at Douglas Point on Lake Huron by the Hon. Gordon Churchill[2] on June 18, 1959, Canada began to use nuclear fission for power generation (37). However nuclear power is still in the experimental stage not only in Canada but also in the rest of the world.

More than half of the Canadian provinces are blessed with tremendous water power potential and rely mainly on hydro power. These provinces are Newfoundland, Quebec, Ontario, Manitoba, British Columbia, and the Yukon.[3] However these provinces use thermal plants also.

---

1 From now on, "any" kind of plant means "any" kind of electric-power plant unless otherwise specified.

2 The minister then responsible for nuclear power projects.

3 From now on, the Yukon will always mean the Yukon and Northwest Territories unless otherwise specified.

One of the reasons is that there are not many suitable hydro sites available in some of the provinces. Another reason is that even if there are abundant power sites auxiliary plants may be essential when the water flows are too low.

From the economic point of view, although the initial cost for constructing a hydro electric generating plant is high the variable cost per unit of electricity generated is extremely low compared with variable generation costs from thermal plants. The physical life of hydro plants (about 50 years) is much longer than that of the thermal plants (about 20 to 30 years). Some provinces, like Nova Scotia, New Brunswick, Saskatchewan and Alberta, which rely largely on thermal plants, also construct hydro plants to the extent that there are suitable sites.

1. Technology

A. Hydro Electric Power

(1) Engineering

Rain that has fallen upon the earth's surface flows down to the sea. The volume of the flow and the distance through which it falls can be concentrated at a given site so that the force of the falling water can be harnessed. Formally :

$$P = \frac{Q\ h\ n}{8.8}$$

Where P is horsepower (1 horsepower = 550 foot-pound per second).
Q is the rate of water flow in cubic feet per second.
h is the height of the water fall in feet.

n is the efficiency of conversion of potential energy to drive the shaft (the efficiency of well-designed plants may approach 90%) (99 p.489).

There are two kinds of plants : run of river and storage. Run of river plants can use the natural fall but they can generate energy only when there is a sufficient flow of water. Storage plants need a dam to give a steady flow of water. Water is brought to the power house by canals and a penstock; and surplus water is discharged through the spillway into the original river channel.[4]

The operation of the hydro generating unit is controlled by the "governor" which regulates the opening of the turbine gates in response to the demand. The impact of the falling water on the blades of the turbine makes them rotate with a small and fairly constant velocity. A shaft from the turbine drives a magnet that spins inside a coil of wire in the generator which thus produces electricity.[5]

(2) Geographical Distribution of Possible Hydro Sites in Canada (64)

Geologically speaking, Canada is naturally divided into five principal regions : The Canadian Shield, the Cordilleran region, the Plains regions, the Appalachian region and the Innuitian region.[6]

The Canadian Shield covers more than 1,800,000 square miles. Its southern part extends a little way into the United States to the west and south of Lake Superior; its eastern section crosses the St. Lawrence River east of Kingston. It has numerous lakes and its surface is less than 2,000 feet above sea level. The highly developed

---

4 An illustration of the flow of water from the river to the powerhouse and out of it to the river is shown in Appendix I.1a.

5 An illustration of the process of electricity generation using a hydro turbine is shown in Appendix I.1b.

6 A map showing these regions is in Appendix I.2.

drainage basins of this Canadian Shield comprise tributaries of the Great Lakes, and the St. Lawrence System. The lakes provide an enormous natural storage system which gives the St. Lawrence great potential for electric power development.

The Cordilleran region, which includes the Rocky Mountains, covers the far West of Canada. The Cordilleran system consists of water power on which there is snow fed from mountain rivers such as the Yukon, Fraser, Columbia, and Kootenay.

The Plains regions include several distinct areas. The Interior Plains region covers a large part of Manitoba, Saskatchewan, and Alberta. This area is underlain largely by flat-lying shales and sandstones of cretaceous age, which are partly of marine, and partly of freshwater origin.[7] Since the Prairies have little potential hydro power it is brought from the Cordilleras in the west and the Canadian Shield in the east and north. Good examples are the Calgary Power Company and the Manitoba Power Commission, which are fed respectively by the Bow river in the mountains and the Winnipeg river in the Shield.

The St. Lawrence Lowlands are the fertile plains that extend south of the Canadian Shield from Lake Huron to Quebec City and along the lower part of the Ottawa River.

The Hudson Bay Lowlands stretch between the southern coast of Hudson Bay and the western coast of James Bay, and the northern edge of

---

7 The Interior Plains region is important not because of its hydro power but because of its resources of petroleum, natural gas and coal.

the Shield. The Arctic Lowlands and Plateaux are underlain by fairly flat-lying sedimentary strata.[8]

The Appalachian region, which is the northern extension of a much longer mountainous belt in the United States, includes the part of Quebec lying south of the St. Lawrence River and east of a line between Quebec City and Lake Champlain. The Appalachian area also includes New Brunswick, Nova Scotia, Prince Edward Island, and the Island of Newfoundland. In these regions the catchment areas of the rivers are small and it is suitable for small scal hydro development. Therefore there are numerous well-distributed, small-scale, potential hydro sites in each of these provinces except Prince Edward Island.

The remote Innuitian region in the northern Archipelago consists of mountains and ridges that rise as high as 10,000 feet.

Although Canada is richly endowed with rivers and lakes, much of her water resource is lost to the ocean because precipitation and run-off are not distributed uniformly throughout the year.[9] Some of these fluctuations in flow can be remedied by the creation of artificial storage by means of dams and reservoirs. In practice, there may be physical, engineering, political or conflicting use obstacles to such construction.

Another problem is the direction in which the water flows. For example, about 60% of the run-off is carried by rivers flowing "down north," but about 90% of the population is concentrated within 150 miles of

---

8 The Hudson Bay, Arctic Lowlands and Plateaux have deposits of petroleum, natural gas, lignite coals and gypsum.

9 See the table of "Seasonal Pattern of Run-off for Settled Areas in Canada" in D. Cass-Beggs, "Water as a Basic Resource", in Krueger, R.K., (ed.), Regional and Resource Planning in Canada (Toronto : Holt, Rinehart and Winston of Canada, Ltd., 1963), p.160.

the southern border. On the other hand, more than 50% of the population lives within the drainage basin of a single river, the St. Lawrence, which has a flow of 240,000 cubic feet per second, the largest average flow among the ten major Canadian rivers.[10]

(3) Other Uses of Water (101)

Even though the availability of water power resources offers potential water power, there are also other competing, or complementary demands for water. For example, navigation is protected by the Federal Government so that navigation channels can be kept free from obstruction and an adequate level of water is maintained. The construction of dams and hydro plants can be an obstacle to navigation. However, power development may provide additional facilities for navigation. For instance, the international section of the St. Lawrence Waterway project provides for the mutual benefit of improved navigation and water power.

Waterways are used by the lumbering and pulp-and-paper industries to float logs down the river. The prior right of floating logs downstream from timber limits to mills is protected by the Ontario, Quebec, Nova Scotia and New Brunswick governments. Therefore power plants and storage dams can be erected only when they can provide suitable slides through which the logs can pass them. On the other hand, storage projects and the construction

10 See the table of "Drainage Areas and Average Flows of Rivers in Canada" in Clark, R.H., Canada's Surface Water Resource, (Ottawa : Department of Energy, Mines and Resources, Inland Waters Branch, 1968) p.5. (The flow in the St. Lawrence is remarkably steady.)

of suitably equipped power plants may at the same time benefit logging interests by improving the river for floating.

Fishing interests are also protected by Federal legislation and provincial statutes. The development of power projects may destroy the fisheries. For example, the development of power possibilities has been delayed on the Fraser River in British Columbia for the sake of the salmon fishery.

Irrigation in the agricultural industry may compete with power development, especially when the water supply is not abundant, as in some parts of British Columbia and the southwestern prairies. When the water levels are raised by a dam, as in the St. Lawrence project, there may be flooding of farms, townsites, roads and railroads. However, power dams may also solve the problems of flood control, as in the Lake St. John region.

When water is scarce, mining operations in some parts of British Columbia and the Yukon may require water which is needed to generate power. Then mining, like irrigation, becomes a hindrance to power development. The use of water for drinking, domestic, municipal and sanitary needs is given precedence over all other water requirements, under the Boundary Water Treaty of 1909, and under Federal legislation concerning water sources in the Northwest Territories.

Moreover, water is vital to other natural resources such as forests, agriculture and wildlife. Sometimes, hydro-electric projects and forests can create mutual benefits. For example, storage projects and regulation of river flow can contribute to the maintenance of forests and check dangerous soil erosion. On the other hand, preservation of forests may help to regulate stream flow.

In addition, there is a desire on the part of the public, to preserve scenic beauty. For example, in the Niagara Falls power development, the preservation of scenic beauty played a large part in the negotiation of the Boundary Waters Treaty in 1909 between Canada and the United States.

B. Thermal Electric Power

(1) Types of Plants

Conventional Steam Electric Power Plants (99,p.151)

Conventional power plants burn fuels, like coal, oil or gas to vaporize water to steam, the pressure of which drives the turbine. The boiler, which is called the steam generator, performs this major process of vaporizing water to steam. The mechanical energy produced by passing high pressure steam through the turbine drives the generator which produces electricity.[11]

Internal Combustion Engines (99, pp.435-469)

Most of the engines in automobiles, trucks, buses, locomotives, tractors, ships and stationary plants are internal-combustion engines. Either air or a mixture of air and vaporized fuel is compressed in a cylinder by a piston. The compressed air or mixture is ignited by injecting fuel or by an electric spark to raise the pressure sharply; the pressurized combustion gas then works on the piston while it expands. Finally the spent combustion gas is exhausted from the cylinder.

Both compression-ignition and spark-ignition engines can also be used to supply standby power in steam generating station.

---

11 An illustration of a conventional power plant is shown in Appendix I.3a.

Internal combustion engines work alongside the steam units to supply the peak-load demands in small plants.

The fuels used in these plants are gasoline, gas, oil, natural gas, gas and oil combined, but oil is predominant.

Gas Turbines (99, p.473)

In a single-cycle gas-turbine engine there is a compressor which takes in air, pressurizes it, and discharges it to the combustor. The heated gas-air mixture leaves the combustor, enters the turbine and works on the blades which are mounted on the rotor. The rotor drives both the compressor and the generator.

(2) Geographical Distribution of fuels in Canada

Fuels can be imported, but transportation cost is reduced if there are fuel reserves available nearby the centre of demand.

Coal (18)

Although there are plentiful coal reserves in Canada, for example, in Nova Scotia, British Columbia, Alberta, and Saskatchewan, many of the industrial plants that require coal or coke are concentrated in Ontario and Quebec.

In Ontario, Quebec and Prince Edward Island there are no deposits of coal of any immediate commercial significance. As a result more than half of the coal consumed in Canada in 1969 was imported from the United States (27), since transportation cost is lower than delivery expenses from the west of Canada.

Of all the coal reserves in Nova Scotia the Sydney Coal Field yields about 80% of the total output of coal in the province and over 30% of the total Canadian production. In New Brunswick there are seventy-six localities widely scattered about twelve counties in the province which have coal deposits. Most of them consist of coal seams less than one foot in thickness.

The biggest reserves of coal are found in Alberta, where it underlies most of the southern half of the province and is found both in the Plains and in the foothills of the Rocky Mountains. Alberta possesses not only the major proportion of Canadian coal reserves of all types, but has a large coal production, especially of sub-bituminous coal. In the south-eastern part of Saskatchewan large areas are underlain by coal-bearing formations, and in the western section there are even wider areas which are underlain by the Oldman Formation. In Manitoba, there is a very limited deposit of lignite of the Tertiary age, in the southwest.

In British Columbia, coal deposits occur in widely distributed areas. Most of them are small and far from the main population centres.

As to the north, other than actual mining operations which are taking place, there is little knowledge of the local resources in these territories.

Petroleum and Natural Gas (58)

There are large supplies of both crude oil and natural gas, mainly in the Great Plains region. Extensive pipelines are planned and have been built but the distance is great between main industrial areas and drilling areas. For some parts of the country it is more economical to import oil from other countries than to ship it from the west. For example, crude oil is imported [11a] to serve the Atlantic provinces and the Montreal market area, while the rest

11a Perhaps Atlantic provinces will not require imported crude oil in future due to offshore discovery.

of the country is supplied by Western Canadian crude oil which is transported by pipelines.

Historically, before the Leduc discovery in Alberta in 1947, the annual Canadian output of crude oil was less than 10 million barrels, of which Alberta provided about 9 million barrels (mostly from the Turner Valley field). Since the Interprovincial Pipe Line was finished in 1950, Alberta has supplied crude oil not only to the prairie provinces but also to Ontario, Minnesota and Wisconsin. The Trans-Mountain Pipe Line, which was finished in 1953, opened up markets in British Columbia and the Pacific Northwest of the United States. The discovery of crude oil in Saskatchewan has helped to furnish part of the supply to the eastern markets.

In 1968 half of Canada's production of crude oil was exported to the United States. Since imports were about the same as exports, total consumption of crude oil was almost equal to total production in Canada (28).

Since the completion of the Trans-Canada and Westcoast Transmission Pipe Lines in 1958, production of natural gas has increased rapidly. In 1968 about half of the marketable gas was delivered abroad and for that year imports were about 13% of exports (28). In other words, Canada was a net exporter of gas in 1968.

C. Nuclear Power

(1) Engineering (40, 56)

Nuclear power is one of the thermal types of generating electricity where steam is used. The only difference is that instead of using fossil fuels in conventional plants, uranium is used in a nuclear plant for fission to generate heat for steam raising. Nuclear fission occurs when a fissionable nucleus captures a neutron. If one of the neutrons emitted is captured by another fissionable nucleus a second fission occurs similar to the first, another neutron may produce a third fission and so on. This phenomenon is termed a chain reaction. The device in which this chain reaction is initiated, maintained, and controlled is called a nuclear reactor.

A reactor must release energy at a sufficiently high temperature for the attainment of a high thermal efficiency in the associated power cycle. A moderator is required to slow down the rate of fission. The moderator can be graphite, light water, heavy water, beryllium or organic material. Since light water is cheap and plentiful it is desirable as a moderator. Heavy water, on the other hand, has a smaller probability for neutron absorption than light water but it is less effective in slowing down the neutrons.

In addition, a reactor coolant is required to remove the heat released by fission from the reactor. Gas, liquid-metal, light water and heavy water can be used as coolants.[12]

---

12 Some illustrations of a nuclear power plant, reactor and nuclear fission are shown in Appendix I.3b,c,d.

As to the types of fuels used in the reactor, there are four radioactive materials that are suitable for fission, namely uranium-233 (U^{233}), uranium-235 (U^{235}), plutonium-239 (PU^{239}) and plutonium-241 (PU^{241}). The isotopes uranium-238 (U^{238}) and Thorium-232 (TH^{232}) are fissionable by what are termed fast neutrons.

Natural uranium (0.7% of U^{235}) is the only fissile material found in nature and is the least expensive fuel available. Enriched uranium (up to 100% of U^{235}) can only be obtained from natural uranium by an elaborate and very expensive process. Plutonium can only be produced in a reactor by neutron bombardment of U^{238}. It then requires a difficult and expensive chemical process to extract it from the remaining uranium. U^{233} must be produced from thorium in a somewhat advanced type of reactor.

(2) Nuclear Power Development in Canada (37)

Towards the end of the World War II the decision to apply nuclear energy to peacetime use encouraged Canada to erect at Chalk River a multi-million-dollar pilot plant for the production of plutonium from uranium, using heavy water as moderator and coolant. The first reactor ZEEP (Zero Energy Experimental Plant), costing $200,000, was designed in 1944-45. The second one NRX (National Research X-perimental) was fifty times as expensive as ZEEP. By 1954 the third one, NRU (National Research Universal), could produce sufficient plutonium and sold part of it to the United States Atomic Energy Commission.

In 1954 another reactor, NPD (Nuclear Power Demonstration), was designed at Rolphton Power Station. NPD was essentially a combination and adaptation of the line of approach already well established in the

ZEEP, NRX and NRU pattern. It was also the first heavy-water nuclear power plant to be designed as a prototype in the world.

The first nuclear power for electricity generation installed in Ontario was justified for the following reasons: First, the demand for electricity continued to increase with the increase of population and economic growth. Secondly, undeveloped power resources in Ontario were running short and therefore the possibility of further hydro power development was limited. Thirdly, there was very little fuel, like coal, oil, gas, for conventional plants. Although coal was available from the United States, perhaps, someday because of political or economic reasons Canada would not be able to import any more coal from there. Finally, Ontario had very promising availability of nuclear fuel.

In 1959 a large scale power plant, CANDU (Canadian-Deuterium Uranium), with generating capacity of 200,000 kilowatts, was built at Douglas Point on Lake Huron. CANDU could produce ten times as much electricity as NPD. In 1964 a one-million-kilowatt nuclear power station named Pickering Generating Station was proposed and subsequently built on the shore of Lake Ontario. Two digital computers were proposed for control of the reactor and turbine systems.

Towards the end of 1966 an advanced type of nuclear power reactor CANDU-BLW with a capacity of 250 megawatts (1 megawatt =1,000,000 watts = 1,000 kilowatts) was built in Quebec. It used natural uranium as fuel and heavy water as the moderator but it was cooled by boiling light water. This cooling medium was an innovation and it would lower per unit capital cost.

Besides those in Ontario and Quebec, there were nuclear power research activities in other provinces. For example, in 1965 the Whiteshell Research Laboratory on the Winnipeg River started the research and development of nuclear power in Manitoba. A plant that produced heavy water for nuclear reactors was erected at Glace Bay, Nova Scotia.

Another project in connection with nuclear power generation was ING (Intense Neutron Generator). A report published by the Privy Council Office in 1967 said that the importance of ING arose from two of its properties : (i) it produced a large number of free neutrons that were not "committed" to use in keeping a reactor critical and therefore might be used to convert fertile to fissile atoms; (ii) the high-energy protons might be used directly to produce fission in fertile materials with a net gain of energy (1). The report further said that either of these properties, or possibly a combination of the two might be exploitable for the production of cheaper nuclear power and for the expansion of our nuclear energy reserves.

D. Transmission and Distribution (74)

Electricity is transferred from the generating station to the customers by means of transmission lines and distribution lines. Transmission lines can be designed to transmit large quantities of electrical energy over relatively great distances. They operate at high voltages in the order of 60,000 to 500,000 volts or even higher. Distribution lines carry limited amounts of power over shorter distances. They usually operate at voltages in the order of 2,000 to 40,000 volts.

For economic reasons, three-phase circuits are generally used for transmission of electrical power. There are five kinds of transmission lines - single lines, parallel lines, radial lines, ring systems and networks. A network is a combination of other systems; often it constitutes several ring systems with sections of single, parallel or radial lines. Also it is most common in large systems.

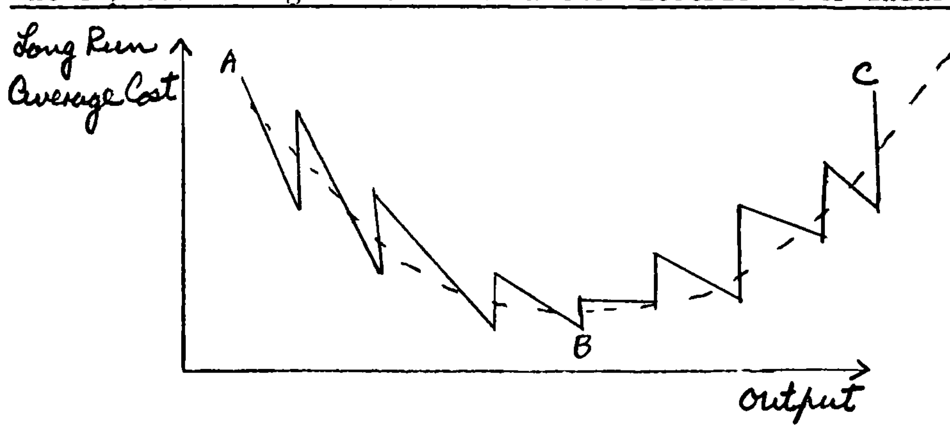
Distribution systems, in general, comprise that part of the network of a power system which distributes power locally. They can be classified according to nature of current, method of connections, number of phases, mounting, voltage and frequency.

The cost of transmission lines including transmission loss is one of the important factors in the selection of a electric power site. All transmission lines have resistance, which is determined by the conductor material, conductor size and length of the line. The transmission loss in watts is the product of the line current squared times the resistance of the line (I^2R) (74).

E. Economic Significance

From the technological characteristics of the electric power industry we can see that there must be great amounts of indivisible and discontinuous costs in this industry. Firstly, load factor varies as a result of fluctuation of demand, therefore a utility company needs sufficient capacity to meet the peak load. Secondly, there is a gap between peak load and low load because it is impossible to produce electricity in advance and store it. Thirdly, for an estimated increase of future demand it is necessary to build a plant immediately, and gradually the load factor will be built up. Fourthly, it takes time to construct a plant.[12a] Therefore a high average cost of the development of a new plant is expected at the initial stage of its development. Even though there is no technical change and the prices of inputs remain constant, the long run average cost curve of this industry will not be smooth. It will be in "steps" form as shown in the following diagram from A to B and to C (if there are decreasing returns to scale).

Fig. 1.1 Anticipated Average Cost Curve in the Electric Power Industry



However, in our following mathematical and econometric analysis we assume that the long run average cost is smooth as shown by the dotted line in the same diagram.

12a See p.20.

2. Production

A. Installed Generating Capacity[13]

(1) Canada as a whole

In 1956 total capacity[14] in Canada was 16 m.k.[15] It gradually increased up to 36 m.k. in 1968. This yields an average rate of increase of 10% p.a. (per annum).

Hydro capacity[16] in 1956 was 13 m.k. and in 1968 it was 25 m.k. These figures are worked out at 85% and 69% of the total capacity in Canada in 1956 and 1968 respectively. The remaining capacity was in conventional thermal plants (15% in 1956 and 31% in 1968.).

Of the total thermal capacity, 2.2 m.k. and 9.6 m.k. was in steam plants in 1956 and 1968 respectively; 0.2 m.k. and 0.5 m.k. in internal combustion plants respectively; 0.01 m.k. and 0.9 m.k. in gas turbine plants respectively.

Even though there has been a rapid rate of increase of thermal capacity, hydro plants are still the major source of electricity generation in Canada.

---

13 This analysis is based on parts of the computer results worked out from data in D.B.S., 57-202 (annual), Electric Power Statistics Vol. II (1956-68). (Since 1956 consistent data were available and the latest available data are for 1968).

14 Total capacity means total generating capacity installed in both publicly and privately-operated utilities as well as in industrial establishments in Canada.

15 From now on, m.k. means nameplate rating in million kilowatts, unless otherwise specified. (In calculating the nameplate rating in kilowatts we assume that the machine works full capacity throughout the year and it gives a total of 8760 kilowatt-hours a year).

16 From now on, hydro or thermal means hydro-electric power or thermal-electric power unless otherwise specified.

(2) Distribution Among Provinces

Hydro-Electric Power Capacity[17]

Of the total hydro capacity in Canada in 1956 Quebec and Ontario had 44% and 32% respectively. In 1968, Quebec had 44% of the total hydro capacity but Ontario had only 26%. Throughout the 1956-68 period British Columbia had about 14% of the total hydro capacity in Canada. In 1968 the remaining provinces had less than 10% of the total hydro capacity in Canada.[18]

Whether or not there is any possibility of further development of hydro power depends on the availability of undeveloped water power sites. In 1968 Quebec had the highest undeveloped water power of 36 m. kw (million kilowatts),[19] which was more than three times its developed water power in the same year. British Columbia was second in undeveloped water power with 24 m. kw, which was more than seven times its installed generating capacity. Manitoba was third, having 6 m. kw. in undeveloped water power, which was more than five times its developed water power in 1968.

Other remaining provinces and territories, the Yukon, Alberta and Newfoundland, had undeveloped water power of more than 3 m.kw. each in 1968. Ontario and Saskatchewan had potential capacity of less than 2 m. kw. each. New Brunswick, Nova Scotia, and Prince Edward Island had potential capacity of less than 0.5 m. kw. each.

---

17 For the historical development of hydro-electric power in Canada, please see the summary account of each province described in Canadian Citizership Branch, Our Resources (Ottawa : Department of the Secretary of State 1968) p.99-109.

18 See Appendix I.4.

19 See Appendix I.5.

Thermal Electric-Power Capacity

Steam Plants - Of the total capacity from steam plants in Canada in 1956 39% belonged to Ontario, 16% to Alberta and 13% to Saskatchewan. In 1968 Ontario had 47% of the total steam power capacity in Canada, Alberta, 13% and British Columbia, 12%. In 1968 the remaining provinces had less than 10% of the total steam power capacity in Canada.[20]

Internal Combustion - Of the total capacity from internal combustion engines in 1956 31% belonged to British Columbia, 17% to Saskatchewan and 11% to Alberta. In 1968 36% belonged to British Columbia, 11% to the Yukon and 10% to Alberta. The remaining provinces had less than 10% of the total internal combustion capacity in Canada in 1968.[21]

Gas Turbines - Apparently not many gas turbines were used in electricity generation in Canada during the 1956-68 period. From the available statistics published by Statistics Canada, only Newfoundland, Ontario and Alberta used gas turbines in 1956. Prince Edward Island, Nova Scotia and New Brunswick still had no gas turbine capacity in 1968.[22]

B. Electricity Output

(1) Canada as a whole

In 1956 the total output[23] in Canada was 88 mt.kwh. (thousand-million-kilowatt hours). By 1968, it was 176 mt.kwh, an average increase of 8% p.a.

---

20 See Appendix I.4 .

21 See Appendix I.4 .

22 See Appendix I.4 .

23 Total output means total electricity generated by both publicly and privately operated utilities as well as industrial establishments in Canada.

Output from hydro plants was 81 mt.kwh in 1956 and 135 mt.kwh in 1968. These figures worked out at 93% in 1956 and 77% in 1968 of total output in Canada. The remaining output was from thermal plants (7% in 1956 and 23% in 1968).

Of the total output from thermal plants 6 mt.kwh and 40 mt.kwh were from steam plants in 1956 and 1968 respectively; 0.5 mt.kwh and 0.9 mt.kwh were from internal combustion engines respectively; 0.03 mt.kwh and 0.7 mt.kwh were from gas turbines respectively.

Hydro plants were responsible for a major portion of the output during the 1956-68 period and steam plants were the second largest group of contributors.[24]

(2) Capacity Utilization Ratio (Output/Capacity)

In the electricity industry, not all the plants can be turned on at every moment because of the fluctuation of stream flows and of demand. Consequently even if the total output is below total capacity we cannot say that the station is inefficient in running its plants. Also it takes time to construct hydro and thermal plants and in anticipation of future increase of demand, which involves some uncertainty, most plants are built ahead of time.[24a] Therefore we should not expect to find that output equals capacity at all times. Perhaps if the aggregate output in a year is much below the aggregate capacity for the year, a remedy should be found to fill up the gap between capacity and the rate of the use of the capacity.

---

24 See Appendix I.6.

24a See p.16a.

Taking Canada as a whole, the utilization ratio in hydro plants was above[25] 60% throughout the 1956-68 period (69% in 1956 and 62% in 1968). The utilization ratio in thermal plants increased from 31% in 1956 to 43% in 1968. The utilization ratio in steam plants increased from 31% in 1956 to 47% in 1968. The utilization ratio in internal combustion plants was 29% in 1956 and 22% in 1968. As to the gas turbines, the utilization ratio was around 10% since 1957.

These results further prove that Canada still relied mainly on hydro generation during the 1956-68 period. Steam plants gradually became important while internal combustion plants and gas turbines still took an auxiliary role.

C. Individual Provinces[26]

In 1956 over 90% of the total output in some of the provinces, namely Newfoundland, Quebec, Ontario, Manitoba, British Columbia and the Yukon, was from hydro plants. In 1968 Newfoundland, Quebec and Manitoba still kept the same high percentage of above 90%. British Columbia had 82% and the Yukon had 78% but Ontario had only 68%. The shift from hydro generation to thermal generation is obvious in Ontario.

Prince Edward Island depended entirely on thermal generation throughout the 1956-68 period. In 1956 a major percentage (almost 60%) of the total output in some of the provinces, namely Nova Scotia, New Brunswick, Saskatchewan

---

25 See Appendix I.7a.

26 See Appendix I.7b and Appendices II.1a-1.

and Alberta, was from thermal plants. In 1968 Nova Scotia and Alberta tended to use thermal plants even more.

In Newfoundland, Quebec, Ontario, Manitoba, British Columbia and the Yukon, the capacity utilization ratio in hydro plants is higher than the capacity utilization ratio in thermal plants throughout the 1956-68 period.[27] In Nova Scotia, Saskatchewan and Alberta the capacity utilization ratio in thermal plants is higher than the capacity utilization ratio in hydro plants in 1968.

3. Conclusion

93% of the total electricity output in Canada was generated by hydro plants in 1956 but only 77% in 1968. The decision to construct a hydro plant depends on the demand for electricity and on the existence of water flows and head. It also depends on the cost of construction which, in turn, depends on the hydro site. In Canada, on the average, there is abundant water but the distribution of water flows does not coincide with the distribution of demand for electricity geographically, seasonally and periodically. There is a shortage of hydro power sites in the densely populated areas. Economically it is not efficient to transmit electricity through a long distance because of transmission losses and the cost of constructing transmission lines.

---

27 See Appendix I.7a.

Possible sites for thermal power plants are not so restricted. Even though there is not much coal in Central Canada, it can be imported from the United States or from elsewhere in Canada. The Leduc discovery of crude oil in Alberta in 1947 and the completion of Trans-Canada and Westcoast Transmission Pipe Lines for natural gas in 1958 further encouraged power companies to construct more thermal plants for electricity generation.

When individual provinces are investigated separately, Prince Edward Island, Nova Scotia, New Brunswick, Saskatchewan and Alberta are found to have used more thermal capacity than hydro capacity throughout the 1956-68 period. The lack of undeveloped water power sites and/or abundance of cheap fuels were the main causes. Therefore they are grouped as thermal provinces, while the remaining provinces, Newfoundland, Quebec, Ontario, Manitoba, British Columbia, and the Yukon are grouped as hydro provinces.

Although output from nuclear plants is only a tiny percentage of the total output in Canada, its potential role in future cannot be ignored. Canada has done much research in solving many nuclear power technological problems since 1945. Up to 1968 there were two nuclear plants in Ontario : CANDU at Douglas Point on Lake Huron (capacity 200,000 kw); Pickering Generating Station on the shore of Lake Ontario (capacity 1,000,000 kw). In Quebec there was a nuclear power reactor style CANDU-BLW at Gentilly Station (capacity 250 megawatts = 250,000 kw.)

CHAPTER II

ELECTRICITY INDUSTRY IN CANADA - COST AND MARKET STRUCTURE

Electric power in Canada is generated by three types of enterprises, namely, public utilities[1], private utilities[2], and industrial establishments. Public and private utilities sell electric power to the public consumers. The public utilities have to comply with their own Provincial Power Commission Acts while the private utilities are regulated by Public Utility Acts of the provinces. Industrial establishments generate electric power only for their own use not as a commercial venture.

In 1956, 49% of electric power produced in Canada was generated by public utilities, 29% by private utilities and 22% by industrial establishments. In 1968, 71% of electric power came from public utilities, 10% from private utilities and 18% from industrial establishments. Although the change was towards public enterprise private enterprises were not small suppliers of electric power in the 1950s.

The pricing policy used for selling power becomes an interesting topic due to the peculiar cost structure and load factor problem. The public utilities have to provide power at cost and analytically this objective in pricing can be called Full Cost Pricing (Average Cost Pricing). On the other hand, owing to the constraint imposed by the Acts, the private utilities are assumed to adopt "Cost Plus Pricing" policy. The relative merits of these two pricing policies together with Marginal Cost Pricing will be discussed.

1 From now on, "public utilities" means "publicly-operated utilities" unless otherwise specified.

2 From now on, "private utilities" means "privately-operated utilities" unless otherwise specified.

In practice, there is no uniform rate for a unit of electric power sold, but the method of "Block Discrimination with Separate Rate Schedules for Different Classes" is generally used in the electricity industry (29). Consumers are separated into several groups, such as industrial, commercial, residential (domestic and farm) and municipal (street-lighting) users and they are charged different schedules of rates. Within each group of consumers "Block Discrimination" is carried out. A consumer pays the highest rate for a certain initial amount of electric power consumed per period, and if he consumes more he will pay a lower rate for the next amount of electric power consumed and so on. This "price discrimination"[2a] serves to encourage more consumption within the period.

1. Organization

A. <u>Types of Corporations</u>

(1) <u>Publicly Operated Utilities</u>[3]

Provincial Power Commissions have been established in most provinces in Canada. They generate, purchase and distribute power, and also develope the electricity network in their own provinces. They are set up by their own Provincial Power Commission Acts.

2a This term "price discrimination" will further be discussed in a later section.

3 Revised Statutes of Canadian Provinces.

Financially most of the Power Commissions are authorized by the Lieutenant Governor in Council (LGC) to raise funds. The money which is raised may be advanced to the Commissions directly or applied by the Treasurer of the province in the purchase of notes, bonds, debentures or other securities issued by the Commission[3a]. In addition, the Commission may from time to time borrow by way of temporary loan from any chartered bank or any person subject to the approval of the LGC. The LGC as representative of the province may guarantee the repayment of advances made by banks or any other form of indebtedness incurred by the Commission.

The power[4] that is supplied to a municipal corporation under a contract is sold at cost price. This usually includes the delivery expenses and an appropriate share of such expenses as : (a) cost of operation, maintenance, depreciation and insurance of the works, and the cost of administration; (b) interest and expenses of debt service; (c) a sinking fund for the repayment of the advances made by the province under the Act for the cost of the works; (d) an amount to be determined by the Commission for the purposes of Reserve Accounts for depreciation,

---

3a See Revised Statutes of Ontario 1970 Chap.354, The Power Commission Act.

4 From now on, power means electric power unless otherwise specified.

reconstruction and repair of works, insurance against loss or damage, Stabilization and Contingencies Reserve[5].

The Commission fixes the rates charged to customers in rural districts which receive power directly from the Commission. It also fixes the rates to be charged by certain small municipal corporations which purchase power from the Commission.

The Power Commission has the right to interrupt or stop delivery of power to customers who fail to comply with any of its conditions. Under legal compulsion it must supply power to customers under the terms of the contracts.

(2) Privately Operated Utilities

Privately-operated utilities are subject to the Public Utility Acts of the individual provinces.

The financial rights of a private utility include selling shares and stocks. They may also borrow money from a chartered bank on mortgage.

In fixing the rates for the supply of electricity private utilities may use their discretion as long as total receipts do not exceed total revenue obtainable at a fair rate of return.

---

5 See Revised Statutes of Ontario, 1970, Chap.354, The Power Commission Act.

(3) Industrial Establishments

Electric power is generated by individual industries and it is not sold in the market.

B. Distribution of Capacity and Output

(1) Canada[6]

Between 1956 and 1968 the capacity in the public utilities increased more than two and a half times. In percentage terms they had 46% of the total capacity in Canada in 1956 and 75% in 1968. On the other hand the absolute capacity operated by the private utilities has dropped since 1962. One possible explanation for these opposite trends is that with the help of Provincial Governments the Power Commissions are financially much stronger. Another explanation is that Provincial Governments have taken over private enterprises.

Generating capacity in the industrial establishments increased between 1956 and 1968. However in percentage terms, it was 21% of the total capacity in Canada in 1956 but only 15% in 1968. This means that industries tended to rely increasingly on power supplied by outside utilities rather than to generate power for their own use.

---

6 The analysis is from parts of Computer Results (worked out from data published in D.B.S. 57-202, Electric Power Statistics, Vol.II, 1956-68).

Between 1956 and 1968 the output from public utilities increased two times. The absolute output from private utilities decreased even more than the capacity reduction. Thus the declining role of the private utilities is further confirmed. Industrial establishments used their plants more intensively as the output from their plants increased at a faster rate than their capacity.

(2) Provinces

The trend in the various province is significantly different from the aggregate behaviour in Canada. For example, in British Columbia and the Yukon, public and private utilities together had capacity of less than 50% of the total capacity in each province in 1956.[7] British Columbia was the only province whose output was mainly generated by industrial establishments in that year. By 1968 the industrial establishments in all the provinces played a minor role.

In Ontario, Manitoba and Saskatchewan public utilities contributed more than 50% of the total output in each province in 1956. By 1968 the public utilities in Quebec, British Columbia, the Yukon and New Brunswick also contributed more than 50% of the total output in each province. In sum, the generation of electricity is becoming more and more provincialized in Canada with the exception of Prince Edward Island, Alberta and Newfoundland.

---

7 See Appendix II.1

2. Cost and Financial Structure

Expenditures in an electric-power utility vary among different types of plants, different types of managements and different geographical locations. The purpose here is to have only a qualitative study of some of the elements of costs. Similarly there will be a qualitative study of the source of funds that cover the total expenditures.

A. Application of Funds - Cost Structure

(1) Investment Cost

To install an electric-power generating plant requires a huge capital investment. The company has to make sure whether it requires an additional energy plant for an extension of an existing energy system or a replacement of an existing energy system. The total cost of constructing a plant depends on the construction facilities encountered, special foundation needs, equipment costs, transportation costs, availability of materials and skilled labour.

Hydro-electric Plants (69)

The investment cost for the dam with pondage and control works is a large part of the cost of development and only when large capacity is installed it is worth consideration. In constructing a plant, many factors affect the total cost such as haul distance, accessibility, access roads, bridges, power for construction, availability of water, excavating, drilling, blasting, hauling, crushing, conveying, screening, construction work, construction material, labour and so on.

Steam-electric Plants (69)

The capital expenditures for a steam plant include costs of foundations, cooling water supply, railroad facilities, fuel handling and storage. Other capital expenditures include costs of turbine-generator, steam generator, water piping system, accessory equipment and high-pressure piping.

3) Transmission and Distribution

The investment cost of transmission and distribution depends on the location of the site, given the technology that is available. It also depends on how the network is constructed, which in turn depends on the nature of current, methods of connections, number of phases, mounting, voltage, and frequency.

In Canada it has been found that the approximate division of capital between the major elements of electric utility systems is : generation 48%, transmission 21%, distribution 25% and other 6% (32).

(2) Production Cost

Hydro-electric Plants

Production cost in hydro plants includes general operation (30%), maintenance (10%) and provision for depreciation (60%)[8].

General operation covers wages such as supervising labour, hydraulic labour, prime-mover labour, generator labour, electric labour

8 These percentages only give a general idea of the composition of production cost in hydro-electric plants in 1951. With technological improvement, perhaps there are some variations (69).

and miscellaneous station labour. It also covers miscellaneous expenses such as lubricants, station supplies and station expenses.

Maintenance covers repairs and replacement of all equipment and structures.

Steam-electric Plants

Production cost in steam plants includes fuel (38%), wages, water, lubrication (15%), maintenance and repairs (9%) and provision for depreciation (38%) [9].

Delivery of fuel to the plant and removal of ash are counted as fuel cost. Maintenance and repairs cover cost of repairing buildings, boiler plants, fuel handling gear, prime movers, generators, electrical equipment and miscellaneous.

(3) Distribution Cost

The daily delivery expenses vary a great deal depending on the number of customers per mile of primary and secondary circuits, the distance of the customers from the generating station and the average amount of power consumption per year and per customer.

The more populated the area and the higher the power consumption per customer the less the distribution cost per kilowatt hour (99).

---

9 These percentages only give a general idea of the composition of production cost in steam-electric plants in 1951. With technological improvement, perhaps there are some variations (69).

(4) Other Costs

All utilities have to pay a premium on insurance against fire risk of the building, steam turbines, waterwheels and governors. Depreciation, which has been mentioned in the production cost, must be provided from the very completion day of the construction of a power-machine unit or plant until it is finally scrapped. Interest, bond discount and dividends are paid for the "money use" in the utility. In addition there are administration and sales costs.

B. Source of Funds - Financial Structure

(1) Construction Investment

In Canada, most of the big projects of power development are carried out by Provincial Power Commissions.[10] In addition to provincial grants, long term debenture issues guaranteed by Provincial Governments and bank loans, there are internally generated funds such as reserves and provision for depreciation.

In Ontario and Manitoba the Power Commissions also issue bonds which are payable in United States currency, West German currency and Canadian currency (84, 71). Saskatchewan also has long-term debts which are repayable in Swiss Francs and United States dollars (96).

Newfoundland, Nova Scotia, New Brunswick have long term loans from the Government of Canada (77, 83, 78).

10 Provincial Power Commissions, Annual Reports and (32 and 32a).

In Prince Edward Island, a private utility called the Maritime Electric Company is the main supplier of electric power in the island (72). Its capital expenditure program is financed by the balance of the proceeds of the sale of its electric system to the customers together with internally generated funds. Sooner or later it will have to resort to outside financing. In order to attract outside funds it has to have a higher rate of return at least comparable to that which investors can obtain elsewhere. However, the average rate for firm power sold there was already the highest in Canada in the 1956-68 period.[11]

(2) Other Source of Funds

Revenue from sales of electricity is the major source of daily income. These sales include the disposal of energy to several groups of buyers : industrial (primary and secondary), commercial, residential (domestic and farm) and municipal (street lighting). With technological improvement in transmission and distribution, power can be transmitted back and forth to neighbour provinces or to the United States. Therefore net sales in each province can be different from the total electricity production in the province.[12] On the other hand payment for the purchase of electricity generated elsewhere has to be deducted from total revenue from sales to all customers.

---

11 See Appendix II.3.

12 See Appendix II.5.

Depreciation and other reserves which have been withdrawn from the previous year's profit are another source of funds for running the routine business. If they have been invested outside the electric business there will be interest receipts. Sometimes it is possible to have a short term loan from a bank when there is unexpected contingency.

3. Average Revenues and Average Charges

A great number of different schedules of rates are designed in each province and therefore it is impossible to make any satisfactory comparison. However, the statistics published by Statistics Canada are classified into five large groups for each province : firm power, secondary power, commercial, domestic and farm, and street lighting. Average revenues have been worked out for Canada as a whole and for individual provinces for the period 1956-68.

(1) Canada[13]

Secondary power is of course sold at a lower price than any other kind of power sold in Canada. In 1956 it was only \$1.8 per 10^3 kwh[14] and after some fluctuation it rose in 1963. By 1968 it was \$3.5. The AR[14a] from firm power also fluctuated with a rising trend from \$6.6 in 1956 to \$8.1 in 1968.

The AR from domestic and farm users was \$16.4 in 1956 but with some fluctuation dropped to \$14.8 in 1968. The AR from commercial users

---

13 See Appendix II.2 .

14 From now on, the figure for average revenue means \$ per 1,000 kilowatt hours, unless otherwise specified.

14a AR means Average Revenue .

dropped from $20.4 in 1956 to $16.6 in 1968.

The AR from street lighting was the highest among all groups and it rose with fluctuation from $23.7 in 1956 to $26.4 in 1968.

32% of the total electricity consumption in Canada in 1968 was by firm power users. Secondary power users consumed 0.6%; commercial users, 11%; domestic and farm users, 21%; street lighting users, less than 1%. 25% of the total consumption was used inside the industrial establishments or generating station, while 10% was lost during the transmission and distribution processes[15].

The average charge for all fuels used to generate electricity in Canada was $3.2 per 10^7 B.T.U.[16] in 1956, but it fluctuated and dropped to $2.9 in 1968. Much imported bituminous coal was used in 1968 (35% of the total fuels used in Canada) and the average charge was $3.3 in 1968. Natural gas was second (20%) with an average charge of $1.9. Heavy furnace fuel oil was third (17%) and the average charge was $3.5. The remaining fuels

---

15 Parts of computer results (worked out from data published in D.B.S., 57-202, Electric Power Statistics, Vol.II, 1956-68).

16 Ibid., 10^7 B.T.U. means 10,000,000 British Thermal Units. The quantities of all kinds of fuels are converted to B.T.U. content, so that average charges can be worked out. From now on, the figure for average charge means $per 10^7 B.T.U. unless otherwise specified.

used included Canadian bituminous coal, sub-bituminous coal, Saskatchewan-lignite coal, other kinds of coal, light furnace fuel oil, diesel fuel oil, other petroleum fuel, manufactured gas and propane.

(2) Provinces[17]

With the exception of British Columbia, Prince Edward Island and Saskatchewan, firm power users were the main consumers in each province in 1956. By 1968 their shares fell because of the increasing demand from commercial, domestic and farm users in most of the provinces.

On the whole the AR_s in the hydro provinces were lower than those in the thermal provinces with the exception of the Yukon. Among all the provinces AR from firm power was the highest in Prince Edward Island, but AR_s from commercial and domestic users were the highest in the Yukon.

(3) International and Interprovincial Transfers of Electricity[18]

The AR from firm power exported to the United States was \$3.3 per 10^3kwh in 1956. It fluctuated and increased to \$6.7 in 1968. The AR from secondary power dropped from \$3.3 to \$0.83 respectively. These AR_s were

---

17 See Appendix II.3 .

18 The National Energy Board may grant a permit to an electric-power utility which intends to export power to the U.S. as long as at least two main conditions are satisfied : quantity and price conditions. Firstly, the corporation has to prove to the Board that there is a surplus of power to Canada. Secondly, the price should be high enough to recover all costs. It must show to the Board that it has tried to meet the opportunity cost which means that the price should be as high as that in the U.S. Furthermore it cannot be less than the price of similar power sold in Canada. Figures are parts of computer results (worked out from raw data published in D.B.S., 57-202, Electric Power Statistics, Vol.II, 1956-68).

lower than the corresponding AR_s received from consumers in Canada. The main reason is that all electric-power exported was generated from excess capacity in Canada and therefore the unit cost was very low. The average charge for electric-power imported from the U.S. was $0.95 in 1964 and $1.4 in 1968.[19]

Interprovincial transfers of electric-power are not for profit but purely for the sake of mutual co-operation in order to minimize costs among provinces by helping to ease the standby problem of the other party. Since the transfers were among the provinces there was no net effect in Canada as a whole although there could be a positive or negative balance among the provinces.[20]

4. Price Determination

Owing to the special characteristics in this electric-power industry, such as the impossibility of storing output, indivisible capital cost and a pattern of fluctuation of demand, there is not a single "price" but several scheduels of rates for different kinds of services.

The objectives of designing several schedules of rates include : (1) spreading of indivisible cost; (2) charging different kinds of price for firm and interruptible power, for commercial and residential users; (3) recovering cost of servicing different groups of users;(4) encouraging consumption in all groups of users.

---

19 Total purchased value of power imported began to be published in 1964. See Appendix II.4a and b . The published data give only one figure for the value of both firm and secondary power.

20 For average revenues and average charges, see Appendix II.4b.

There is much controversy about how to determine the rates and what pricing policy is appropriate in this industry. Before going to the literature it is necessary to understand the demand pattern of this industry.

A. <u>Demand Pattern</u>

As an illustration, the following two diagrams give us some ideas of the periodical fluctuation of demand for electricity in the industrial and dwelling sectors.[21]

Fig. 2.1a
Industrial Load

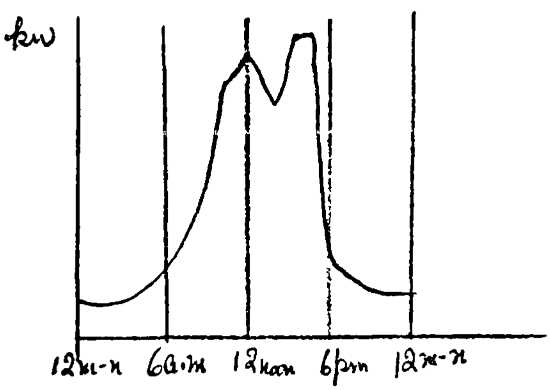
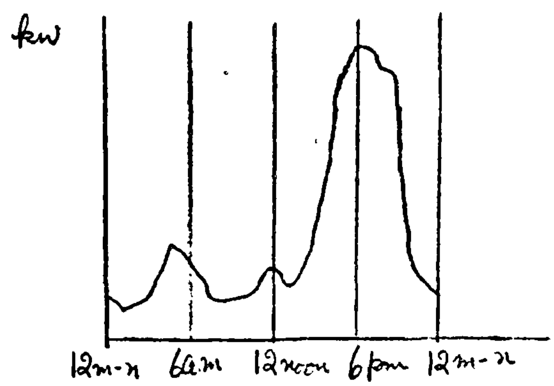


Fig. 2.1b
Dwelling Load



Source : Skrotzki, B.G.A., & Vopat, W.A., Power Station Engineering and Economy (99 p.585)

The load curve for the industrial sector in Canada shows that early in the morning there is only some lighting and auxiliary energy for heating the boiler plant in the factory. At 8 a.m. the whole factory is in full operation and energy demand remains constant at high level until noon. There is a break for lunch but later in the afternoon the whole

---

21 These diagrams only give a general idea of the patterns of fluctuation of demand in 2 sectors. They do not represent any particular place or day or any particular industry.

factory is in full operation again. At about 5 p.m. some machines slow down and by 6 p.m. most of the machines stop leaving one or two working overtime.

The dwelling load refers to a residential community in winter in Canada. Early in the morning, energy is required only for central heating, water heating and constantly used household appliances. At about 6 p.m. most of the people are at home and turn on electrical equipment especially stoves. After 10 p.m. people gradually retire and by 12 mid-night, not much electricity is needed.

The demand pattern in any sector may change from time to time, day to day and season to season. As a result of this fluctuation, the electric-power utility has to be aware of several "factors" including the following three (99) :

1) Load factor $= L_{avg}/L_{max}$

2) Capacity factor $= L_{avg}/Cap$

3) Utilization factor $= L_{max}/Cap$

Where $L_{avg} =$ average load for a certain period
$L_{max} =$ peak load for a certain period
$Cap =$ rated capacity of the plant

("a certain period" means either instantaneous or average, for periods of 1 hr. or less. When the peak load is equal to the capacity of the plant, load factor and capacity factor will be identical. A low utilization factor may mean that the plant is used only for stand-by purposes on a system comprised of several stations or that capacity has been installed well in advance of need.)

In designing any electric-power plant the company has to estimate the maximum demand (peak demand) from its customers in a certain period. It will then build a plant that provides sufficient capacity.

B. Theory of Pricing in the Electricity Industry

(1) Allocation of Capacity Cost

The principle of allocation of capacity cost is to try to allocate to each unit of output the long run incremental cost for producing the extra unit of output. The design of the tariff structure should be such that it is fair to every customer. If there is any shift of consumption as a result of the tariff structure, it should be from peak period to off peak period so that additional capacity is not required.

Among all the methods discussed by Davidson Nordin's Method is the best to the extent that it gives least incentive to consumers to shift to the peak period. The capacity responsibility for each increment of capacity is allocated to the hours during which that increment of capacity is used (29).

Other methods discussed by Davidson are less effective in encouraging consumers to shift to the off-peak period. In fact, in some cases, a consumer can shift to the peak period without any extra burden to himself. These methods include Greene's Consumption and "Demand", "Phantom Customer", "Complete Peak", "Modified Complete Peak", "Capacity Credit", and "Non-Coincident Demand".[22]

---

22 Further explanation and examples of Nordin's Method and other methods are illustrated in Davidson, R.K., Price Discrimination in Selling Gas and Electricity, (29 pp.111-147).

(2) Peak Load Pricing

The main purpose of Peak Load Pricing is to lower the peak demand. Normally supply to meet on-peak demand is priced at long run marginal cost and supply to meet off-peak demand is priced at short run marginal cost only because off-peak capacity is free (36).

In France, Electricité de France has developed a scheme to enforce peak load pricing. A small 133-cycle generator is used, which can give a short high-intensity pulse so as to permit different rates to be applied (12). Presently this system is operated so as to apply three levels of rates : peak, normal and slack period.

(3) Electricity Tariffs

The concept of a "tariff" implies a "flow" which means that a price list is drawn up not simply to dispose of stocks which come casually onto the market but to strike a permanent balance between the flow of demand and the flow of production (12). The objective of the tariff-making process is to encourage customers to adopt the pattern of consumption which is least costly (13).

There are many kinds of tariffs, namely (49) :-

1) Flat Rate - It is strictly proportional to total consumption.

2) Multiple Tariffs - Different flat rates are charged according to the purpose of supply.

3) Two-part Tariff - A standing charge, which consists of a large share of capacity costs, and running charge or unit price, which is connected with operating costs.

4) Block Tariff - It consists of different charges for different loads of consumption.

5) Maximum-demand Tariff - It is a system designed for large and medium-sized industrial consumers.

6) Time-of-day Tariff - It is to charge different rates according to the time of supply.

7) Seasonal Tariff - Lower rates are charged in the season when demand is relatively low.

For example, in Quebec, there are rates for domestic use, general service using small power, general service using medium power and industrial use. Among them there are annual contracts as well as seasonal contracts. Altogether there are more than thirty rates charged by Hydro-Quebec. As an illustration, the following schedules give us some idea of the diversity of rates charged by Hydro-Quebec in 1971 (51) :

(i) Rates for domestic use in the municipalities of Montreal and and Quebec under annual contracts :

"$0.60 fixed charge, plus
3.2¢ per kilowatt hour for the first 100 kwh
1.2¢ " " " " " next 200 kwh
1.0¢ " " " " " remaining consumption
minimum monthly bill was $1."

(ii) Rates for industrial use for the municipalities of Montreal and Quebec under annual contracts :

"$1.43 per kilowatt of billing demand, plus
2.2¢ per kwh for the first 50 hours use of billing demand
1.1¢ " " " " next 50 hours " " " "
0.66¢ " " " " next 50 hours " " " "
0.38¢ " " " " remaining consumption
minimum monthly bill was $1.43 per kilowatt of billing demand."

(4) Price Discrimination

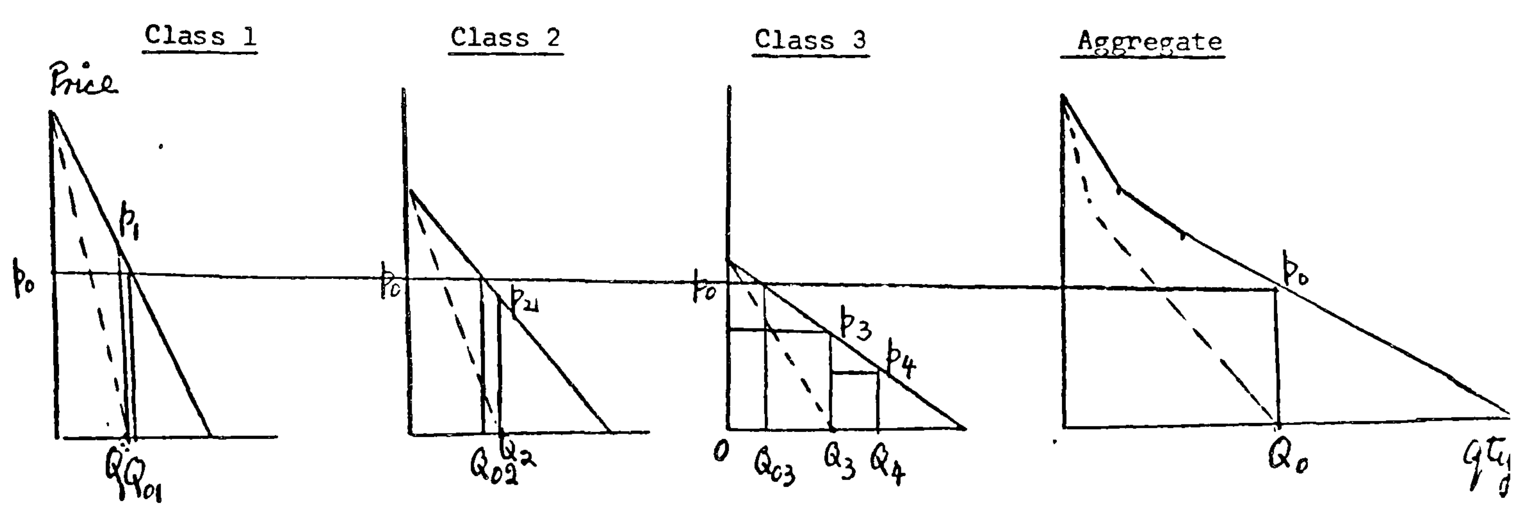
Davidson said that there are two kinds of price discrimination in the electricity industry (29). The first kind is Mrs. Robinson's Price Discrimination in monopoly markets where the elasticities of demands in these markets are different and resale of the commodity is impossible (92), In Canada the customers are separated into several groups. Presumably these groups have different elasticities of demand and definitely resale of electricity is impossible.

Another kind of price discrimination is Pigou's Second Degree Discrimination such that a monopolist can quote several separate prices to the same customer. For instance, in Pigou's words (87):

> "all units with a demand price greater than x were sold at a price x, all with a demand price less than x and greater than y at a price y, and so on."

A monopoly price and the two kinds of price discrimination can be illustrated in the following diagrams :

Fig. 2.2 A Comparison of Price Discrimination



In the above figures there are three classes of customers with different elasticities of demand and the marginal costs are assumed to be zero. (i) If these three classes cannot be separated the monopoly will set a uniform price at p_o and Q_o will be sold at that price. (Q_{o1} will be sold by Class 1, Q_{o2} by Class 2, Q_{o3} by Class 3). (ii) If the classes can be separated he will sell the same total output Q_o. At the same time he can maximize his profits by selling Q_1 to Class 1 at p_1, Q_2 to Class 2 at p_2 and Q_3 to Class 3 at p_3. (iii) If "Block Discrimination with one rate schedule" (Second Degree Discrimination) is to be adopted for Class 3, he may sell OQ_{o3} at price p_o, $Q_{o3}Q_3$ at price p_3, Q_3Q_4 at price p_4.[23]

Paradoxically the "Block Rate Discrimination" scheme is in fact not discriminatory when price differentials are compared with cost differentials. Owing to the nature of the electric-power industry, where indivisible cost is predominant, the short run marginal cost may fall or rise. Assuming the consumer is the only customer and a plant is built for him, the initial cost per unit is high for a small rate of consumption and therefore he has to pay a high price for that rate of consumption. If he consumes more the cost per unit is lower and therefore he pays a lower price for the extra unit of consumption.

---

23 For a further explanation see Davidson R.K., Price Discrimination in Selling Gas and Electricity, (29 pp.44-59).

Although this "Block Rate Discrimination" scheme cannot be considered as Marginal Cost Pricing[24] as there is no proof that each rate equals the exact marginal cost at the particular output level, it can be assumed that this method will yield prices proportional to marginal cost if the rates are worked out accurately. Perhaps it is more appropriate to include this scheme in the "Second Best" method.[25]

(5) Average Cost Pricing and the Electricity Industry in Canada

Even though there are many schedules of rates charged in Canada there must be some basic principle in fixing these rates. The pricing policy in the electricity industry is different from perfect competition analysis discussed in some economic text books. However, in order to show the difference, we begin this section with a review of the text book analysis.

We have been assuming that profit maximization is the goal of a firm and to achieve this, the level of output should be at such a point that marginal revenue is equal to marginal cost. As to the "price" it depends on whether or not the market is competitive.

1) Competitive Industry

In a competitive industry there is :

> "a group of firms closely related in the competitive process by reason of the great substitutability of their respective products, and distinguished from other firms by a 'gap' in the range of of substitute products." (14 p.570)

---

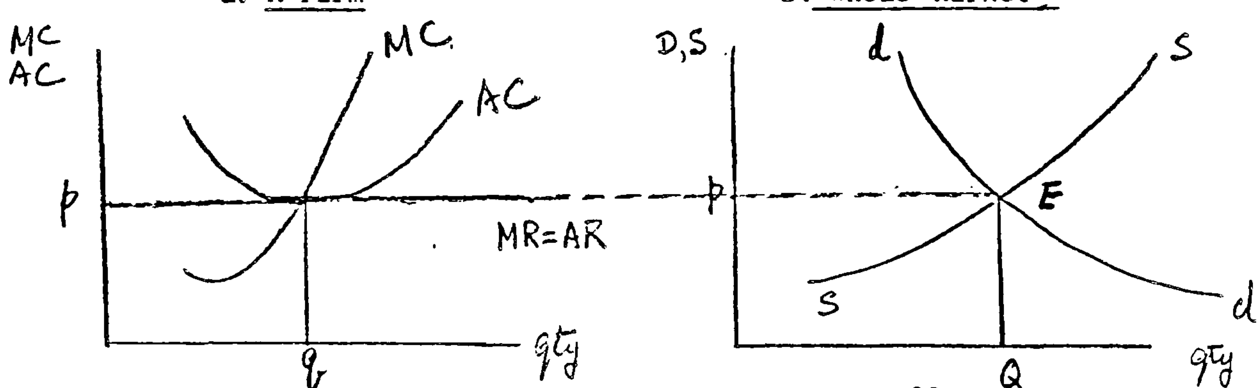
24 Marginal Cost Pricing will be discussed in a later section.

25 Second Best method will be discussed in a later section.

It is assumed that, in the long run, all the firms in the competitive industry can only earn normal profit which is included in the total cost. Equilibrium is at the point where MC = MR and AC = AR.[27] as shown in the following diagrams.

Fig. 2.3 Pricing in a Competitive Industry

a. A Firm b. Whole Market



In fig. 2.3b the sum of the individual firms' MC_s[26] is represented by the supply curve ss. dd is the demand for the homogeneous commodity. At the equilibrium point E, the total quantity sold in the market is Q and the price is p.

In fig. 2.3a any firm in the competitive industry has to sell its commodity at the same price p whatever quantity it sells. Thus the

---

26 At the minimum points of AC_s.

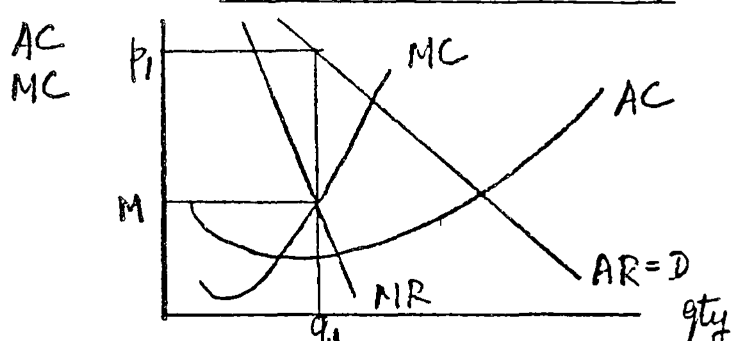
27 From now on, AC means average cost, MC means marginal cost, MR means marginal revenue, AR means average revenue and p means price, unless otherwise specified.

demand curve for the product of a firm is a horizontal line at price p. If the average cost curve (AC) of the firm is below the price line, windfall profit will attract new comers. With an increase of total supply in the market the price will fall. On the contrary, if its AC is above the price line some firms will close down. Thus, in the long run, the price line touches the minimum point of AC where the MC cuts it from below. Automatically any firm in a competitive industry conforms itself to Marginal Cost Pricing as well as Average Cost Pricing.

2) Monopoly

An opposite extreme case shown in some economic text books is that a single firm is the only seller in a market. Thus the demand curve for the firm's product is not a horizontal line but negatively inclined as shown in the following diagram.

Fig. 2.4 Pricing in one-firm industry (monopoly)

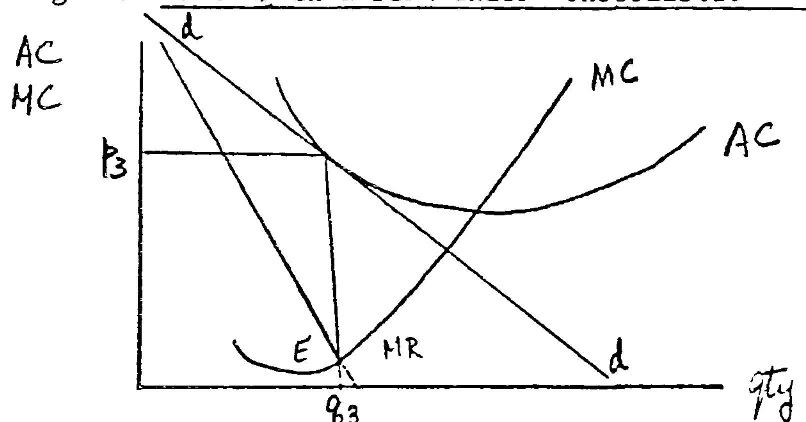


The level of output is still at the point where MR and MC cut. However, a monopoly can take advantage of the consumer's demand curve by charging at p_1. Therefore a price at p_1 does not conform to Marginal Cost Pricing.

3) Monopolistic Competition

Monopolistic competition is in between the above two extreme cases. There are differentiated commodities which are close substitutes but owing to advertisement or packaging, consumers believe that they are different. When monopolistic competition is keen, even though a particular firm can be considered to have a market of its own in the narrow sense, this firm may not be able to enjoy any abnormal profit at all in the long run. For example, in the following diagram, at the point where MR and MC intersect, the firm will sell q_3 at price p_3. At this price d (demand curve) touches AC which means that $p = AC$.

Fig. 2.5 Pricing in a firm under Monopolistic Competition



A price at p_3 happens to be the same price for output q_3 if Average Cost Pricing is adopted. In fact, the firm's original objective is to maximize profit but owing to the market situation it cannot make any abnormal profit.

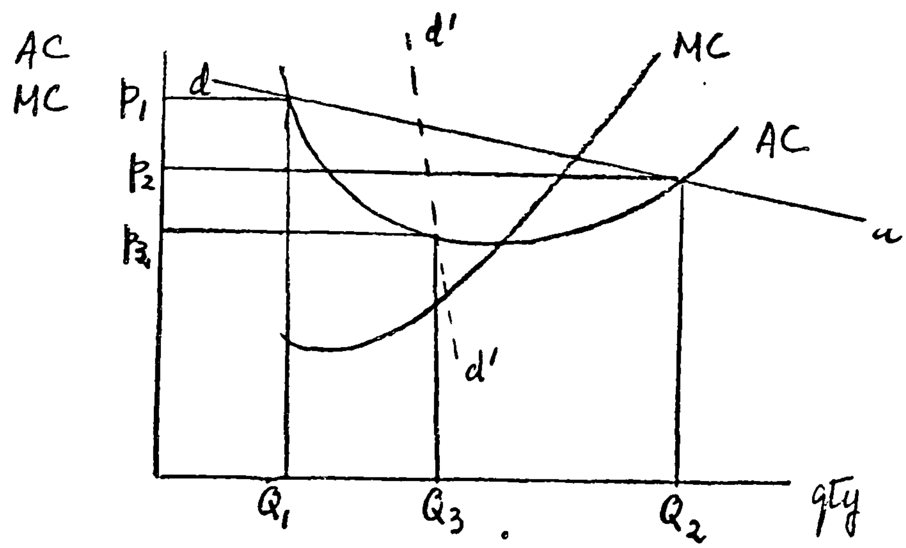
4) <u>Electricity Industry</u>

The electricity industry in Canada does not fall into any one of the above categories. Public utilities aim at recovering total expenditures and therefore they have no intention to maximize profit. Private utilities are very much interested in having high profit but they are regulated by a profit constraint of a "fair rate of return". Therefore an alternative goal is to maximize output. As a result the pricing policy in this industry is different from profit maximization pricing policy.

<u>Average Cost Pricing</u>

As the public utilities have to recover total expenditures for any amount of power sold analytically this objective in pricing can be called Full Cost Pricing (or Average Cost Pricing). This can be illustrated in the following diagram.

Fig. 2.6 <u>Average Cost Pricing</u>

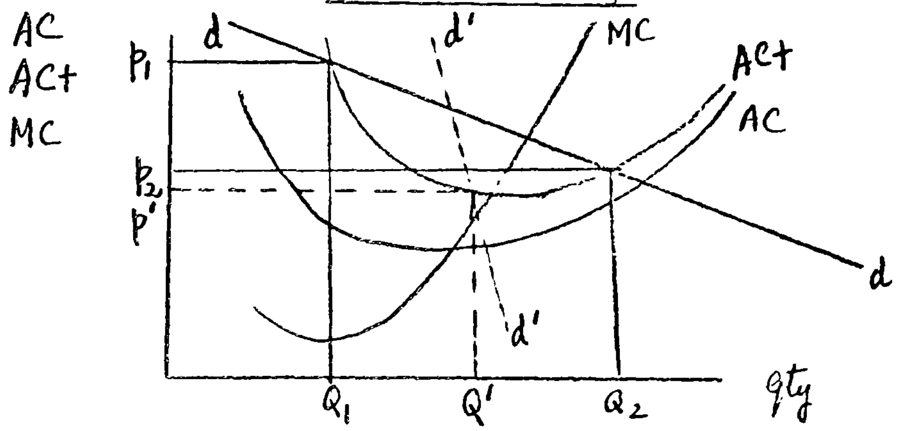


If the demand is dd, the utility can sell Q_1 at p_1. In order to maximize output it is better to sell Q_2 at p_2 because output is larger and price is lower. If the demand is d'd' it will sell Q_3 at p_3.

Cost Plus Pricing

In view of the regulatory constraint the appropriate pricing policy in the private utilities is "Cost Plus" because it can help them to maximize their profits within the profit constraint. This can be illustrated in the following diagram.

Fig. 2.7 "Cost Plus Pricing"



If the demand is dd, the utility can sell Q_1 at price p_1. However, if it sells Q_2 at p_2 output is larger and the price is lower. If the demand is d'd' it can only sell Q' at p'.

In fact, the final results from both of the above analyses will not be too different because usually the "fair rate of return"[27a] does not allow the private utilities to earn much more than the normal profit. This means that the shape and position of ACt in figure 2.7 will not be much different from AC in figure 2.6 as long as other things are equal in both types of utilities.

27a Oral discussion with a member of the Staff in National Energy Board.

Similarly , it is assumed that industrial establishments "sell" electricity to themselves at "full cost" Therefore, in sum, "Average Cost Pricing" is adopted in the electricity industry in Canada.

(6) Marginal Cost Pricing

Marginal Cost Pricing (MCP) means that the amount paid by the consumer for each unit of the product is equal to the marginal cost of the output. MCP in the electricity industry means that a tariff structure is designed in such a way that the cost to any consumer for the level of his consumption equals the marginal cost of the supplier for the quantity produced.

An example of using Marginal Cost Pricing in France (76)

Historically, Electricité de France was the first enterprise in the world to proceed from the theory of MCP in both a schedule of rates and a series of rules for investment policy. The main reason is that most of the public utilities were nationalized after World War II in France. All of them sought a basis for pricing which would both benefit the consuming public as much as possible, and at the same time, offer maximum protection against political pressure for low price levels and a special price structure.

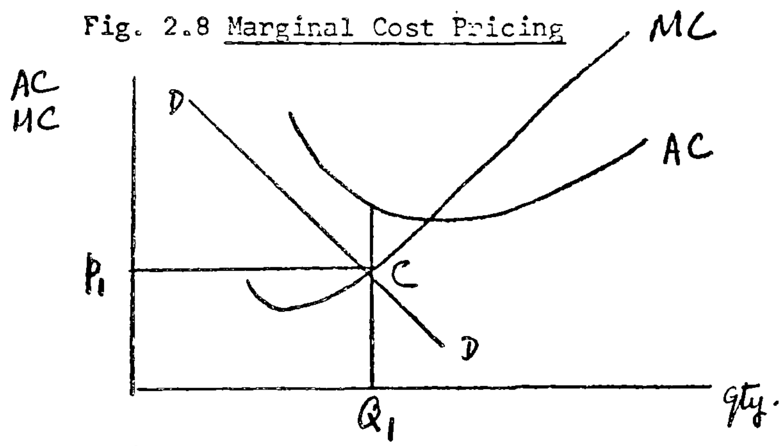
Another reason is the geographical situation. 50% of the hydro power is in the Alps, the Pyrenees and the Massif Central where the snow melts and water flow reaches its peak in summer but consumption is concentrated in winter. Moreover, Paris is the heaviest centre of electricity consumption but it is far from the major sources of hydro supply.

Specifically in France, the short run marginal cost of electricity delivered in Paris is the cost of fuel for an extra unit of output from the least efficient thermal plant. The price which covers this MC will give a surplus over the fuel cost of all other plants in service. The long run marginal cost is either of the following two costs whichever is lower : the unit cost of a plant specially designed for peak loads or the net cost of the base-load plant after subtracting fuel economies.[28]

Further Discussion about Marginal Cost Pricing

When output is at such a level that the corporation is enjoying increasing returns to scale MC is below AC. MCP will result in a deficit. This can be illustrated in the following diagram.

Fig. 2.8 Marginal Cost Pricing



If MCP is adopted and if MC cuts the demand curve DD at C, output Q_1 is produced and the price is p_1. This price is below the average cost.

28 It is because the old base load plant is less efficient than a new plant.

How the deficit is to be financed creates a problem.[29]

Particular Case

On the other hand Davidson argues that decreasing long run marginal cost at the point of production is only a sign of market imperfection or bad planning (29, p.73-4). As the number of electric suppliers increases and network interconnections spread, indivisibilities will not be significant in the long run.

(7) The Effects of Regulation on Price Determination

Between 10 to 30% of the total electricity generated in Canada originated from privately-operated utilities in the 1956-68 period. However, over 50% of the provincial generation originated from privately-operated utilities in Newfoundland, Prince Edward Island and Alberta.

1) The Averch-Johnson Model (A-J Model) (4)

The main argument is that a "fair rate of return" being imposed on the utility companies may lead to over-investment.[30] The "fair rate of return" based on invested capital can create a "regulatory bias" and there will be a misallocation of economic resources. The company will not try to

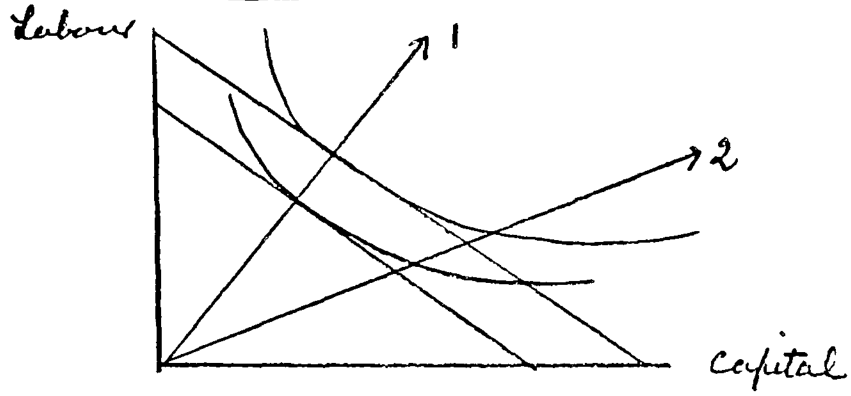
---

29 One suggestion is to raise taxes on inheritances and rent of land because these are lump-sum taxes and will not interfere with the marginal conditions (22). Another suggestion is to raise excise taxes on specific commodities because this will diminish the welfare of the individual paying the tax less than a generalized income tax (93).

30 In Canada, it is said that the Public Utility Commissions watch overinvestment closely and, hopefully, misallocation of economic resources does not happen.

minimize cost . On the other hand, it will substitute capital for another factor of production (e.g. labour) in order to increase its rate base. The following diagram shows that instead of taking expansion path 1 which minimizes costs at all levels of output, it may take path 2.

Fig. 2.9 Misallocation of Resources



Moreover, if there are many markets for the firm and the "fair rate of return" criterion is on the firm's over-all value of plants and equipments for all markets taken together, it may enter a new market even though the additional cost exceeds the additional revenues because it can inflate its rate base.

Another drawback of this kind of regulation may result in a conspiracy between the firm and the suppliers of equipment to this firm.

2) Further discussion about the model

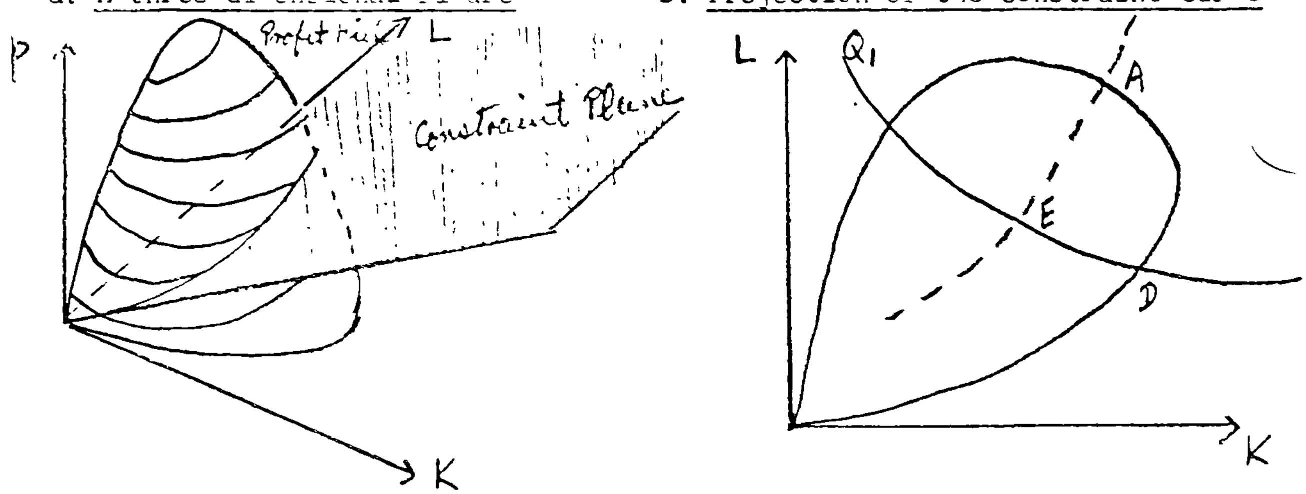
There are many ways in inflating the book value of capital such as including extra items from the accounting record in the rate base, making additions of useless or idle plants or increasing plants at a rate faster than called for by an optimum investment strategy. In this case the other factor ot production (e.g. labour) is not displaced by capital.

Geometrical Presentation of the A-J Model

Zajac tried to find a solution for the model by means of a profit hill constraint curve and constraint plane on the assumption that only two factor inputs labour (L) and capital (K) are used (117).

Fig. 2.10 An Illustration of Profit under Regulatory Constraint

a. A three dimensional figure b. Projection of the constraint curve



In order to maximize profit the firm has to operate at the top of the profit hill in fig. 2.10a and have the necessary combination of capital and labour accordingly. Owing to the constraint it can only operate at the level below or on the plane. If it operates at D in fig.2.10b it will "maximize" profit within the constraint. However, according to the locus of efficient points, at such a level of output the combination of labour and capital should be at E. Therefore to operate at D is to overcapitalize.

Problem of Lag

The A-J model assumes that the economy is static and the regulation is imposed continuously. In fact, regulation is imposed in a discrete manner and there is a lag between the old and the new regulation. There is also a lag between announcing the regulation and the actual imposition of the regulation. Assuming that before the announcement of the new regulation the firm operated at efficient point A in fig. 2.10b, when it hears about the announcement of the regulated rate of return and if it gradually shifts to D before the imposition of the regulation there is a trade-off of losing some profit now and gaining allowed profit in future (5). Thus the final decision depends on the length of the time lag and the net gain or loss from the shift.

Let us assume that, in an extreme case, the regulation imposes a fair rate close to the true capital cost. If the regulation is continuous the firm has no preference in choosing any point on the constraint curve because surplus profit will be zero in any case. If there is a regulatory lag, the firm will compare the present profit stream with the profit streams obtainable by changing the level of capitalization (5).

Graduated Fair Return

Klevorick supported A-J argument but suggested "Graduated Fair Rate of Return" such that the fair rate of return assigned to a corporation will decrease as the size of capital stock increases (60). This will eventually discourage the shift of inputs and the corporation will operate at a point nearer to the optimal allocation of resources. Perhaps, this will further create more jobs among the accounting staff and regulatory body.

A More Practical View

Theoretically A-J model sounds logical but in practice the industry may not work out as expected in the analysis. Corey, a public utility manager in the United States, examined the investment behaviour in the regulated industries and pointed out that these industries do not respond in the way expected by the A-J model (24). There was real over-investment in the depression but it was due to business conditions rather than regulatory practice. Recently, the public demand for reliable, pollution-free, good-looking facilities is a real cause for more capital investment rather than the A-J effect. The A-J input-shift and the increase of rate base (total costs) tend to be minimized for the following reasons : price elasticity on the demand side and the technical limits of substitution among input factors in the electricity industry. Moreover, returns allowed by the regulatory body are seldom much higher than the marginal capital costs and, on the other hand, income taxes are charged on corporate investment. Therefore it is not worthwhile to shift.

Other Criteria

A firm can have many objectives besides maximizing profit. For example it can aim at maximizing sales receipts (total revenue) or output. On the other hand, the regulatory body can use constraints other than a fair rate of return on invested capital. For example it can limit a firm to a fixed profit or a fair profit per unit of production or a profit equal to a fair fraction of total costs (6).

3) Regulator's Problem

The purpose of the regulator is to direct the regulated firm to act in a way that is most beneficial to the society from the social welfare point of view. Therefore the constraint he uses is very important. For example, if he has chosen the "rate of return" regulation as his criterion he still has to decide what the proper rate is - should it be equal to or above the capital cost? Can the decision lead to the final result that satisfies the society's objective of maximizing the sum of producers' surplus and consumers' surplus?

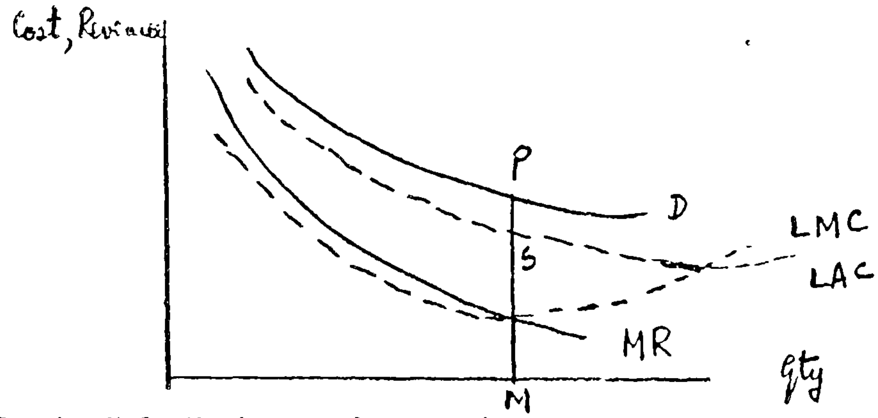
Klevorick found from his model and numerical example that the fair rate of return should be equal to capital cost if there are constant or increasing returns to scale. The regulated company will continue to produce efficiently at minimum cost. If there are decreasing returns to scale the fair rate of return can be greater than the capital cost (61).

4) Net Result of Regulation and Further Comments

Even if misallocation of resources and conspiracy do not occur there is still a question whether or not direct regulation has any net advantage over normal market performance. The appraisal of direct regulation of an industry depends on measuring the difference between its going market performance under regulation and its potential performance under some different regulatory standard or alternative system of social control (19). In the United States Stigler and Friedland found that there is no effect of regulation on the average level of rates (103). From their regression analysis they concluded that the electricity rate structure for domestic consumers is independent of the existence of regulation. No effect of regulation is detectable in the comparative charges to domestic and industrial buyers. There is a slight, statistically insignificant effect of regulation on market values for investors. The main reason is that the individual electric utility system does not have much long run monopoly power because it faces the competition of other energy sources.

Furthermore, since the accounting costs can be computed in many different ways it will be difficult for the regulatory body to distinguish between costs represented by MS and MP shown in the following diagram. (MS=price within the constraint, MP=monopolistic price)

Fig. 2.11 Long Run Equilibrium Prices



In the U.S. MacAvoy made a review of the Federal Power Commission Reports, Vol. 42 (1969) and concluded from a study of the cases that regulation has no economic effect (70).

(8) An Evaluation of the Above Pricing Policies (97, 90, 11a, 9)

From the general welfare point of view, an economy is believed to be in a state of optimal efficiency when it is impossible for a person to increase his satisfaction without reducing another person's satisfaction and it is impossible to increase the production of one commodity without decreasing the production of another one. This situation can be achieved when all sectors of the economy are under perfect competition - that is perfect competition on both product and factors markets. In particular, a perfectly competitive firm will have its marginal cost equal to its product price and its marginal value products equal to its input prices.

In the case of an electric power utility, in the absence of any constraint, Marginal Cost Pricing is optimal only when prices equal marginal costs in the rest of the economy.[31] If its output level is at the point where marginal cost is less than average cost (increasing returns to scale) some kind of subsidies is needed.This is likely to distort the marginal conditions in the rest of the economy. If its output is at the level where marginal cost is greater than average cost (decreasing returns to scale), normally the authorities will by some means force the utility to return the excess revenue to the public.
When a constraint is imposed on an electric power utility or when it is operating at increasing returns to scale Marginal Cost Pricing is not optimal. Under such circumstances it is necessary to seek for another

31 In all markets throughout the economy.

pricing policy that can maximize efficiency subject to a constraint. This means that we are in a position of choosing another basis of price policy which is referred to in the literature as the "second best" pricing policy. It will satisfy Pareto quasi-optimality which means Pareto optimality under the constraint that governmental revenues suffice to make up for the deficits (surpluses) of the individual firms that constitute the economy (9).

Full Cost Pricing (or Average Cost Pricing) meets the objective of recovering total cost for a given level of output. However, there is no indication that this policy will achieve the "quasi-optimal" efficiency.

Cost Plus Pricing meets the objective of maximizing total profit within a profit constraint of "a fair rate of return" for a given level of output in a privately-operated utility. Even though the utility is given the freedom to arrange input and output combination and to set its schedules of rates, there is also no indication that this policy will achieve the "quasi-optimal" efficiency.

Boiteux found that in order to maximize profit subject to a constraint of budget equilibrium the following relationship should hold for a firm exhibiting increasing returns to scale:

> "The relative divergence between price and marginal cost should be proportional to the elasticity of (demand for) the good considered. The constant of proportionality is chosen as required to realize the desired budgetary equilibrium......... This policy consists in taxing a market the more heavily the less elastic is its demand and of applying the profit thus acquired to cover the deficit from sale at marginal cost of goods whose demand is very elastic." (11a p.235)

It appears that "price discrimination" among consumers with different elasticities of demand is justified as long as the differentiation meets the above conditions. In Canada the average revenue from street lighting was the highest throughout the 1956-68 period; commercial users, second; domestic and farm, third; firm power, fourth; and secondary power, fifth.[32] Actually this ranking by average revenues seems to correspond fairly well to the expected ranking by elasticities.[32a]

We need to remind ourselves that Pareto optimality or quasi-optimality is a static concept. However, a policy maker has to think about dynamic economy. Weintraub suggested that the objective of a schedule of tariffs must be to encourage productivity (113a). Therefore any pricing principle that confines itself to the objective of promoting a more optimal resource allocation under known techniques will be inferior to a policy that promotes technical change.

---

32 See Appendix II.2

32a Further research may be required.

5. Conclusion

A major percentage of the total electricity generated in Canada originates from publicly-operated utilities (71% in 1968) as a result of political, geographic, economic and demographic situations. Publicly-operated Power Commissions have been established in most of the provinces in Canada with the exceptions of Prince Edward Island and Alberta. Most of these Power Commissions are responsible for the province-wide development of electric power, generation and distribution.

The remaining percentage of total electricity generated originates from privately-operated utilities (10% in 1968) and industrial establishments (18% in 1968). Like publicly-operated utilities, privately-operated utilities sell their electric-power to the public consumers while industrial establishments keep their electric-power for their own plants use.

Pricing process in the electricity industry does not conform to perfect competition analysis where profit maximization is the main goal of a firm and no constraint is imposed. However, publicly-operated utilities have to recover total expenditures and a profit constraint of a "fair rate of return" is imposed on the privately-operated utilities.

Analytically Average Cost Pricing and Cost-Plus Pricing are the appropriate policies to be adopted in publicly-operated utilities and privately-operated utilities respectively. Since the "fair rate of return" is usually not much higher than the cost of capital, the prices worked out from Cost-Plus Pricing method will not be too much different from Average Cost Pricing method provided other things are equal in both types of utilities. Presumably the industrial establishments sell their electricity to themselves at cost. Therefore the analysis in this study concludes that Average Cost Pricing is followed in the electricity industry in Canada.

We now turn to the empirical estimation of the returns to scale of the electricity generation in Canada.

CHAPTER III

AN ECONOMETRIC STUDY OF THE PRODUCTION FUNCTION

Most writers on the electricity industry believe from empirical work [1] that the long run average cost curve (LAC) slopes downward for an increase of output. Johnston found, however that LAC would be constant. The present Chapter is devoted to the estimation of the returns to scale in the electricity generation in Canada and the dual principle of production and cost functions is used for this purpose.

A cost function is derived from a generalized Cobb-Douglas function as was done by Nerlove in the United States. A survey[2] of other estimates of production and cost functions in this industry has been made, but none of these are as useful as Nerlove's study. His model can find a unique return to scale (RTS) from the reciprocal of the coefficient of output variable in logarithm. From the relationship between LAC and RTS we can figure out on which part of the assumed "U" shape LAC the electricity industry in Canada operates its plants.

In this study the results are not meant to explain the production situation in a particular plant. This is analogous to the study of "Input-Output Table" in the economy where industries are taken as "big plants" and technical coefficients of inputs are worked out for each "big plant". There is much aggregation. Therefore a certain

1 See Appendix III.6.

2 See Appendix III.6, Johnston, p.140 below.

degree of homogeneity in production behaviour among the firms grouped in one industry is assumed.[3]

1. Necessary Theoretical Background for Model Building

(1) Production Function

One of the many ways in defining a production function is :

> "Assuming that the entrepreneur has certain technological knowledge concerning the relationship between the various possible combinations of inputs and the various possible outputs, this technological information is thought of as embodied in what is known as a 'production function'. Specifically, for any given combination of amounts of inputs, and any given combination of the amounts of all but one of the outputs, the production function is supposed to tell the entrepreneur what is the maximum amount of the remaining output that can be produced." (110)

A general production function can be written in the following mathematical form :

$$Y = F(X_1, X_2, \ldots\ldots\ldots\ldots X_i, \ldots\ldots\ldots X_n)$$

where $Y =$ output
X_i $(i = 1, 2, \ldots\ldots n)$ are inputs of various factors

Neoclassical production functions are of particular interest in this study. These models assume that there is continuity of[3a] substitution of one factor for another with all factors of production essential and positive marginal productivities. Supposing two input factors are required to produce an output Y such that $Y = F(X_1, X_2)$.

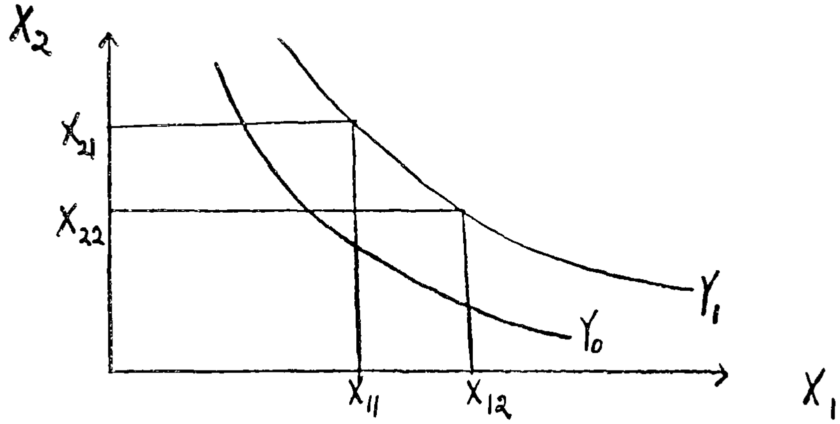
---

3 Since electric power utilities are grouped together in each province a part of the administration cost and transmission cost back and forth among power plants needs to be included in the production cost. Unfortunately it is difficult to separate administration cost and transmission cost for this purpose from the general administration cost and the transmission cost to customers from published data.

3a The limitation of substitution will be discussed in a later section.

As shown in the following diagram, if Y_1 is to be produced it is possible to use a combination of X_{11} and X_{21} or another combination of X_{12} and X_{22}.

Fig. 3.1 An Illustration of a General Neoclassical Model by using isoquants



1) Constant Elasticity of Substitution (CES or ACMS) (3, 113, 39, 35)

This function allows the elasticity of substitution (σ) to be constant but not necessarily unity (in the case of Cobb-Douglas function) or zero (in the case of Leontief Model). Supposing two factors of inputs capital (K) and labour (L) are used, the function can be represented mathematically as :

$$Y = V\left[\delta K^{-\rho} + (1-\delta) L^{-\rho}\right]^{-1/\rho}$$

Where $V > 0$, $0 \leqslant \delta \leqslant 1$, $\delta \leqslant \rho \geqslant -1$ and $\sigma \neq 0$.

This function has the following properties :-

a) It is linear and homogeneous which means that there are constant returns to scale.

b) The efficiency parameter V changes output for given quantities of input. (It is equivalent to A in Cobb-Douglas function.)

c) The distribution parameter δ determines the input intensity and the division of factor income.

d) The Marginal productivity of capital is $\delta V^{-\rho} (Y/K)^{1/\sigma}$ and of labour, $(1 - \delta) V^{-\rho} (Y/L)^{1/\sigma}$ where $\sigma = 1/(1 + \rho)$. The marginal productivities are positive for nonzero value of inputs and they decrease monotonically throughout their entire range. Also if $\rho = -1$, $\sigma = \infty$; if $\rho = \infty$, $\sigma = 0$; if $\rho = 0$, $\sigma = 1$.

e) The marginal rate of technical substitution is $\left[\delta/(1 - \delta)\right] (L/K)^{1/\sigma}$ and therefore the elasticity of substitution σ is a constant.

The CES can be generalized to include cases in which there are increasing or decreasing returns to scale by including another parameter v in the above function such that (113 p.6)

$$Y = V\left[\delta K^{-\rho} + (1 - \delta) L^{-\rho}\right]^{-v/\rho}$$

Where $v > 0$. Depending on whether $v > 1$, $v < 1$, or $v = 1$, increasing, decreasing or constant returns to scale will prevail.

Furthermore this CES can be generalized to accommodate n input factors grouped into s categories (109). Mathematically it is written as :

$$Y = \prod_{j}^{s} \left\{ \left(\sum_{i \in N_j} a_i X_i^{-b_j}\right)^{-1/b_j} \right\}^{c_j}$$

Where $a_i > 0$, $b_j > -1$, $c_j > 0$, $\sum_{1}^{s} c_j = 1$.

This is a linear homogeneous production function and constant returns to scale prevail.

2) Variable Elasticity of Substitution (VES)

In the VES the substitution parameter can vary linearly with the capital-labour ratio around the intercept term of unity (91). In mathematical term it can be written as :-

$$Y = V \left[(1 - \delta) K^{n} + \delta K^{mn} L^{(1-m)n} \right]^{1/n}$$

When $m = 0$ it reduces to CES. The elasticity of substitution for the function is $\sigma = 1/(1 - n + mn/S_k)$ where S_k is capital's share. When $\sigma = 1$ it reduces to CD (Cobb Douglas Function).

In fact VES has been generalized from CES in many ways, and detailed discussion of the latest development are in some recent publications.[4]

3) Cobb-Douglas Production Function (CD) (23, 113, 39)

Mathematically this function can be written as :

$$Y = A L^{\alpha} K^{\beta}$$

Where Y = output > 0, L = Labour > 0, K = Capital > 0, $\alpha \geqslant 0$, $\beta \geqslant 0$, A = constant > 0.

It has the following properties :

a) The α and β are the elasticities of production with respect to labour and capital respectively.

b) The function is homogeneous of degree $r = \alpha + \beta$ where $r > 1$ means increasing returns to scale; $r = 1$ means constant returns to scale; $r < 1$ means decreasing returns to scale.

---

4 Seven articles in Review of Economics and Statistics, Vol.L, No.4 (Nov. 1968) p.443-480 by the following authors : Dobell, R., Saskice, D., Lu, Y.C., and Fletcher, L.B., Sato, R., and Hoffman, R.F., Mitchell, E.J., Gupta, S.J., and Minsol, A.

c) Marginal physical productivity of labour ($\alpha A L^{\alpha-1} K^{\beta}$) and/or capital ($\beta A L^{\alpha} K^{\beta-1}$) declines if α and/or $\beta < 1$ as labour and/or capital is increased.

d) The marginal rate of substitution is $\alpha k / \beta L$ and therefore the elasticity of substitution σ is unity.

The CD can be extended to a general form using more than two inputs X_i ($i = 1 \ldots\ldots\ldots n$) as follows (98) :

$$Y = A \prod_{1}^{n} X_i^{a_i}$$

Where $A > 0$, $\sum_{1}^{n} a_i = 1$ for constant returns to scale or homogeneous function of degree one or $\sum_{1}^{n} a_i = r$ where the constrained to be unity is not imposed.

(2) The Duality of Production and Cost Functions

The Theory of Production is primarily concerned with the optimum allocation of factors of production that minimizes the total cost of each output and with the nature of cost curves derived from the production process under neoclassical hypotheses (95). In econometric studies of production it is customary to specify the form of the production function such as CD or CES and then estimate the parameters through the cost curves which are usually derived by minimization of the total cost (109). This dual determination of production functions from cost curves has been established by Shephard (98).

1) Factor Minimal Cost Function

The cost function depends on the production function which in turn depends on the technical combination of inputs (98). Mathematically it is written as :

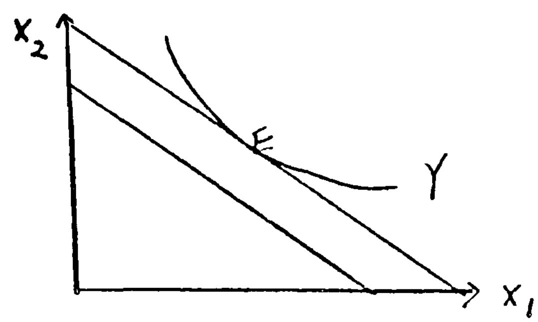
$$C\ (Y,\ p) = F\ (X)\ .\ P\ (p) = \sum_{1}^{K} p_i X_i$$

Where output $Y = F(X)$, $X = (X_1, X_2 \ldots\ldots\ldots\ldots X_n)$ a vector of inputs,

and $p = (p_1, p_2, \ldots\ldots\ldots\ldots p_n)$ a vector of prices per unit of inputs

Diagrammatically these functions can be shown in the following equilibrium point of the isoquant and isocost curve (97).

Fig. 3.2 An Illustration of Minimization of Cost



Supposing two inputs X_1 and X_2 are used to produce Y. At E which is the tangency between the isoquant and isocost, the marginal rate of technical substitution between the factors (slope of the isoquant) equals the ratio of their market prices (slope of the isocost).

2) Cost Functions derived from CD and CES (39)

With fixed input prices, the total cost is a function of output. Since output is determined by the production function, if a specific production function is known the associated cost function can always be derived. From the above CD where $Y = A\,L^{\alpha}\,K^{\beta}$ its cost function is derived as follows :

$$C = p_1\left(\frac{\alpha+\beta}{\beta}\right)\left[\left(\frac{\beta\,p_2}{\alpha\,p_1}\right)^{\alpha}\frac{Y}{A}\right]^{1/\alpha+\beta}$$

Where p_1 and p_2 are prices for capital K and labour L. Also from the above CES where $Y = V\left[\delta\,K^{-\rho} + (1-\delta)\,L^{-\rho}\right]^{-1/\rho}$ its cost function is derived as follows :

$$C = \left(\frac{1-\delta}{p_2}\right)^{\sigma/(1-\sigma)}\left[p_1\left(\frac{\delta}{1-\delta}\right)^{\sigma}\left(\frac{p_2}{p_1}\right)^{\sigma} + p_2\right]^{1/1-\sigma}\frac{Y}{V}$$

There is an obvious difference between these two cost functions. For CD, MC (marginal cost) $=$ 1/ $(\alpha+\beta)$ of AC (average cost) and this means that if $\alpha+\beta \gtreqless 1$, MC $\lesseqgtr$ AC. For CES, MC $=$ AC all the time and this means that returns to scale are always constant.

3) The Connection among Dual Expansion Paths (DEP), Returns to Scale (RTS) and Long Run Average Cost Curve (LAC)

The Dual Expansion Path in the price structure is defined as the locus of least cost factor price vectors p(Y,X) as a function of output rate for any input vector X and the price minimal cost function (98).

Mathematically it can be written as :

$$D(Y,X) = X.\ p(Y,X) = \sum_{1}^{n} X_i p_i\ (Y,X)$$

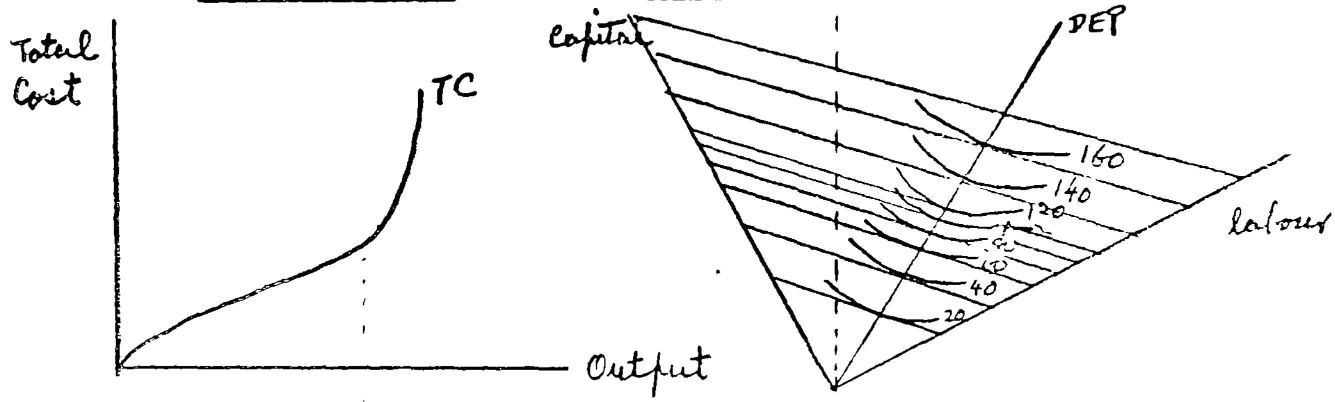
Also along this DEP the ratios of the marginal productivities of the factors to their prices have a common value equal to the reciprocal of the marginal cost with respect to output rate.

Returns to Scale describe the output response to a proportionate increase of all inputs. If output increases in the same proportion as input increase RTS are constant for the range of input combinations under consideration. They are increasing if output increases by a greater proportion and they are decreasing if output increases by a smaller proportion (46). A production function is homogeneous of degree k if $F(tX_1, tX_2) = t^k F(X_1, X_2)$ where RTS are increasing, constant, or decreasing if $k > 1$, $k = 1$ or $k < 1$.

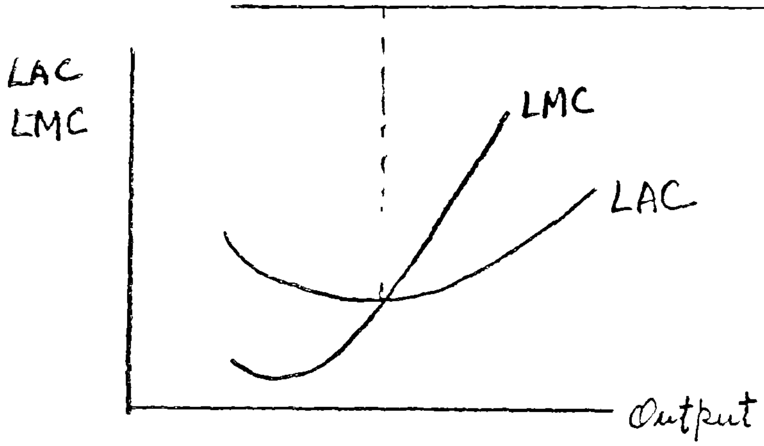
When the production is homogeneous the relationship among DEP, RTS and LAC can be illustrated in the following three diagrams which show that the downward sloping, horizontal and rising LAC correspond with the increasing, constant and decreasing RTS (110). Fig. 3.3a is purposely drawn to show increasing, constant and decreasing RTS by varying the distances among the isoquants. Also constant relative factor prices are purposely drawn by the parallel isocosts. The DEP is the locus of points of tangency between isoquants and isocosts. From this DEP the long run total cost curve can be traced in fig. 3.3b. Also LAC can be derived from the total cost curve in fig. 3.3c .

Fig. 3.3 An Illustration of the relation among DEP, RTS & LAC

b. Total Cost Curve a. Dual Expansion Path (3 dimensional)



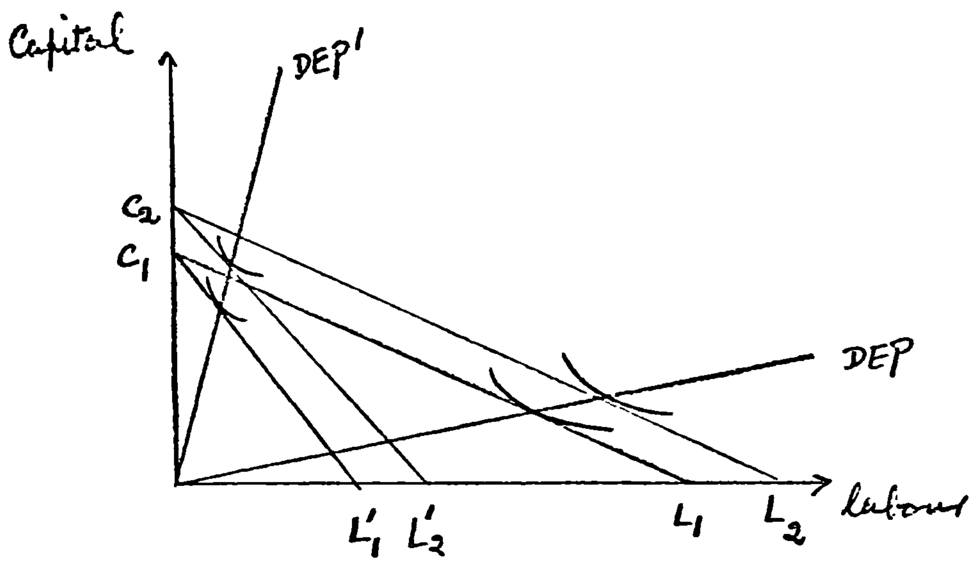
c. Average Long Run Cost Curve and Marginal Cost Curve



If the prices of capital and labour change in the same ratio, the relative factor prices (i.e.the slope of the isocost) will still be the same. There will be no change in the position of the DEP and hence there is no change in the proportions of the inputs used (14). However, there will be a change of total outlay for the same level of output and the total cost curve and LAC will be shifted upward or downward.

If there is a change in the relative prices of inputs, the proportion of inputs used will be changed too. This means that the slope of the DEP will change. Supposing the wages for labour are increased while capital price remain constant, the isocosts will be C_1L_1' and C_2L_2' instead of C_1L_1 and C_2L_2 in the following diagram. The DEP will shift to DEP' which shows that more capital is substituted for labour. As a result, the same amounts of outputs will require more outlays and different capital-labour ratios. Also the LAC as well as the total cost curve will shift upward.

Fig. 3.4 Result of Relative Prices Change



2. Formulation of the Model

(1) Objective

The electricity industry in Canada is presently facing a few problems. It has to increase its production to meet the growing demand from the customers. On the other hand, it is facing an increasing cost of financing and more pressing constraints of environment restrictions.[4a] To solve these problems it has to try to achieve an optimum balance among technical, social and economic considerations. It is the last consideration to which we are attempting to make some contribution.

The aim of this study is to try to find the returns to scale in the electricity industry in Canada. If increasing returns to scale prevail the average per unit cost of a larger output will fall. As we assume from the analysis in Chapter II that Average Cost Pricing is adopted in this industry, a falling average per unit cost of output means a falling average price per unit of consumption. From the economic point of view, to increase the production of electricity is justified for the benefit of both consumers and producers. The policy makers will still have to consider the technical and social problems. If decreasing returns to scale prevail, the consumers will be charged an increasing average price per unit of electricity consumed for larger quantities per period and they may look for another source of energy.

[4a] See Department of Energy, Mines and Resources, (Energy Development Sector), Electric Power in Canada - 1970, (Ottawa, 1970).

Owing to the development of transmission systems within provincial boundaries, the electricity industry in each province takes advantage of the possibility of using larger generating facilities, optimizing construction schedules and operating the least expensive generating stations to meet system loads. The reliability of electricity supplied to each customer is not only assured, the cost of production is also minimized. Since the objective of policy makers is to design policies for the electricity development in the whole province, this study will aim at finding the returns to scale of electricity production in a province.

Perhaps there is objection to the choice of the level for this analysis. Most of the previous studies on electricity production have used the plant level.[5] Galatin even used machine level to study the relationship between inputs and degree of capacity utilisation, size of the machine and number of machines in the United States (41).

It is true that the lower the level we choose to study the more accurate the information about the unit. However, provincial-wide policy makers are more interested in the overall behaviour of the province rather than any particular plant. This is analogous to the surveyor in a helicopter, who is interested in the area covered by the forest as a whole rather than the space taken up by a tree. However, it is just as useful and interesting to investigate individual trees in another research project.

---

5 See Appendix III.6.

(2) The Function to be Tested

1) Derived Cost Function

The function that is going to be tested is a cost function :-

$$c = k\, y^{1/r} p_1^{a_1/r} p_2^{a_2/r} p_3^{a_3/r} v$$

Where $c =$ cost of production | $y =$ output
$p_1 =$ wage rate | $p_2 =$ rental rate on capital equipment
$p_3 =$ fuel price | $r = a_1 + a_2 + a_3 =$ returns to scale
$k = r(a_o a_1^{a_1} a_2^{a_2} a_3^{a_3})^{-1/r}$ = constant term
$v = u^{1/r} =$ disturbance coefficient

2) Production Function and Duality Principle

The above cost function is derived from a generalized Cobb-Douglas production function using the duality principle worked out by Nerlove.[6] (79)

(i) Production Function : $y = a_o x_1^{a_1} x_2^{a_2} x_3^{a_3} u$

(ii) Cost Identity : $c = p_1 x_1 + p_2 x_2 + p_3 x_3$

(iii) Marginal Productivity Conditions : $p_1 x_1 / a_1 = p_2 x_2 / a_2 = p_3 x_3 / a_3$

Where $y =$ output | $x_1 =$ labour input
$x_2 =$ capital stock | $x_3 =$ fuel input
$a_0 =$ constant term | $u =$ disturbance coefficient

3) Assumptions

(i) Output as well as input prices in the cost function are exogenous.

(ii) Total cost is minimized at the provincial level for any given output.

(iii) There is logarithmic linear relationship between c and y. p_1, p_2, and p_3.

---

6 See Appendix III.6 for a detailed proof of the derivation of the cost function from the generalized Cobb-Douglas production function.

(iv) $E(\log v) = 0$

(v) $E\left[(\log v)(\log v)'\right] = \sigma^2 I_n$

4) Constraint for Estimation

The derived cost function indicates that $r = a_1 + a_2 + a_3$ which means that $a_1/r + a_2/r + a_3/r = 1$. In order to have consistent estimates of the parameters for prices, one method is to use one of the prices as the divisor of the equation. For example, if p_3 is used as the divisor :-

$$c/p_3 = k \ y^{1/r} (p_1/p_3)^{a_1/r} (p_2/p_3)^{a_2/r} v$$

Another method is to assume that capital price is constant so that it can be eliminated from the equation.

Both methods of using one of the prices as divisor (p_1, p_2 or p_3) and eliminating p_2 in the equation have been tried. The results show that, on the whole, the equation using p_3 as divisor appears superior than the the other equations.[7] Therefore only this equation will be analysed in a later section.

5) Other Constraints of the Model

(i) Form of the Model

The Cobb-Douglas function (CD) implies unit elasticity of substitution between capital and labour. In practice, there is a limitation to the substitution between these two factors at the present technical level.

---

7 In fact, whichever price (p_1, p_2 or p_3) is used as the divisor the results of the coefficients are the same. Our criterion of choice is to select the highest R^2 that appears in most of the provinces.

If constant elasticity of substitution model (CES) is used, there is still a constraint. The only difference is that the elasticity of substitution is not zero or one but another constant. In the original CES, the function is linearly homogeneous which means that constant returns to scale prevail. In this study, we try to avoid this restriction. Although CES has been improved to include cases of increasing or decreasing returns to scale and generalized to accommodate more than two input factors, because of the form of the function, it is not easy to estimate by using ordinary least squares method.

One study on electricity production used CES as a theoretical starting point but it did not estimate the CES directly, nor the cost function derived from it. In their study of the Scale in Electricity Generation in the United States, Dhrymes and Kurz used two-stage least squares method to estimate the nonstochastic part of the capital function first and then the labour and fuel functions (34).

For the purpose of this study, the cost function which is going to be analysed is superior to Dhrymes and Kurz's method. Firstly, there is a saving of energy and time because only ordinary least squares method is required. Secondly, by estimating one cost function we can find the returns to scale from the reciprocal of the coefficient for output in logarithm. Further information as to the scales of individual inputs can be obtained easily after a few simple arithmetic operations. Thirdly, it provides answers not only as to the relationship between cost and output, wage rate, capital price and fuel price, but also as to the technical relationship between output and inputs as long as the cost minimization principle is satisfied.

Another choice is to use the variable elasticity of substitution model (VES) which relaxes the constraint of zero, unity or constant elasticity of substitution. There are many problems. In the original VES, only two variables, for example capital and labour, are included. If one additional variable fuel is included, the form of the function will be different. There is no simple way of estimating the production function directly. If it is reduced to a cost function it will be even more complicated.

(ii) Specification

When the generalized Cobb-Douglas function is reduced to a cost function, the prices of inputs together with the level of output appear sufficient to explain the total cost of production. However the components of the total cost creates some specification problems in the model.

The total quantity of fuel used for a level of output in published data is assumed to be most accurate because it is a variable factor. Thus fuel cost component is correct. Presumably the amount of labour used in the electricity industry is semi-fixed. Once a plant is inaugurated it requires a minimum operating staff even though production is much below capacity. As to capital cost, we can only find the cost of total capacity, In some other industries where output can be stored and demand is not required to be met instantly, an efficient firm will be able to produce at a rate of output not too far below total capacity. Therefore the capital cost for capacity is not too far from the capital cost for output. In the electricity industry, there is a peak load problem and, in the case of a hydro plant, there may be a river flow problem. In addition the construction cost for an electric power plant is high and is indivisible.

Perhaps one remedy is to include the load factor variable and/or capacity variable in the cost function. This has been done in some of the previous studies[8].

In this study, such additional variables (output/capacity ratio and total capacity) have been tested in the cost function. The results were unsatisfactory. Moreover, from the theoretical point of view, there is an identification problem, because these additional variables are not substitutes for the inputs of capital, labour or fuel and therefore the marginal productivity condition and the price ratio of inputs condition do not apply to them.

6) <u>Technical Change</u>

Some previous studies have taken technical change into consideration by including a time variable in the equation or using the stratification method. For example, Johnston used a time variable to represent the shift in the

---

8 See Appendix III.6.

cost function as a result of changed management techniques, production methods and obsolescence of plant from 1928 to 1947 (55). Komiya used the stratification method for 235 plants built in the periods of 1930-45, 1946-56, 1951-53, 1954-56 (63). Dhrymes and Kurz also used the stratification method for 362 newly constructed plants built in 1937-59 according to technological period (1937-45, 1946-50, 1951-54, 1955-59) (34). Galatin stratified his sample data according to vintage of machines (1920-24, 1925-29, 1930-34, 1935-39, 1940-44, 1945-50, 1951-53) (41).

In Canada, an obvious technical change was the nuclear power development. However, the percentage of output from these plants during the 1956-68 period was small. There was also steadily continuous technical change in each province. In particular, Quebec took advantage of the development of transmission especially high voltage direct current (HVDC) transmission. Some other provinces took the advantage of cheaper per unit construction cost for building large plants. Prince Edward Island, Nova Scotia and New Brunswick have small plants and do not take advantage of either of these possibilities.[9]

Since the technical change in the electricity industry is continuous an attempt is made to include a time variable to the cost function that is going to be estimated. Of the eleven equations tested for all provinces, the coefficients for the time variable are significant for Manitoba, Quebec and Ontario. The coefficient for output in each of these equations, however,

---

9 This information is from an oral discussion with an Assistant Adviser in Department of Energy, Mines and Resources, Ottawa. See (32a).

has an unexpected negative sign. If returns to scale and the elasticities of output with respect to inputs are to be worked out from these coefficients, it appears that an increase of inputs will reduce total output. This is impossible in a minimized cost model. Even though the coefficients of determination of these regressions are high, these equations therefore have to be abandoned. The coefficients for the time variable in other hydro provinces[10], Newfoundland, British Columbia, the Yukon and Northwest Territories, and New Brunswick[10a] are not significant. The coefficients for the time variable in all thermal provinces, Prince Edward Island, Alberta, Nova Scotia and Saskatchewan are also not significant[11].

(3) Data[12]

All data covered a period of thirteen years from 1956-68. Since 1956 consistent data of the following required variables began to be published and 1968 was the last publication available at the beginning of this study.

---

10 Hydro provinces and thermal provinces are classified according to the mean percentage of output from hydro plants to total output generated by publicly and privately-operated utilities. For further information please see Appendix III.1.

10a Note that when output generated from industrial establishments was included in the analysis in Chapters 1 and 2 New Brunswick had to be classified as a Thermal Province.

11 In order to satisfy our curiosity further analyses have been carried out to test the significance of technical change in the electricity industry in Canada. The results are shown in Appendix III.7.

12 All data collected are published in D.B.S. 57-202, Electric Power Statistics, Vol.II, 1956-68. Thirteen observations of the required variables are shown in Appendix III.2(1)-(11). Fuels used in each province and the average price of each kind of fuel are shown in Appendix III.3. Possible biases from the collected data will be discussed in a later section.

Annual aggregate data are used not only because they are available but also because they can provide the overall result of the production behaviour in each province. Galatin criticized that most of the studies for using annual data ignored the instantaneous nature of the production process in the electricity industry and the varied degree of capacity utilization of machines as a result of daily or seasonal fluctuation of demand (41). Yet, it is because of this uncertainty of on-peak and off-peak phenomena that we feel more secure in using annual data rather than a short period data. A customer can change his on-peak demand from one period to another period but his total consumption through a year normally does not change much.

The output of electricity from industrial establishments[13] is excluded from this analysis because data about fuels used, wages paid to labour, interest on long term debts of this category are not available. Our initial intention was to have a separate analysis for the publicly and privately-operated utilities,[14] but published data about fuels used, wages paid to labour, interest on long-term debt are not separated.

The cost of production is divided into three components : fuel cost, wages and salaries and capital cost. Both fuel cost and wages and salaries are given in the publication. Capital cost is estimated by adding depreciation and payment of interest on long term debt.[15]

---

13 See for the declining importance of industrial establishments, Appendix II.1.

14 See for the declining importance of privately-operated utilities, Appendix II.1.

15 Since depreciation is for all kinds of fixed assets and payment of interest is on all kinds of long-term debts, the estimated cost includes capital cost of transmission and distribution. The inclusion of this cost is suitable when we consider cost minimization is at the provincial level. (Analytically cost of physical capital and cost of financial capital are different. "Depreciation" represents the cost of actual physical capital that is used up. "Interest on long term debt" represents the cost of financial capital which makes the purchase of the physical capital feasible. Both types of costs are necessary .)

Output (Y) is given in the publication in thousands of kilowatt-hours. Some of the output is from nuclear power plants. Since its percentage of total output in the province is small, no adjustment has been made.

P_1 (wage rate) is estimated by dividing total wages and salaries by the number of workers[16]. P_3 (fuel price) is estimated by dividing total fuel cost by the sum of fuels used expressed in B.T.U.s[16a]. P_2 ("rental rate" on capital equipment) is estimated by dividing the total payment of interest on long term debt by the value of net assets[17].

3. Analysis of the Regression Results

(1) Statistical Analysis

1) Time Series Analysis

The attached table 3.1 shows that the coefficients of determination (R^2) for all the regressions are high. This means that the "fit" of each equation is good.

The F-statistic of each regression is highly significant. The hypothesis that all the coefficients in each equation are equal to zero is rejected.

---

16 Salaries to some engineers who are responsible for the designing, planning and operation of generating plants and transmission lines should be included in the estimation of wage rate. From the aggregate published data it is difficult to separate engineers from other office staff who are responsible for the accounting and daily sale of electricity.

16a All kinds of fuels used are converted into B.T.U.s (British Thermal Units).

17 Figures worked out in this manner are proxies only. To improve on the estimated "rental rate" we tried to include capital consumption allowances in the estimate. The results of a trial run proved to be statistically unsatisfactory.

Table 3.1

Results from Regressions Based on Time Series data from 1956 to 1968

The equation in logarithmic form :

$C - P_3 = K + (1/r)\,Y + (a_1/r)(P_1 - P_3) + (a_2/r)(P_2 - P_3)$ | R^2 ($\bar{R}^2$) | DW | F[i]

Constant, Coefficients, standard errors[a], t-values[b], and other statistics

	K	(1/r) Y	$(a_1/r)(P_1-P_3)$	$(a_2/r)(P_2-P_3)$	R^2 ($\bar{R}^2$)	DW	F[i]
Hydro Provinces[c]							
Quebec	5.571[d]	0.264[d]	0.233[d]	1.042	0.991	2.018[g]	1038
	(3.110)	(0.445)	(0.313)	(0.287)	(0.989)		
	((1.8))	((0.6))	((0.7))	((3.6))			
Manitoba	1.608	0.514	0.714	0.426	0.992	1.174[f]	1070
	(0.523)	(0.076)	(0.149)	(0.165)	(0.989)		
	((3.1))	((6.8))	((4.8))	((2.6))			
Newfoundland	-0.331[d]	0.811	0.573	0.412	0.996	2.337[h]	2088
	(0.238)	(0.050)	(0.064)	(0.052)	(0.994)		
	((-1.4))	((16.3))	((8.9))	((7.9))			
British Columbia	0.897[d]	0.639	0.588	0.360	0.994	1.876[e]	1433
	(1.504)	(0.267)	(0.214)	(0.107)	(0.992)		
	((0.6))	((2.4))	((2.7))	((3.4))			
The Yukon and N.W.T.	-1.876	1.310	-0.066[d]	0.612	0.976	2.773[h]	365
	(0.750)	(0.135)	(0.248)	(0.151)	(0.968)		
	((-2.5))	((9.7))	((-0.3))	((4.0))			
Ontario	1.309[d]	0.436	1.024	0.033[d]	0.988	1.294[f]	712
	(1.127)	(0.176)	(0.316)	(0.498)	(0.983)		
	((1.2))	((2.5))	((3.2))	((0.1))			
New Brunswick	0.977[d]	0.691	0.434[d]	0.528	0.972	1.695[f]	317
	(1.525)	(0.253)	(0.281)	(0.159)	(0.963)		
	((0.6))	((2.7))	((1.5))	((3.3))			
Thermal Provinces[c]							
Saskatchewan	3.413	0.348[d]	0.532	0.703	0.983	1.800[e]	513
	(0.826)	(0.186)	(0.232)	(0.192)	(0.977)		
	((4.1))	((1.9))	((2.3))	((3.7))			

Table 3.1 (continued)

Nova Scotia	-0.382[d]	0.735	0.523	0.025[d]	0.992	2.236[g]	1065
	(0.733)	(0.125)	(0.142)	(0.162)	(0.989)		
	((-0.5))	((5.9))	((3.7))	((0.2))			
Alberta	0.613	0.707	0.533	0.477	0.995	2.259[h]	1694
	(0.178)	(0.046)	(0.104)	(0.091)	(0.993)		
	((3.4))	((15.2))	((5.1))	((5.3))			
Prince Ed.Is.	2.434	0.232[d]	0.752	0.283[d]	0.988	1.772[e]	726
	(0.771)	(0.144)	(0.176)	(0.159)	(0.984)		
	((3.2))	((1.6))	((4.3))	((1.8))			

Note

a. Figures in ( ) are standard errors.

b. Figures in (( )) are t-values.

c. Hydro provinces and thermal provinces are classified according to the mean percentage of output from hydro plants to total output generated by publicly and privately operated utilities. For further information see Appendix III.1.

d. The coefficients are not significantly different from zero. (Using 2-tailed test, 95% confidence interval and with 9 degree of freedom the critical limits for t are ± 2.262) (54 p.426).

e. For $d > (d_U = 1.75)$ we do not reject the null hypothesis that there is zero autocorrelation. (For the 5% level of significance with degrees of freedom ($k' = 3$, $n = 15$, the minimum number of observations in (54 p.430) the Durbin-Watson statistics are $d_L = .82$ and $d_U = 1.75$ for positive first-order autocorrelation.)

f. The test is inconclusive as $(d_L = .82) < d < (d_U = 1.75)$.

g. For $d < (d_L = 2.25)$ we do not reject the null hypothesis that there is zero autocorrelation. (The Durbin-Watson statistics are $d_U = 3.18$ and $d_L = 2.25$ for negative first-order autocorrelation.)

h. The test is inconclusive as $(d_L = 2.25) < d < (d_U = 3.18)$.

i. F-Distribution, upper 5% points with degrees of freedom (3,9), $(F_{.95}) = 3.86$ (54 p.428).

The Durbin-Watson test statistics (DW) in the equations for Quebec, British Columbia, Saskatchewan, Nova Scotia and Prince Edward Island show that we do not need to reject the null hypothesis of zero authocorrelation. This means that successive disturbances are drawn independently of previous values. As to the equations for Manitoba, Newfoundland, the Yukon and Northwest Territories, Ontario, New Brunswick and Alberta the results are inconclusive.

Some of the coefficients in these regressions are not significantly different from zero. From the matrix of correlation coefficients[18], it appears that there is much multicollinearity in some of the equations. When the explanatory variables in a relation are so highly correlated with each other it becomes very difficult to disentangle their separate influences.

2) Possible Biases

Specification errors can be the result of misspecification of the functional form of the model, omission of some important variables or inclusion of unrelated variables.

First of all there is the question of whether or not the Cobb-Douglas production function is the appropriate form. If the function were additive output would be possible even though a certain input is not used at all. As it is impossible to generate electricity without capital equipment, it is more reasonable to use a multiplicative form for the production

---

18 See Appendix III.4.

function. Since we cannot expect that the returns to scale in the electric power industry will be constant any production function that limits the returns to scale to constant is not suitable.

In this study we estimate the cost function so as to infer the parameters of the production function. This is possible only when cost minimization is carried out in each province. If this assumption is not satisfied, there will be a possible bias of underestimating the returns to scale and, therefore, underestimating the output.

In the equation, cost depends only on output and prices of inputs. If load factor, capacity or the number of machines variables should be included in the equation, there will be omission of some variables in the model specification. In this case the assumption that $E(\log v) = 0$ is not true. When there is such a specification error the estimated regression coefficients will be biased estimates of the true coefficients (54). The magnitude of the biases depends on the coefficients of the excluded variables and the correlations between the included and excluded variables. The estimate of the residual variance will be biased upwards. If inferences are to be based on the biased estimated coefficients the results will be inaccurate.

When the independent variables are subject to measurement error the ordinary least squares estimates will not only be biased but will also be inconsistent. As the salaries to engineers who are responsible for operating the generating plants are not included, the calculated average wage rate will likely be underestimated. If other variables are measured without errors the coefficient for wage rate will be overestimated. However, salaries to engineers are also not included in the dependent variable, total cost. Presumably the magnitude of the over-estimated coefficient for wage rate will be less. On the other hand, the coefficients for other variables may be underestimated because the dependent variables are underestimated.

It appears that the rental rate on capital is underestimated[18a] in most of the provinces. Therefore the coefficient for the capital price will be overestimated. Since actual figures are not available it is impossible to compare the weight of this overestimation with the weight of the underestimation caused by the measurement error in the dependent variable.

3) Aggregation Problem

At least four types of aggregation are involved in this study.

i) Aggregation over time for all the variables.

ii) Aggregation of a great numbers of variables such as different kinds of machines, different types of prime movers, different skills of labour and different types of fuels used.

iii) Aggregation of input variables as well as output variables for all methods of electricity generation.

iv) Aggregation of variables from a great number of plants in a province.

Some econometricians believe that aggregation is not necessarily bad in econometric testing (44). It can reduce specification errors that very often happen in microtheory because we do not know enough

18a See Appendix III.2 (1) - (11) "Rental Rate on Capital Equipment" about micro behaviour and we cannot specify the micro-equation perfectly. Thus an aggregate equation will be better than all microequations combined. In this study, we can see the whole picture of a province better than if we test many micro equations of several sets of samples of machines.

Moreover those econometricians even believe from their empirical study that aggregation may produce an aggregation gain. They found that R^2 (coefficient of determination) of the aggregate relation can be higher than any oneof the R^2s of the micro relations as a result of "grouping" effect. The poor quality of micro data compared with aggregate data may be another source of aggregation gain (2). This is true. For example, if we try to collect some detailed data from Statistics Canada[19] or from any company, they will either refuse immediately saying that the data are confidential or, if they are polite enough, they may try to show part of the information or disaggregate their data according to their own judgement.

If the aggregate variables are observed without error and the micro behavioral parameters are identical, which means that there is no aggregation bias, least squares estimation of macro equation will yield consistent parameter estimates (23). Presumably the micro behavioral parameters of the production function of a steam-power plant may be different from those of a hydro-power plant. Therefore there may be aggregation bias.[19a]

19 Previously it was called Dominion Bureau of Statistics (D.B.S.).

19a In theory, we cannot aggregate data of output and inputs that come from different kinds of plants. In practice, it is one of the ways in carrying out statistical analysis as long as we always remind ourselves that, in some cases, there is deviation from the mean.

4) Cross Section and Time Series Analysis

An attempt is made to pool all cross section and time series data so that the number of observations is increased. In the attached table 3.2 the results of this regression show that all the coefficients are significant.

A covariance analysis is carried out to test the overall homogeneity among all the provinces (54). This hypothesis is rejected.[20] Another test is to find the overall homogeneity of the equations worked out for hydro and thermal provinces (21). This hypothesis is also rejected.[21] Separate equations for the two groups of provinces are tested and the results are shown in the same table 3.2.

Further covariance analysis is carried out to test the differential slope vectors of the last two equations. Final results show that the Yukon and Northwest Territories and Prince Edward Island should be excluded from the hydro group and thermal group respectively.[22] The two equations for selected hydro provinces and thermal provinces are shown in the attached table 3.3. The coefficients of determination (R^2) are as high as above .99. All the coefficients are significant. The returns to scale, elasticities of output with respect to labour, capital and fuel are worked out and shown in the same table.

---

20 See Appendix III.5(1)a.

21 See Appendix III.5(1)b.

22 See Appendix III.5(2).

Table 3.2

Results from Regressions Based on Cross Section and Time Series Data of Eleven Provinces from 1956 to 1968

The equation in logarithmic form :

$$C - P_3 = K + (1/r)\,Y + (a_1/r)(P_1-P_3) + (a_2/r)(P_2-P_3)$$

Constant, Coefficients, standard errors[a], t-values[b], and other statistics

	K	$(1/r)\,Y$	$(a_1/r)(P_1-P_3)$	$(a_2/r)(P_2-P_3)$	R^2 ($\bar{R}^2$)	F
All provinces	1.240	0.705	0.434	0.688	0.987	10311
	(0.201)	(0.010)	(0.057)	(0.057)	(0.986)	
	((6.2))	((68.3))	((7.6))	((12.0))		
All Hydro Prov.	0.488	0.740	0.625	0.546	0.991	9396
	(0.214)	(0.013)	(0.071)	(0.061)	(0.9905)	
	((2.3))	((58.0))	((8.8))	((9.0))		
All Thermal Prov.	1.712	0.705	0.155	0.735	0.997	14590
	(0.229)	(0.015)	(0.045)	(0.062)	(0.9965)	
	((7.5))	((47.1))	((3.4))	((11.8))		

Note a. Figures in ( ) are standard errors.

b. Figures in (( )) are t-values.

Table 3.3

Results from Regressions Based on Cross Section and Time Series Data of Selected Provinces[a] from 1956 to 1968

The equation in logarithmic form :

$$C - P_3 = K + (1/r)\,Y + (a_1/r)(P_1 - P_3) + (a_2/r)(P_2 - P_3)$$

Constant, Coefficients, standard errors,[b] t-values,[c] and other statistics

	K	$(1/r)\,Y$	$(a_1/r)(P_1-P_3)$	$(a_2/r)(P_2-P_3)$	R^2	F
Selected Hydro Prov.	0.892[d]	0.635	0.636	0.417	0.996	17935
	(0.251)	(0.048)	(0.058)	(0.051)	(0.9957)	
	((3.6))	((13.2))	((10.9))	((8.1))		
Selected Therm. Prov.	1.139[e]	0.698	0.356	0.579	0.992	4148
	(0.314)	(0.072)	(0.114)	(0.114)	(0.991)	
	((3.6))	((9.7))	((3.1))	((5.1))		

Parameters worked out from the above coefficients[f] :

	r	$e_1 = a_1$	$e_c = a_2$	$e_f = a_3$
Selected Hydro Prov.	1.573	1.000	0.656	-0.083[g]
Selected Thermal Prov.	1.433	0.510	0.830	0.093

Note

a. The selected provinces are based on covariance analysis. See Appendix III.5(2).

b. Figures in ( ) are standard errors.

c. Figures in (( )) are t-values.

d. D.K for provinces other than New Brunswick are :
Manitoba : -0.030 ((-1.2)) Newfoundland : -0.172 ((-9.1))
Quebec : 0.011 ((0.2)) Ontario : 0.154 ((2.6)) B.C. : 0.102 ((3.3)).

e. D.K for provinces other than Alberta are :
Nova Scotia : 0.074 ((2.5)) Saskatchewan : 0.070 ((3.9)).

f. r (returns to scale) is the reciprocal of the coefficient for Y.
e_1 (elasticity of output with respect to labour) is $r(a_1/r)$.
e_c (elasticity of output with respect to capital) is $r(a_2/r)$.
e_f (elasticity of output with respect to fuel) is $r(a_3/r)$.

g. A test of unity of the coefficients for P_1 and P_2 shows that $t = .7$. This means that e_f is not significantly different from zero (54).

(2) Economic Interpretation

The econometric results show that increasing returns to scale ($\hat{r}$) prevail in both hydro and thermal provinces. Their magnitudes are almost the same (1.573 for hydro and 1.433 for thermal).[23] In other words, hydro and thermal provinces enjoy decreasing average cost for a further increase of output.

The elasticity of output with respect to labour (e_l) is 1 in hydro provinces and 0.51 in thermal provinces. It appears that the marginal physical productivity of labour in hydro provinces remains constant since e_l is 1. On the other hand, the marginal physical productivity of labour in the thermal provinces declines with an increase of the use of labour.

The elasticity of output with respect to capital (e_c) is higher in thermal provinces (0.83) than in hydro provinces (0.656). Since both figures are less than 1 the marginal physical productivity of capital in both hydro and thermal provinces declines with an increase of the use of capital.

The elasticity of output with respect to fuel (e_f) in the thermal provinces is 0.093. This means that the marginal physical productivity of fuel in the thermal provinces also declines with an increase of the use of fuel. As to hydro provinces e_f is not significant.

---

23 See p.98.

The conclusion that there are increasing returns to scale and the proportion of the increasing returns to scale attributable to fuel and capital are less than that attributable to labour happen to be similar to the results found in Nerlove's and Dhrymes and Kurz's studies (81,34).

---

23 Since the equations for hydro provinces and thermal provinces do not give identical results we suspect that there are biases in the technical coefficients. For example, if Ontario did not continuously change the proportion of output from hydro plants to thermal plants since 1962 and British Columbia did not do the same since 1965 the magnitude of the figure for (r) in the Hydro equation may be greater given that Thermal equation has a lower (r). The figures for e_l and e_c may be different too. Similarly if the proportion of output from hydro plants to thermal plants in Alberta, Nova Scotia and Saskatchewan had not fluctuated as much as it did the results for r, e_l, e_c and e_f in the Thermal equation can be different. This is mainly due to the problem of aggregation.

4. Conclusion

Among the Neoclassical Models a generalized Cobb-Douglas function is chosen for this study. The cost function derived from it is tested by using time series data covering a period of thirteen years from 1956 to 1968.

The results from regressions of ten provinces and the Territories based on time series data show that the coefficients of determination (R^2) are high but the t-values of some coefficients are not significant. An attempt is made to test the equations again using additional variables like total capacity and (output/capacity) ratio. The results are not satisfactory.

Having taken technical change into consideration, another attempt is made to test the equations again with an additional time variable. The results from this attempt are also not satisfactory.

Cross section and time series data are pooled in order to increase the number of observations. A few tests of the homogeneity of the provinces are carried out. Our final results show that we can have two separate equations, one for the hydro provinces (Quebec, Manitoba, Newfoundland, British Columbia, Ontario and New Brunswick) and one for the thermal provinces (Saskatchewan, Nova Scotia and Alberta).

Both hydro and thermal provinces enjoy increasing returns to scale (see Table 3.3). The elasticity of output with respect to labour (e_l) is higher in hydro provinces than that in thermal provinces.[24] On the other hand the elasticity of output with respect to capital (e_c) is higher in thermal provinces than that in hydro provinces. The elasticity of output with respect to fuel (e_f) is close to zero in both hydro and thermal provinces.

---

24 This surprising result is perhaps attributable to the comparatively insignificant role of labour in hydro-electric plants. When a large, new hydro-electric plant comes into operation the extra capacity and output may be far more than proportionate to the extra labour required, which gives a statistical result suggesting a high elasticity of output with respect to labour in hydro provinces, though, in fact, there may be technically a rigid relationship between the amount of labour and capital required.

SUMMARY AND CONCLUSIONS

A major percentage of the electricity generated in Canada originates from hydro-electric power plants (77% of the total in 1968). Newfoundland, Quebec, Ontario, Manitoba, British Columbia and the Yukon and Northwest Territories are geographically blessed with tremendous water power. Over 50% of the total electricity generated in each of these provinces originates from hydro-electric power plants. The remaining provinces, Prince Edward Island, Nova Scotia, New Brunswick, Saskatchewan, Alberta have over 50% of the total electricity generated from thermal power plants.

Construction costs vary among plants. In general, the capital cost contributes a larger proportion of the total cost in the case of a nuclear power plant or a hydro-electric power plant than in the case of a conventional thermal power plant. On the other hand, the average fuel cost per unit of electricity generated from the conventional thermal power plant is high. In addition, the average fixed cost of electricity generated from conventional thermal power plants can be substantial too as the life of this plant is relatively short. Therefore, in the long run, the total average cost of output from conventional thermal power plant may be higher than that from hydro-electric power plant.

As to the distribution of the types of corporations that generate electricity in Canada, a high percentage of output originates from publicly-operated utilities (71% of the total in 1968). The remaining part comes from privately-operated utilities (10%) and industrial establishments (18%). Electricity generated by the former two types of corporations is sold in the market while electricity generated by industrial establishments is kept for their own plants use.

In selling electricity the Power Commissions in the provinces have to recover total expenditures. Analytically the pricing policy adopted by publicly-operated utilities is "Average Cost Pricing" (or Full Cost Pricing). The privately-operated utilities are interested in maximizing their profits but are subject to a regulatory constraint of a "fair rate of return" on net capital invested. Therefore the pricing policy is assumed to be "Cost Plus Pricing". Presumably the industrial establishments "sell" the electricity to themselves at cost.

In practice, owing to the cost structure and the peculiar fluctuations of demand in this industry there are many schedules of tariffs charged to the customers. In Canada these customers are divided into five main groups : firm power, secondary power, commercial, domestic and farm, and street lighting users. It is assumed that the elasticities of demand from the customers within a group are homogeneous but differ between groups. Since electricity cannot be stored monopolistic price discrimination can be carried out effectively among different groups of customers. For individual customers "block discrimination" is carried out so that they pay the highest per unit price for a small rate of consumption and reduced prices for progressively larger rate of consumption.

The main purpose of this study is to find the returns to scale in the electricity industry in Canada and to see at which part of the average cost curve it is operating. Among the Neoclassical production functions such as Constant Elasticity of Substitution, Variable Elasticity of Substitution and Cobb-Douglas, a Generalized Cobb-Douglas production function has been chosen. From the duality principle this production function can easily be reduced to a cost function such that total cost depends on output and prices of inputs only. "Returns to Scale" are worked out from the reciprocal of the coefficient of output in logarithm.

Of all the time-series regressions estimated for each province the coefficients of determination (R^2) are high but some of the coefficients in a few regressions are insignificant. This may be due to measurement errors in variables and multicollinearity.

When provinces are pooled (excluding output produced by industrial establishments) through covariance analysis according to the generation processes (hydro and thermal) all the coefficients of the pooled regressions are significant. These two groups are respectively Quebec, Manitoba, Newfoundland, British Columbia, Ontario and New Brunswick (hydro) and Saskatchewan, Nova Scotia and Alberta (thermal).

The two pooled regressions show that there are increasing returns to scale. The elasticities of output with respect to labour, capital and fuel of both groups are equal to or less than one.

In conclusion, we have found interesting results by applying Nerlove's derived cost function. However, for policy making purpose, further work has to be done. Owing to the different technological processes used in Canada, one suggestion is to test several functions in each province. For example, in Ontario, we need to test a function for hydro power plants, a function for thermal power plants, a function for nuclear power plants and a function for the whole system. A computer program is required to estimate the total cost at each level of output; to derive the total cost, marginal cost and average cost curves; and to minimize total cost at each level of output. Since electricity loss is unavoidable in the transmission process, it should be included in the program. Moreover this computer program can be extended or connected with other programs for Quebec and Manitoba where there is transfer of electricity between neighbour provinces. Thus total cost is not only minimized at the provincial level but also among provinces.

BIBLIOGRAPHY

1. A Committee of the Science Council of Canada, The Proposal for an Intense Neutron Generator - Scientific and Economic Evaluation, (Ottawa : Science Secretariat, Privy Council Office, Special Study No.4, Dec. 1967) , p.28.

2. Aigner,D.J.,& Goldfeld, S.M., "Estimation and Prediction from Aggregate Data when aggregates are measured more accurately than their components" (Center for Operations Research and Econometrics, Universitè Catholique de Louvain, Belgium Core Discussion Paper No.7114 July 1971).

3. Arrow, Chenery, Minhas,& Solow, "Capital Labor Substitution and Economic Efficiency", Review of Economics and Statistics, Vol.63 (1961) p.225-50.

4. Averch, H.,& Johnson, L.L., "Behaviour of the Firm under Regulatory Constraint", American Economic Review, Vol.52 (1962) p.1052-69.

5. Bailey E.E.,& Coleman, R.D., "The effect of lagged regulation in an Averch-Johnson Model", The Bell Journal of Economics and Management Science, Vol.2, No.1 (Spring, 1971) p.278-292.

6. Bailey E.E.,& Malone J.C., "Resource Allocation and the Regulated Firm", The Bell Journal of Economics and Management Science, Vol.1, No.1 (Spring, 1970) p.129-142.

7. Barzel, Y., "Productivity in the Electric Power Industry 1929-55", Review of Economics and Statistics, Vol.45 (1963) p.395-408.

8. Barzel, Y., "The Production Function and Technical Change in the Steam Power Industry", Journal of Political Economy, Vol.72 (1964) p.133-50.

9. Baumol, W.J.,& Bradford, D.F., "Optimal Departures from Marginal Cost Pricing", American Economic Review, Vol.60 (1970) p.265-283.

10. Beckmann, M.J.,& Sato, R., "Aggregation Production Functions and Types of Technical Progress : A Statistical Analysis", American Economic Review, Vol.59 (1969) p.88-95.

11. Boiteux, M., "Marginal Cost Pricing" in Nelson, J.R. (ed.), Marginal Cost Pricing in Practice, (New Jersey : Prentice-Hall, Inc. 1964).

11a. Boiteux, M., "On the Management of Public Monopolies Subject to Budgetary Constraints", Journal of Economic Theory, Vol.3 (1971) p.219-240.

12. Boiteux, M., "Peak-Loading Pricing" in Nelson, J.R. (ed.), op. cit.

13. Boiteux, M.,and Stasi, P., "The Determination of Costs of Expansion of an Interconnected System of Production and Distribution of Electricity", in Nelson, J.R. (ed.), ibid.

14. Boulding, K.E., Economic Analysis (Microeconomics), Vol.1, (4th ed.) (New York : Harper & Row Publishers, 1966)

15. Bronfenbrenner, M., "Price Control under Imperfect Competition", American Economic Review, Vol.37 (March, 1947) p.107-20.

16. Brown, T.M., Specification and Uses of Econometric Models, (Toronto : The Macmillan Co. of Canada Ltd. 1965).

17. Cabot, P., "Public Utility Rate Regulation", Harvard Business Review, Vol.7, No.3 (April, 1929) p.257.

18. Carroll, J.W.F., Report of the Royal Commission on Coal, 1946, (Ottawa : King's Printer, 1947).

19. Caves, R.E., "Direct Regulation and Market Performance in the American Economy", American Economic Review, Vol.54 (May, 1964) p.172-81.

20. Chetty, V.K., "Pooling of Time Series & Cross Section Data", Econometrica, Vol.36, No.2 (April, 1968) p.279-290.

21. Chow, G.C., "Tests of Equality between sets of Coefficients in two linear regressions", Econometrica, Vol.28, (1960) p.591-605.

22. Coase, R.H., "The Marginal Cost Controversy", Economica, N.S.13 (1946) p.169-182.

23. Cobb, C.W., & Douglas, P.H., "A Theory of Production", American Economic Review, Vol.18 (Supp.) (1928) p.139-165.

24. Corey, G.R., "The Averch & Johnson Proposition. A Critical Analysis", The Bell Journal of Economics and Management Science, Vol.2, No.1 (Spring, 1971) p.358-373.

25. Coyle, J.J., "A Reconsideration of Value of Service Pricing", Land Economics, Vol.XLI (May 1965) p.193-99.

26. Crabbè, P.J., "The Pure Economic Theory of 'Just' rates and of the 'Fair' rate of return", (Operations Research, National Energy Board, July 14, 1969).

27. D.B.S. Cat. No.26-206 (annual), The Coal Mining Industry, 1969, p.24.

28. D.B.S. Cat. No.26-213 (annual), The Crude Petroleum and Natural Gas Industry 1968, p.5.

29. Davidson, R.K., Price Discrimination in Selling Gas and Electricity, (Baltimore : The Johns Hopkins Press 1955)

30. Davis, J., Canadian Energy Prospects, (Ottawa : Royal Commission on Canada's Economic Prospects, 1957).

31. Demsetz, H., "Why Regulate Utilities?", Journal of Law and Economics, Vol.XI (April, 1968) p.55-66.

32. Department of Energy, Mines and Resources, (Energy Development Sector), Electric Power in Canada - 1969, (Ottawa; 1969).

32a. Department of Energy, Mines and Resources, (Energy Development Sector), Electric Power in Canada - 1970, (Ottawa; 1970).

33. Dessus, G., "The General Principles of Rate-Fixing in Public Utilities" in Nelson, J.R., (ed.) op.cit.

34. Dhrymes, P.J., & Kurz, M., "Technology and Scale in Electricity Generation", Econometrica, Vol.32, No.3 (July, 1964) p.287-315.

35. Dobell, R., "A Symposium on CES Production Functions : Extensions and Comments", Review of Economics and Statistics, Vol.50 (1968) p.443-5.

36. Drèze, J.H., "Some Postwar Contributions of French Economists to Theory and Public Policy", American Economic Review, Vol.54, No.4 (June, 1964).

37. Eggleston, W., Canada's Nuclear Story, (Toronto : Clarke, Irwin & Co. Ltd. 1965) p.322.

38. Eiteman, D.K., "Interdependence of Utility Rate-Base Type, Permitted Rate of Return, and Utility Earnings", Journal of Finance, Vol.XVII, (March, 1962) p.38-52.

39. Ferguson, C.E., The Neoclassical Theory of Production and Distribution, (Cambridge : The University Press, 1969).

40. Foster, A.R., & Wright, R.L., Jr., Basic Nuclear Engineering, (Boston : Allyn & Bacon, Inc., 1968).

41. Galatin, M., Economies of Scale and Technological Change in Thermal Power Generation, (Amsterdam : North-Holland Publishing Co., 1968).

42. Goldberger, A.S., Econometric Theory, (New York : John Wiley & Sons, Inc. 1964).

43. Griliches, Z., & Ringstad, V., "Error-in-the-Variables Bias in Nonlinear Contexts", Econometrica, Vol.38, No.2 (March, 1970) p.368-370.

44. Grunfeld, Y., & Griliches, Z., "Is Aggregation Necessarily Bad?", Review of Economics and Statistics, Vol.XLII (Feb., 1960) p.1-13.

45. Gurinsky, D.H., & Dienes, G.J., Nuclear Fuels, (Princeton : D. Van Nostrand Co. Inc., 1956).

46. Henderson, J.M., & Quandt, R.E., Microeconomic Theory (A Mathematical Approach) (Toronto : Mc-Graw Hill Book Co., 1958).

47. Hirshleifer, J., "Peak Loads and Efficient Pricing : Comment", Quarterly Journal of Economics, Vol.LXXII, (1958) p.451-462.

48. Hock I., "Simultaneous Equation Bias in the Context of the Cobb-Douglas Production Function", Econometrica, Vol.26 (1958) p.566-578.

49. Houthakker, H.S., "Electricity Tariffs in Theory and Practice", Economic Journal, Vol.LXI (1951) p.1-25.

50. Houthakker, H.S., "Peak Loads and Efficiency Pricing - Further Comment", Quarterly Journal of Economics, Vol.LXXII, (1958) p.463-4.

51. Hydro-Quebec, Electricity Rates (By-Laws 95, 110 and 117) (pamphlet No.963-3931 (1/70)).

52. Iulo, W., Electric Utilities - Costs and Performance, (Washington State Univ. Press 1961) cited from Galatin M., op.cit.

53. Johnston, J., Econometric Methods (Toronto : McGraw-Hill Book Co., Inc. 1963).

54. Johnston, J., Econometric Methods (2nd ed.) (New York : McGraw-Hill Book Co. 1972).

55. Johnston, J., Statistical Cost Analysis, (Toronto : McGraw-Hill Book Co., Inc. 1960).

56. Kidd, W.L., "Types of Reactor", in Taylor, E.O., (ed.), Nuclear Reactors for Power Generation (London : George Newness, Ltd. 1958) pp.29-42.

57. Kirchmayer, L.K., Economic Operation of Power Systems, (New York : John Wiley & Sons, Inc., 1958).

58. Kjellberg, S.O., and Lounsbury, J.P., The Canadian Petroleum Industry, (Achievements & Prospects) (Dept. of Economic Research, The Toronto-Dominion Bank, 1964 & 1968).

59. Klein L.R., "Macroeconomics and the Theory of Rational Behavior", Econometrica, Vol.14 (1946) p.93-108.

60. Klevorick, A.K., "The Graduated Fair Return : A Regulatory Proposal", American Economic Review, (June, 1966) p.477-84.

61. Klevorick, A.K., "The Optimal Fair Rate of Return", The Bell Journal of Economics and Management Science,. Vol.2, No.1 (Spring, 1971) p.122-153.

62. Knight, B.W., "Control of Investment vs. Control of Return", Quarterly Journal of Economics, Vol.44 (Feb., 1930) pp.263-85.

63. Komiya, R., "Technological Progress and the Production Function in U.S. Steam Power Industry", Review of Economics and Statistics, Vol.44, (1962) p.156-66.

64. Lang, A.H., Prospecting in Canada (Geological Survey of Canada - Economic Geology Series No.7) (Department of Mines and Technical Surveys) (Ottawa : Queen's Printer, 1966).

65. Lerner, A.P., "Conflicting Principles of Public Utility Price Regulations", Journal of Law and Economics, Vol.VII (Oct., 1964) p.61.70.

66. Ling, S., Economies of Scale in the Steam-Electric Power Generating Industry (Amsterdam : North Holland Publishing Co. 1964) cited in Galatin M., op.cit.

67. Loehman, E., & Whinston, A., "A New Theory of Pricing and Decision-making for Public Investment", The Bell Journal of Economics and Management Science, Vol.2 (Aug., 1971) p.606-625.

68. Lomax, K.S., "Cost Curves of Electricity Generation", Economica, Vol.19 (1952) pp.193-7.

69. Lovell, A.H., Generating Stations : Economic Elements of Electrical Design, (4th ed.) (New York : McGraw-Hill, 1951).

70. MacAvoy, P.W., "The Effectiveness of the Federal Power Commission", The Bell Journal of Economics and Management Science, Vol.1, No.2 (Autumn, 1970).

71. Manitoba Hydro-Electric Board (The), Annual Report, 1970.

72. Maritime Electric Co. Ltd., Annual Report, 1970 (Prince Edward Island).

73. Marschak, J., & Andrews, W.H., Jr., "Random Simultaneous Equations and the Theory of Production", Econometrica, Vol.12 (1944) p.143-203.

74. Miller, R.H., Power System Operation (New York : McGraw-Hill Book Co., 1970).

75. Mundlak, Y., & Hock, I., "Consequences of Alternative Specifications in Estimation of Cobb-Douglas Production Functions", Econometrica, Vol.33, No.4 (Oct., 1965) p.814-828.

76. Nelson, J.R., "Practical Application of Marginal Cost Pricing in the Public Utility Field", American Economic Review, Vol.53 (1963) p.474-481.

77. Newfoundland and Labrador Power Commission, Annual Reports (1970, 1969, 1967).

78. New Brunswick Electric Power Commission, Annual Report, 1971.

79. Nerlove, M., Estimation and Identification of Cobb-Douglas Production Function (Chicago : Rand McNally, 1965).

80. Nerlove, M., "Further Evidence on the Estimation of Dynamic Economic Relations from a time series of cross sections", Econometrica, Vol.39, No.2 (March, 1971) p.359-382.

81. Nerlove, M., "Returns to Scale in Electricity Supply" in Zellner, A. (ed.) Readings in Economic Statistics and Econometrics (Canada : Little, Brown & Co. Ltd. 1968) p.409-39.

82. Nordin, J.A., "Note on a Light Plants' Cost Curves", Econometrica, Vol.15 (1947) p.231-5.

83. Nova Scotia Power Commission, Annual Reports (1970-71, 1969).

84. Ontario Hydro, Annual Report, 1970.

85. Orcut, G.H., Watts, H.W., Edwards, J.B., "Data Aggregation and Information Loss", American Economic Review, Vol.58 (Sept. 1968) p.773-787.

86. Peston, M.H., "A View of the Aggregation Problem", Review of Economic Studies, Vol.27-28 (1959-61) p.51-63.

87. Pigou, A.C., The Economics of Welfare, (London : Macmillan & Co. Ltd., 1950) 4th ed., p.279.

88. Powelson, J.P., Economic Accounting (Toronto : McGraw-Hill Book Co., Inc., 1955)

89. Pressman, I.,"A Mathematical Formulation of the Peak-Load Pricing Problem", The Bell Journal of Economics and Management Science, Vol.1, No.2 (Autumn, 1970) p.305-324.

90. Rees, R.,"Second-Best Rules for Public Enterprise Pricing", Economica, Vol.35 (1968) p.260-273.

91. Revnakar, N.S., "A Class of Variable Elasticity of Substitution Production Functions", Econometrica, Vol.39 (Jan., 1971) p.61-71.

92. Robinson, J., The Economics of Imperfect Competition, (London : MacMillan & Co. Ltd. 1936) p.179-202.

93. Ruggles, N., "Recent Developments in the Theory of Marginal Cost Pricing", Review of Economic Studies, Vol.17 (1949-50) p.107-26.

94. Salter, W.E.G., Productivity and Technical Change (Cambridge : University Press 1966) p.23.

95. Samuelson, P.A., Foundation of Economic Analysis (Cambridge : Harvard University Press, 1947).

96. Saskatchewan Power Corporation, Annual Report, 1970.

97. Scitovsky T., Welfare and Competition (London : Unwin University Books, 1966).

98. Shephard, R.W., Theory of Cost and Production (New Jersey : Princeton University Press, 1970) p.35.

99. Skrotzki, B.G.A., & Vopat, W.A., Power Station Engineering and Economy (2nd ed.) (Toronto : McGraw Hill Book Co., Inc., 1960)

100. Solow, R.M., "Technical Change and the Aggregate Production Function", Review of Economics and Statistics, Vol.39 (1957) p.312-20.

101. Spry, I.M., "Water Power", in Encyclopedia Canadiana (Ottawa : Grolier of Canada Ltd. 1966) p.277-283.

101a. Spry, I.M., "Hydro-electric Power", in Encyclopedia Canadiana (Ottawa : Grolier of Canada Ltd., 1966) p.211-222.

101b. Spry, I.M., "Power Commissions, Provincial", in Encyclopedia Canadiana (Ottawa : Grolier of Canada Ltd., 1966) p.288-292.

102. Steiner, P.O., "Peak Loads & Efficient Pricing", Quarterly Journal of Economics, Vol.LXXI (1957) p.585-610.

103. Stigler, C.J., & Friedland, C., "What can Regulators regulate? The Case of Electricity", Journal of Land and Economics, (Oct. 1962) p.1-16.

104. Taylor, E.O., Electric Power Distribution 415V-33kV (London : Edward Arnold Publishers Ltd., 1966).

105. Theil, H., Linear Aggregation of Economic Relations (Amsterdam : North-Holland Publishing Co., 1954).

106. Turvey, R., Optimal Pricing and Investment in Electricity Supply, (Massachusetts : The MIT Press, 1968).

107. Ullmann, J.E., "Economics of Nuclear Power", in Henley, E.J.,(ed.), Advances in Nuclear Science and Technology, Vol. 1 (New York: Academic Press, 1962).

108. Uzawa, H., "Duality Principles in the Theory of Cost and Production", International Economic Review, Vol.5, No.2 (May, 1964) p.216-220.

109. Uzawa, H., "Production Functions with Constant Elasticities of Substitution", Review of Economic Studies, Vol.30, No.4, (Oct., 1962).

110. Vickrey, W.S., Microstatics, (New York : Harcourt, Brace & World, Inc., 1964).

111. Viner, J., "Cost Curves and Supply Curves" in Kamerschen, D.R. (ed.) Readings in Microeconomics (New York : The World Publishing Co., 1967) p.197-223.

112. Wallace, T.D., and Hussain A., "The Use of error components Models in Combining Cross Section with Time Series Data", Econometrica, Vol.37, (Jan., 1969) p.55-72.

113. Walters, A.A., "Production and Cost Functions : An Econometric Survey", Econometrica, Vol.31 (1963).

113a. Weintraub, S., "Rate Making and an Incentive Rate of Return", Public Utilities Fortnightly (April 25, 1968) p.23-33.

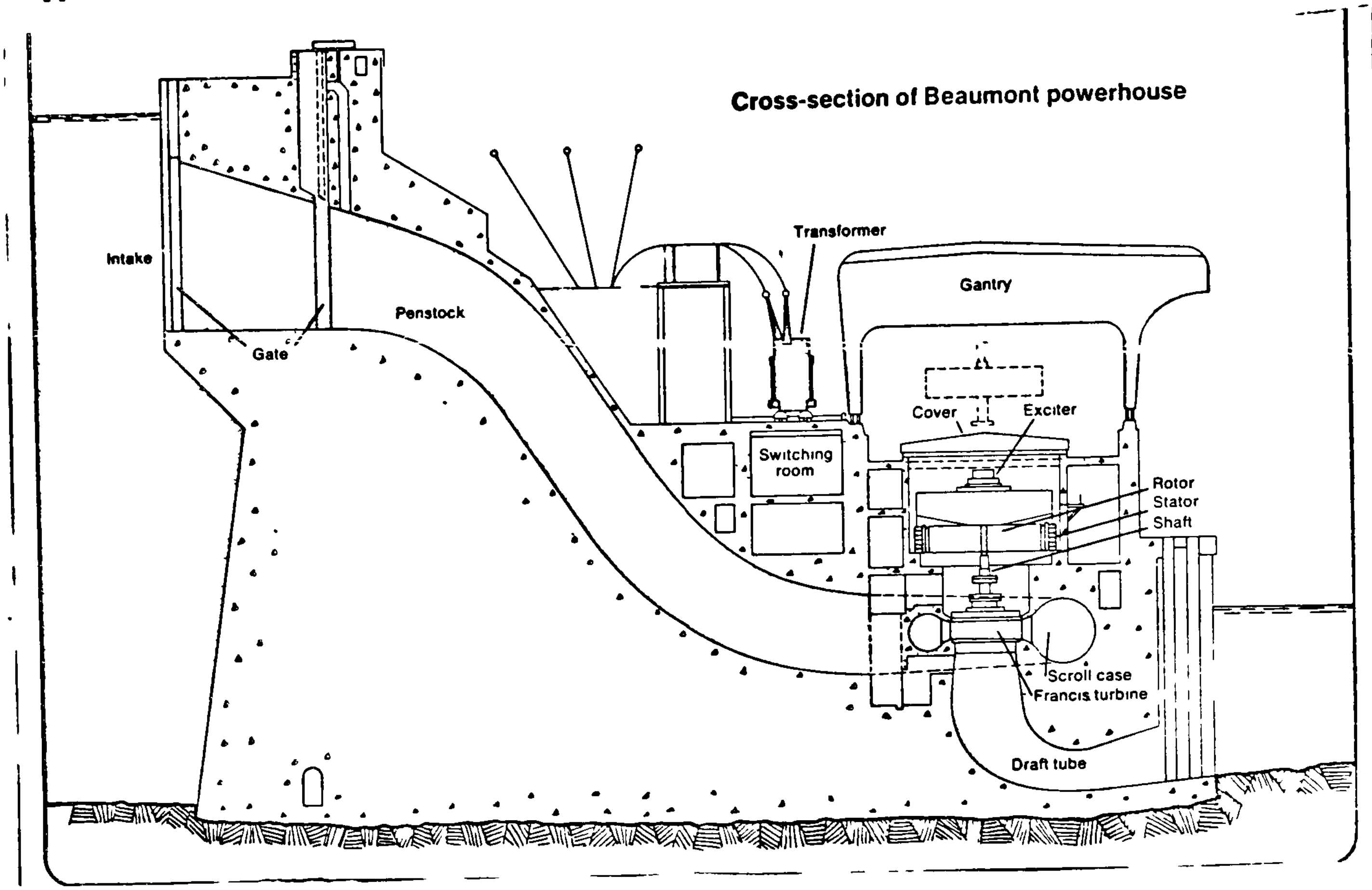
114. Westfield, F.M., "Regulation and Conspiracy", American Economic Review, Vol.55 (1965) p.424-443.

115. Williamson, O.E., "Peak-Load Pricing and Optimal Capacity under Indivisibility Constraints", American Economic Review, Vol.56 (1966) p.810-29.

116. Zajac, E.E., "A Geometric Treatment of Averch-Johnson's Behavior of the Firm Model", American Economic Review, Vol.60 (March, 1970) p.117-25.

117. Zarembka, "A Note on Consistent Aggregation of Production Functions", Econometrica, Vol.36, No.2 (April, 1968) p.419-20.

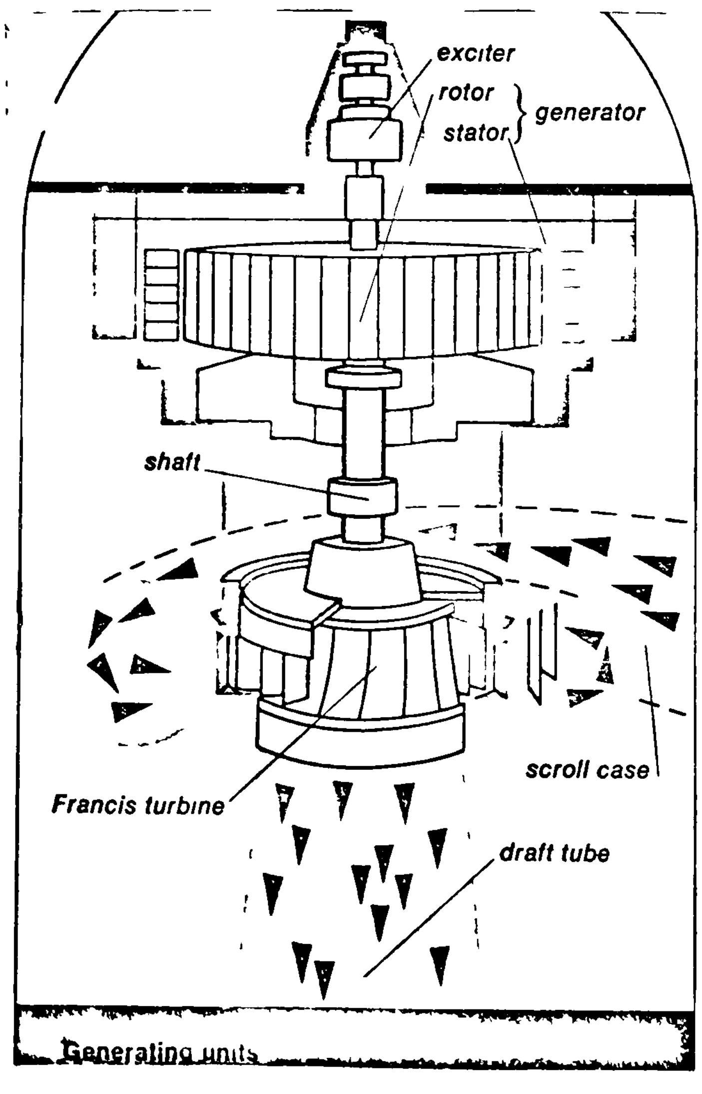
Appendix I.1a : Hydro Power



Source : Hydro-Quebec, St. Maurice River Power Stations (pamphlet : 70-4021A)

Appendix I.1b :

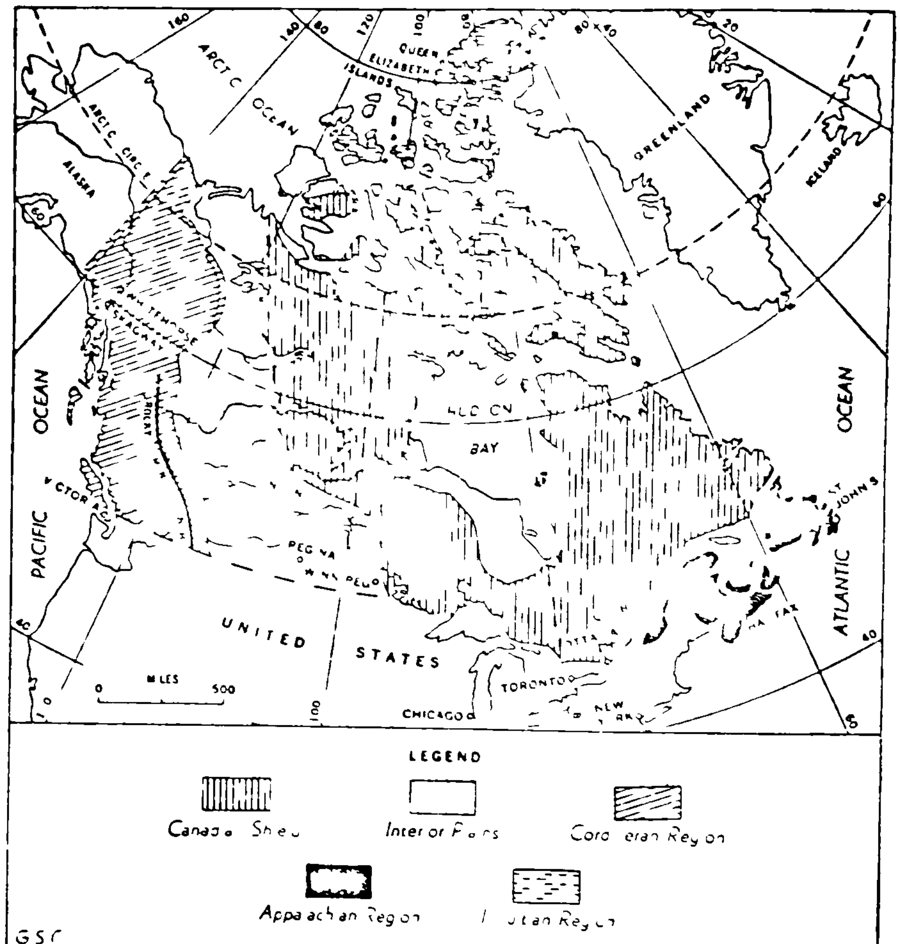
Hydro Turbine and Generator



Source : Hydro-Quebec, Manicouagan 1 (Pamphlet :69-4006A)

APPENDIX I.2

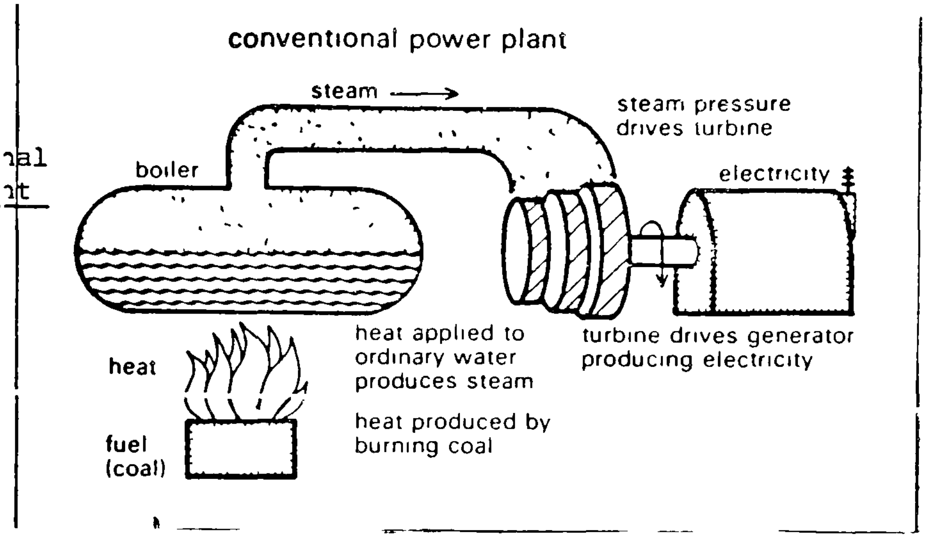
A Map of Main Geological Regions in Canada :



Source : Lang, A.H., Prospecting in Canada (Geological Survey of Canada - Economic Geology Series No.7) (Department of Mines and Technical Surveys) (Ottawa : Queen's Printer, 1966) p.76.

Appendix I.3a :

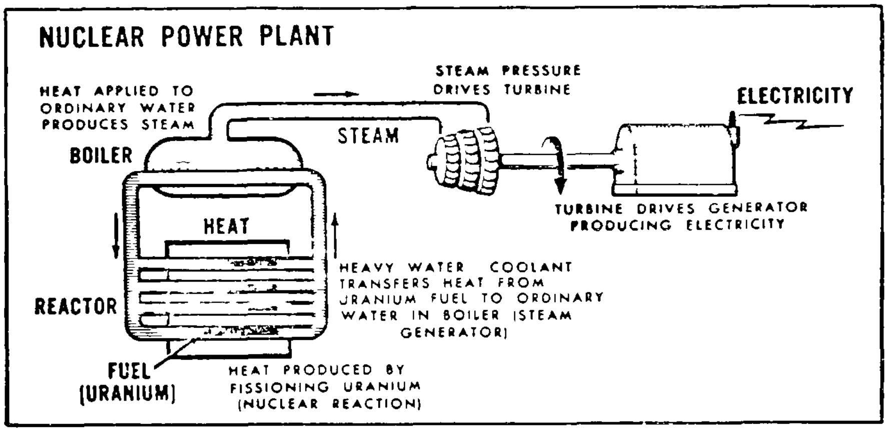
Conventional Power Plant



Source : Ontario Hydro, Lambton Generating Station (pamphlet P.R.D A9399-30M)

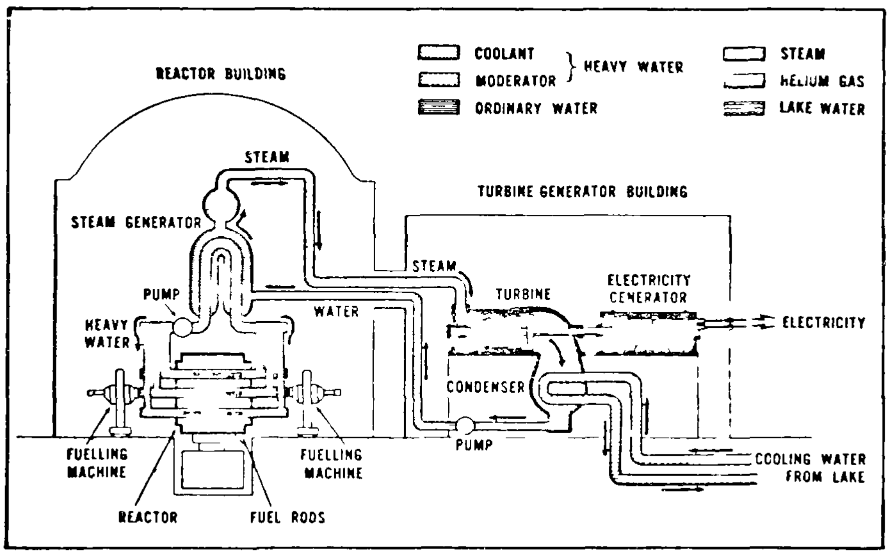
Appendix I.3b :

Nuclear Power Plant



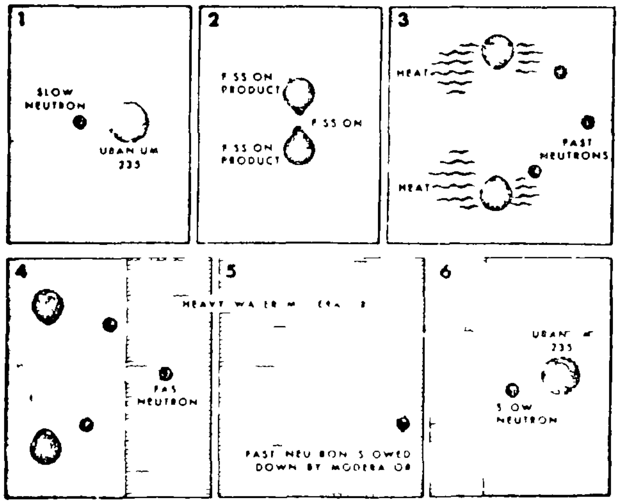
Appendix I.3c :

Reactor Design



Appendix I.3d :

Nuclear Fission



Source: Ontario Hydro, Douglas Point Nuclear Power Station (Pamphlet PPD-9397-10M)

CAPACITY

(of each province as % of the total in Canada)

	Total 1968	Total 1956	Hydro 1968	Hydro 1956	Total Thermal 1968	Total Thermal 1956	Steam 1968	Steam 1956	Internal Combustion 1968	Internal Combustion 1956	Gas Turbines 1968	Gas Turbines 1956
Canada (Actual)[a]	(36)	(16)	(25)	(13)	(11)	(2.4)	(9.6)	(2.2)	(0.5)	(0.2)	(0.9)	(0.01)
(%)	100	100	100	100	100	100	100	100	100	100	100	100
Hydro Prov.[b]												
Newfoundland	3	1	3	2	1.1	1.2	0.5	1	8	3	3	15
Quebec	33	37	44.2	43.7	7	3	7	2	9.8	9	4	-
Ontario	32	32	26	32	45	37	47	39	8	9	37	3
Manitoba	4.3	4.1	5	4	3	2	3	2	4	3	3	-
British Col.	14	13	14.1	14.4	13	8	12	6	36	31	23	-
Yukon & N.W.T.	0.32	0.26	0.3	0.2	0.5	1	0.01	-	11	8	0.3	-
Thermal Prov.[b]												
Prince Ed.Isd.	0.22	0.17	-	0.001	0.7	1.1	0.7	1	1.5	1.9	-	-
Nova Scotia	2.0	2.4	0.7	0.9	5	11	6	11	1.9	2	-	-
New Brunswick	3	2	2	0.9	5	8	5	8	2	5	-	-
Saskatchewan	3.5	3	2	0.6	6	14	6	13	8	17	10	-
Alberta	6	4	2.5	1.7	13	16	13	16	10	11	19	81

a Actual capacity is in nameplate rating in million kilowatts.

b A province that generates over 50% of the total electricity output in the province from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output in the province from thermal plants is listed under thermal provinces.

Source : Parts of computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II, 1956-68).

ESTIMATED WATER POWER RESOURCES

Province or Territory	Undeveloped Water Power — Available Continuous Power At 88% Efficiency — At Q95(a)kw	At Q50(b)kw	At Qm(c)kw	Developed Water Power — Installed Generating Capacity kw
British Columbia	4,697,000	15,954,000	23,984,000	3,538,000
Alberta	895,000	3,244,000	4,866,000	616,000
Saskatchewan	650,000	1,171,000	1,434,000	584,000
Manitoba	2,964,000	5,501,000	5,853,000	1,184,000
Ontario	462,000	1,088,000	1,635,000	6,412,000
Quebec	7,791,000	27,657,000	36,276,000	11,049,000
New Brunswick	29,000	106,000	276,000	563,000
Nova Scotia	21,000	112,000	161,000	163,000
Prince Ed.Isd.	-	1,000	2,000	-
Newfoundland	1,195,000	3,450,000	4,641,000	820,000
Yukon Territory	664,000	3,237,000	5,689,000	18,000
Northwest Ter.	864,000	2,232,000	3,322,000	35,000
Canada	20,232,000	63,783,000	88,139,000	24,982,000

(a) - Power equivalent of flow available 95% of the time.
(b) - Power equivalent of flow available 50% of the time.
(c) - Power equivalent of arithmetical mean flow.

Source : Department of Energy, Mines and Resources (Inland Waters Branch), Electric Power in Canada, 1968 (Ottawa : Queen's Printer for Canada, 1969) p.9.

OUTPUT

(of each province as % of the total in Canada)

	Total		Hydro		Total Thermal		Steam		Internal Combustion		Gas Turbines	
	1968	1956	1968	1956	1968	1956	1968	1956	1968	1956	1968	1956
Canada (Actual)[a]	(176)	(88)	(135)	(81)	(41)	(7)	(40)	(6)	(0.9)	(0.5)	(0.7)	(0.03)
(%)	100	100	100	100	100	100	100	100	100	100	100	100
Hydro Prov.[b]												
Newfoundland	2.2	1.6	2.7	1.8	0.3	0.5	0.2	0.3	8	3	0.01	5
Quebec	37	42	45.7	45.6	8	3	9	3	7	4	0.2	0.1
Ontario	32	33	28	34	44	24	45	26	9	7	13	3
Manitoba	3.84	3.83	5	4	0.8	0.3	0.7	0.1	3	3	1	-
British Col.	13	11	14	11	10	11	10	8	30	40	0.04	-
Yukon & N.W.T.	0.2	0.1	0.2	0.1	0.2	0.04	0.01	-	9	0.6	0.2	-
Thermal Prov.[c]												
Prince Ed.Isd.	0.11	0.06	-	0.001	0.5	0.8	0.5	0.7	1	2	-	-
Nova Scotia	1.74	1.68	0.5	0.7	6	14	6	15	2	0.4	-	-
New Brunswick	2.4	1.6	1.2	0.6	6	13	7	14	1	3	-	-
Saskatchewan	3	2	1.3	0.7	8	16	7	15	18	25	25	0.1
Alberta	4	2	0.8	1.2	16	18	15	18	12	13	60	92

a Actual output is in millions-thousands-kilowatt hours.

b A province that generates over 50% of the total electricity output in the province from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output in the province from thermal plants is listed under thermal provinces.

Source : Parts of computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

APPENDIX I.7 a

CAPACITY UTILIZATION RATIO

((ouput/capacity) in each province)

	Hydro Plants		Thermal Plants	
	1968	1956	1968	1956
Hydro Prov.[a]				
Canada	62	69	43	31
Newfoundland	51	75	13	14
Quebec	64	72	52	36
Ontario	68	74	42	20
Manitoba	62	65	10	4
British Columbia	63	55	33	44
Yukon & N.W.T.	54	51	20	2
Thermal Prov.[a]				
Prince Ed. Isd.	-	36	29	22
Nova Scotia	49	54	50	39
New Brunswick	32	51	56	52
Saskatchewan	35	74	52	36
Alberta	20	50	53	35

a A province that generates over 50% of the total electricity output from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity from thermal plants is listed under thermal provinces.

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, *Electric Power Statistics*, Vol.II 1956-68).

CAPACITY AND OUTPUT

(from hydro and thermal plants as percentages of the totals in individual provinces)

	Capacity				Output			
	Hydro		Thermal		Hydro		Thermal	
	1968	1956	1968	1956	1968	1956	1968	1956
Hydro Prov.[a]								
Canada	70	85	30	15	77	93	23	7
Newfoundland	88	88	12	12	97	97	3	3
Quebec	94	99	6	1	95	99	5	1
Ontario	57	83	43	17	68	95	32	5
Manitoba	76	91	24	9	95	99	5	1
British Columbia	70	91	30	9	82	93	18	7
Yukon & N.W.T.	56	63	44	37	78	98	22	2
Thermal Prov.[a]								
Prince Ed.Isd.	-	1	100	99	-	1	100	99
Nova Scotia	23	33	77	67	23	40	77	60
New Brunswick	52	39	48	61	38	38	62	62
Saskatchewan	45	20	55	80	36	35	64	65
Alberta	30	37	70	63	14	46	86	54

a A province that generates over 50% of the total electricity output from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output from thermal plants is listed under thermal provinces.

Source : Parts of computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics Vol.II 1956-68).

APPENDIX II.1

CAPACITY AND OUTPUT

(from PUB (a), PRI (b), and IND (c) as percentages of the totals in individual provinces)

	(1) PUB&PRI		(2) PUB		(3) PRI		(4) IND	
Capacity	1968	1956	1968	1956	1968	1956	1968	1956
Hydro Prov.[d]								
Canada	85	79	75	46	11	32	15	21
Newfoundland	90	75	37	.2	54	75	10	25
Quebec	80	76	71	29	9	47	20	24
Ontario	95	90	92	77	3	13	5	10
Manitoba	99	98	99	98	0	0	1	2
British Columbia	64	44	63	13	1	31	36	56
Yukon & N.W.T.	79	31	68	25	10	6	21	69
Thermal Prov.[d]								
Prince Ed. Isd.	100	99.99	9	14	91	86	0	0.01
Nova Scotia	89	86	44	33	45	53	11	14
New Brunswick	89	68	86	43	3	25	11	32
Saskatchewan	96	99.72	88	70	9	30	4	0.28
Alberta	92	94	24	30	68	64	8	6
Output								
Hydro Prov.[d]								
Canada	82	78	71	49	10	29	18	22
Newfoundland	90	73	21	0.04	69	72.47	10	27
Quebec	75	73	66	28	9	45	25	27
Ontario	94	93	92	87	3	5	5	7
Manitoba	99	99	99	99	0	0	1	1
British Columbia	53	42	52	11	.1	31	47	58
Yukon & N.W.T.	84	55	78	50	7	5	16	45
Thermal Prov.[d]								
Prince Ed. Isd.	100	99.99	4	15	96	85	0	0.01
Nova Scotia	87	89	44	35	43	54	13	11
New Brunswick	86	66	84	40	2	25	14	34
Saskatchewan	96	98	82	55	14	42	4	2
Alberta	92	94	25	36	67	58	8	6

---

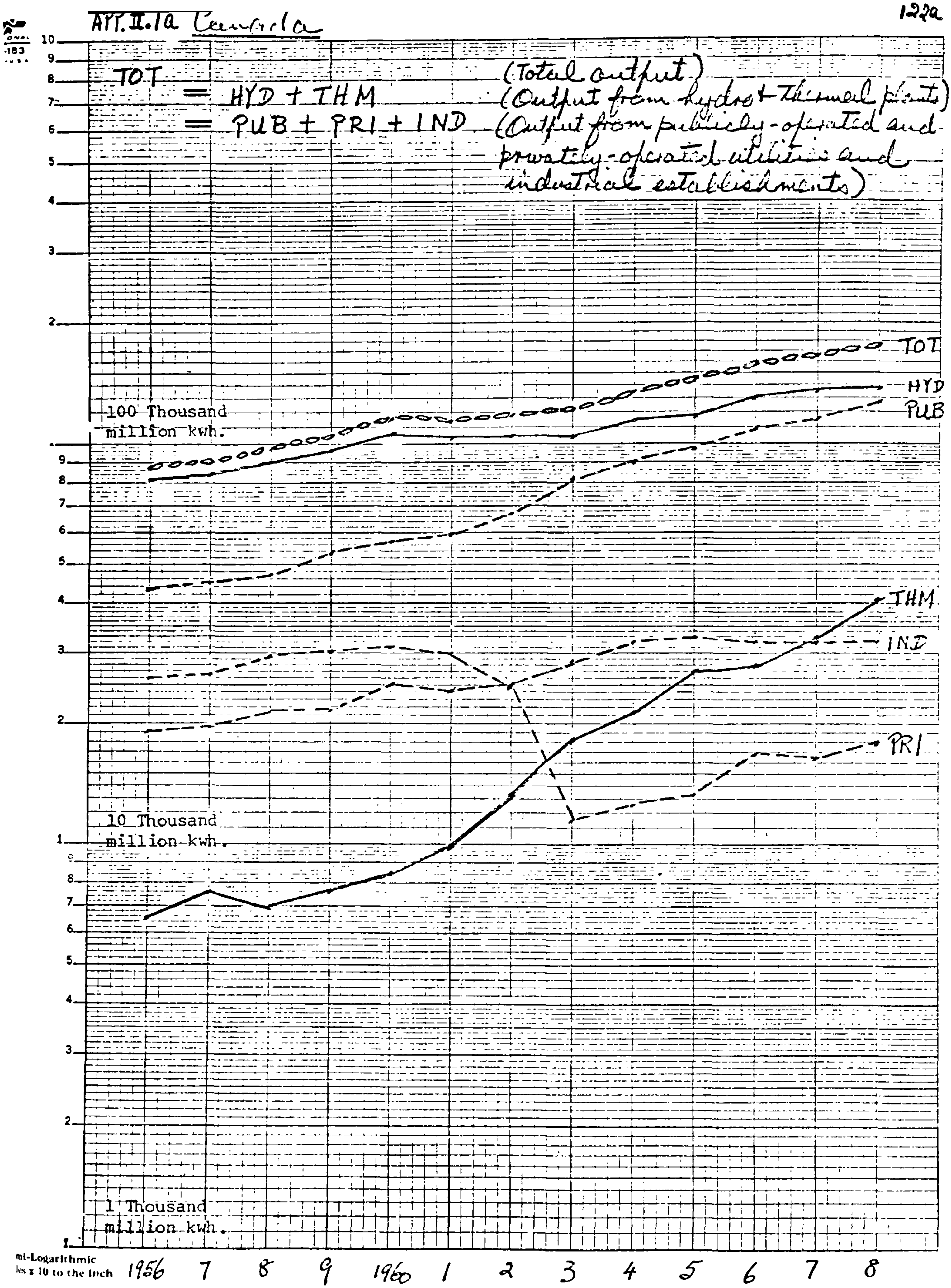
a PUB means publicly-operated utilities.

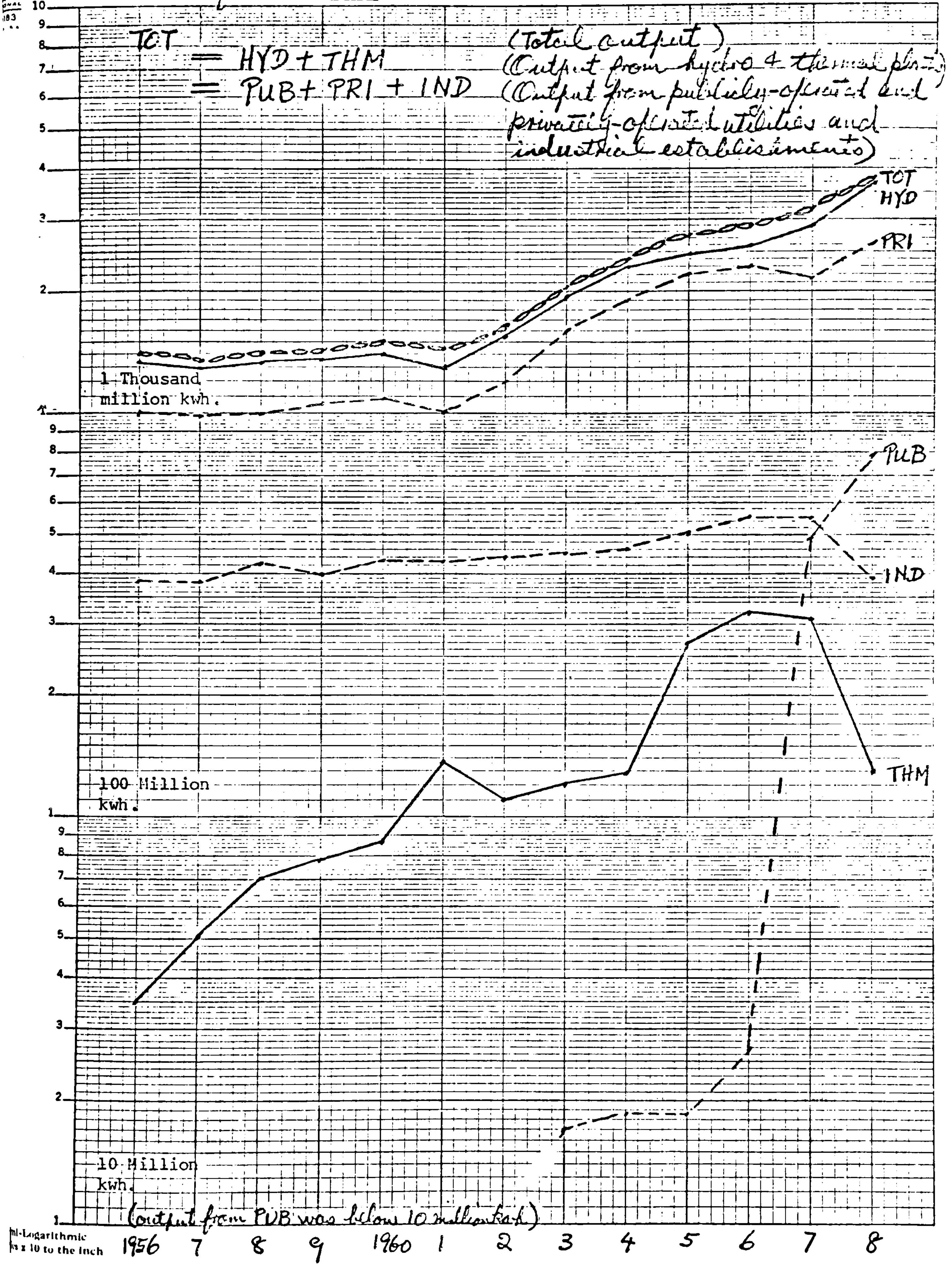
b PRI means privately-operated utilities.

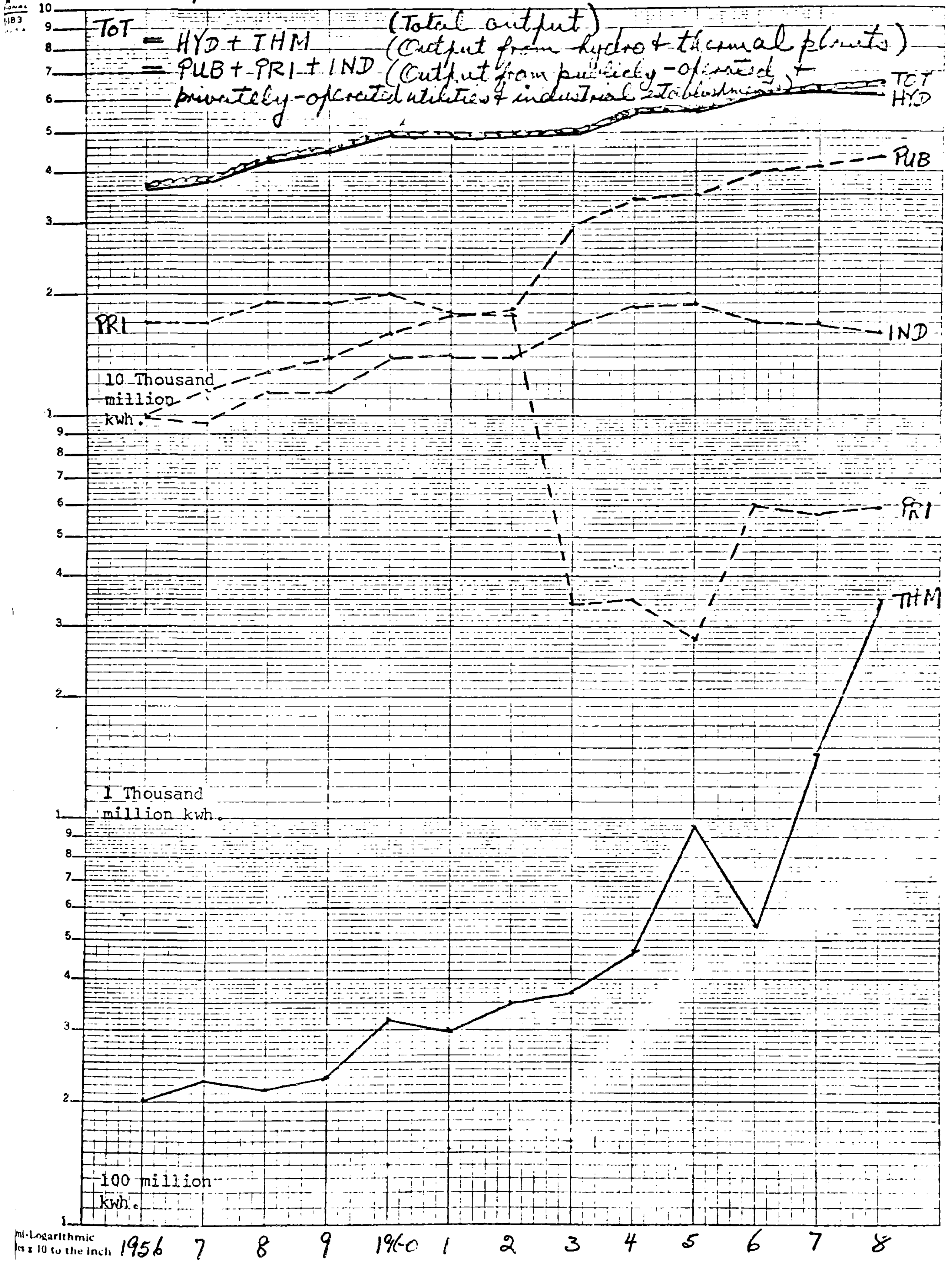
c IND means industrial establishments.

d A province that generates over 50% of the total electricity output in the province from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output in the province from thermal plants is listed under thermal provinces.

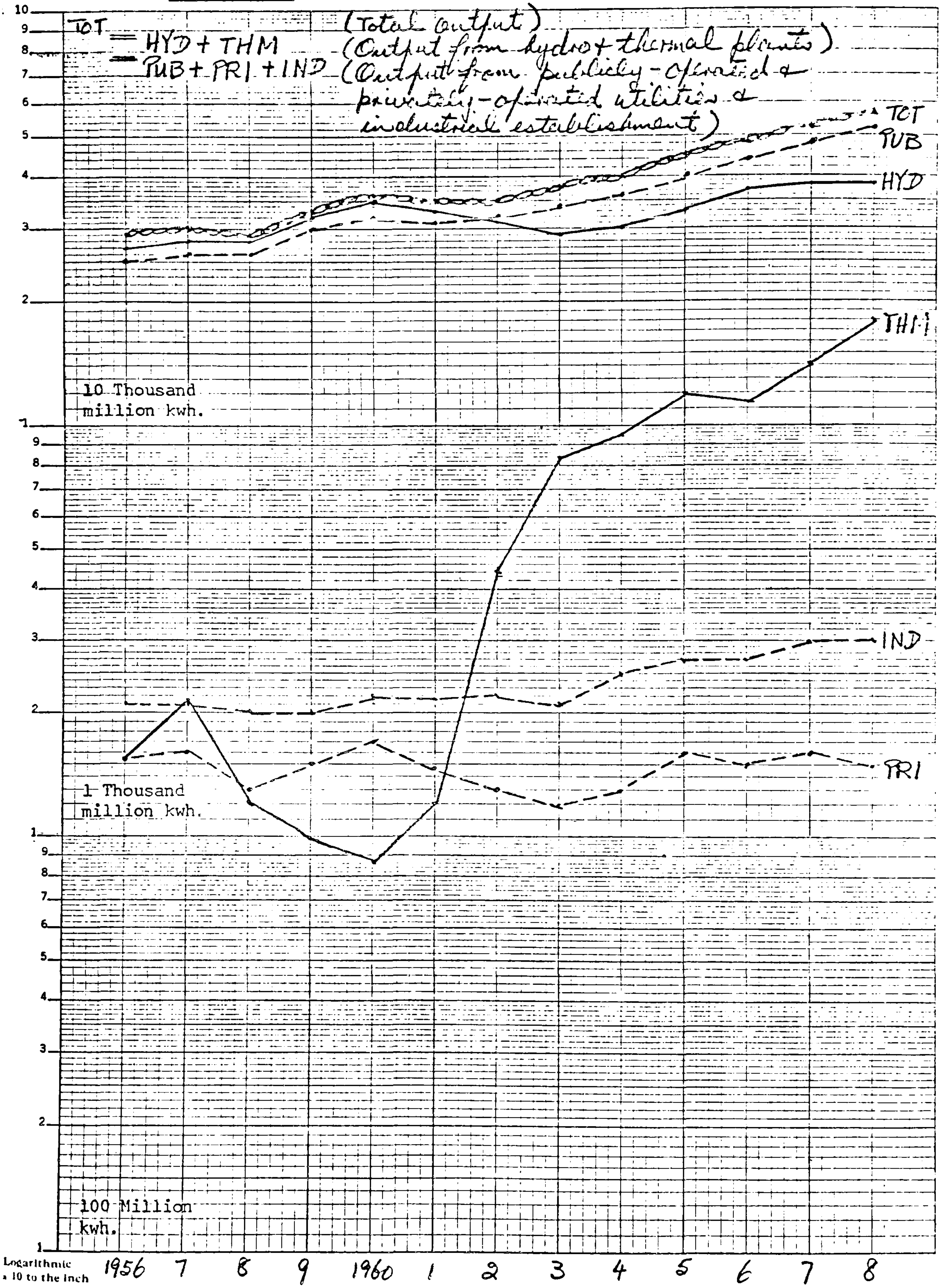
Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, *Electric Power Statistics*, Vol.II 1956-68).


APP. II.1a Canada
TOT = HYD + THM (Total output) (Output from hydro + thermal plants)
= PUB + PRI + IND (Output from publicly-operated and privately-operated utilities and industrial establishments)
100 Thousand million kwh.
10 Thousand million kwh.
1 Thousand million kwh.
TOT
HYD
PUB
THM
IND
PRI
1956
7
8
9
1960
1
2
3
4
5
6
7
8
Semi-Logarithmic
3 Cycles x 10 to the inch

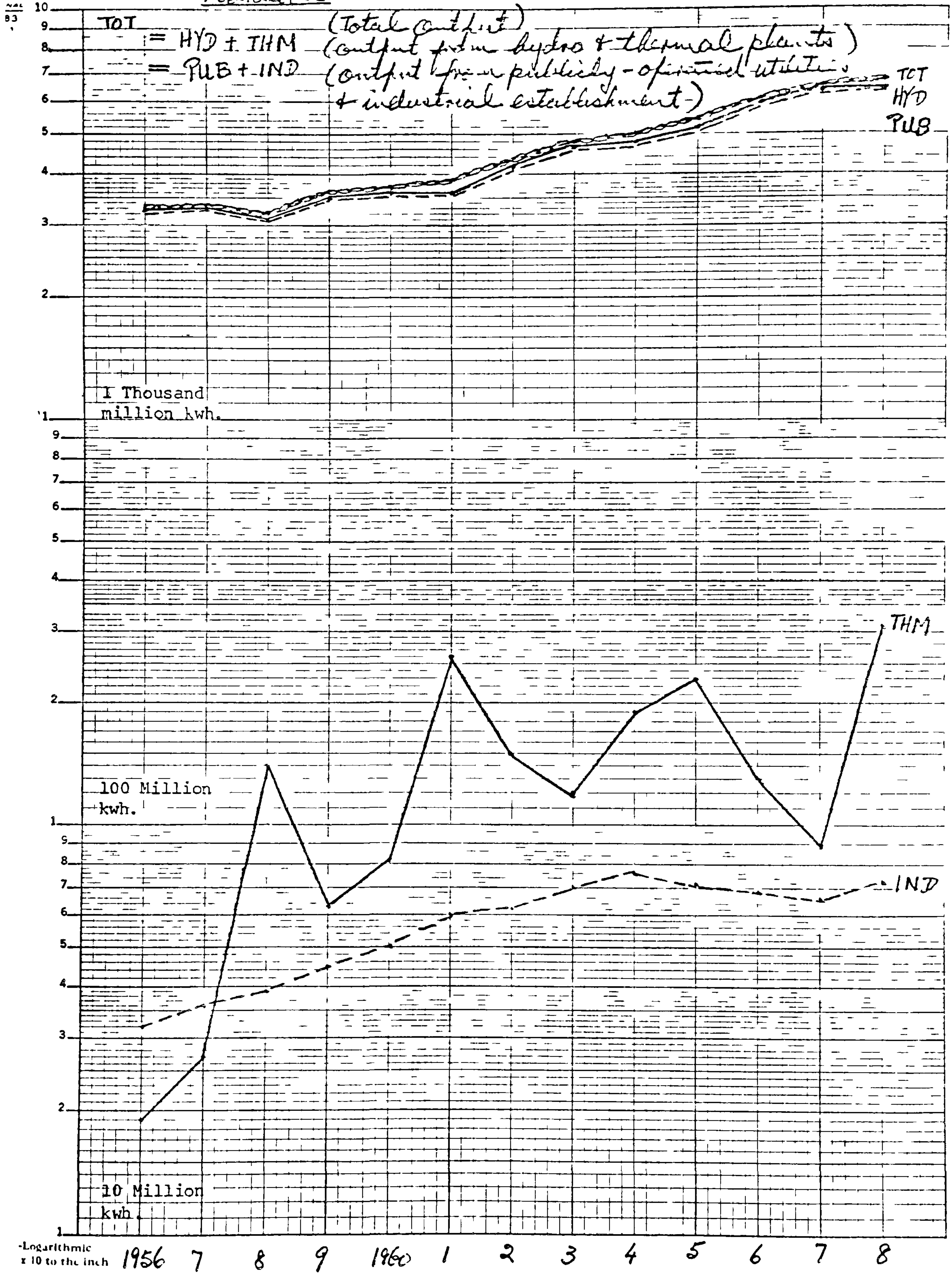

TOT = HYD + THM
= PUB + PRI + IND
(Total output)
(Output from hydro & thermal plants)
(Output from publicly-operated and privately-operated utilities and industrial establishments)
TOT
HYD
PRI
PUB
IND
THM
1 Thousand million kwh.
100 Million kwh.
10 Million kwh.
(output from PUB was below 10 million kwh)
1956
7
8
9
1960
1
2
3
4
5
6
7
8
Semi-Logarithmic
3 Cycles x 10 to the inch

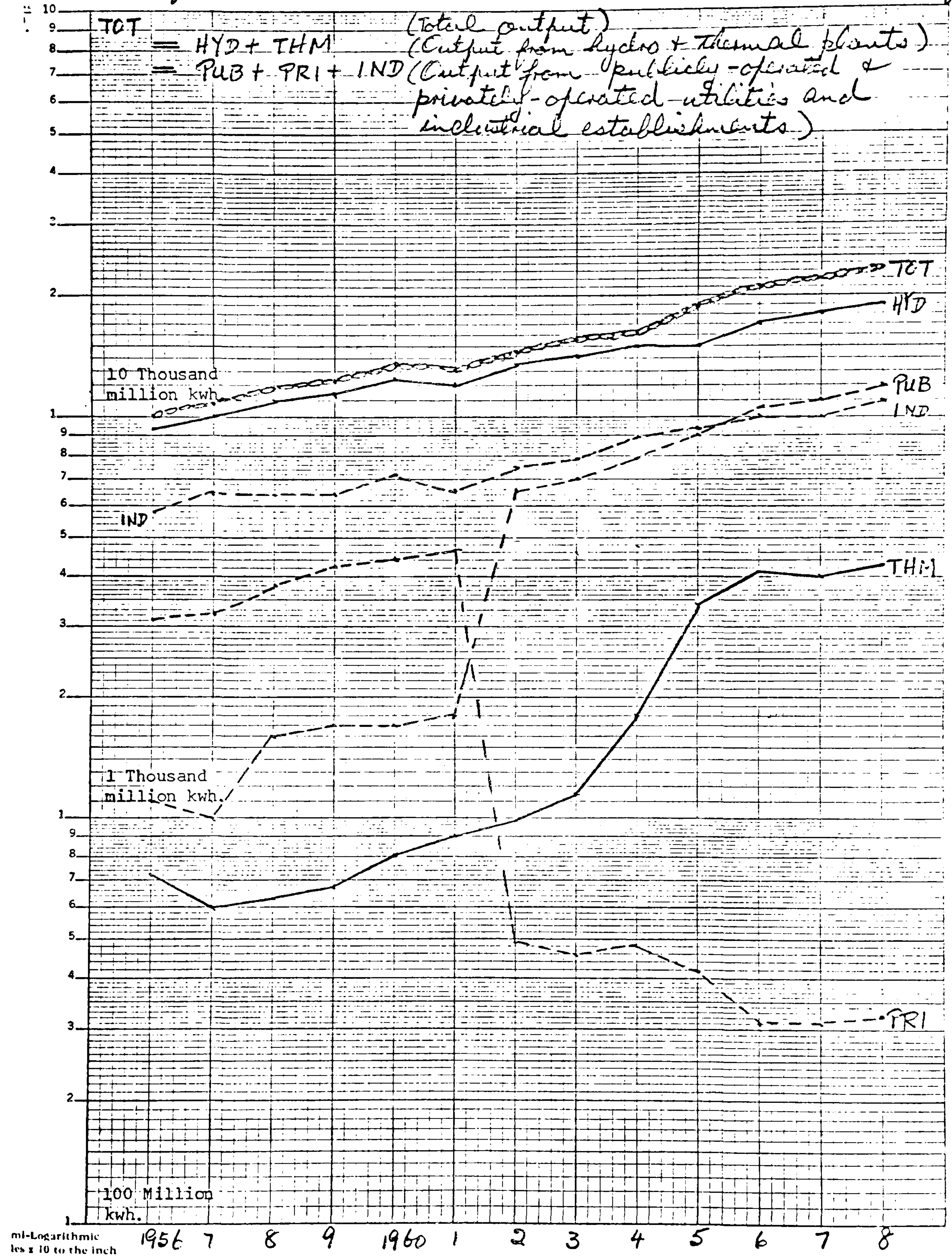

TOT = HYD + THM (Total output) (Output from hydro + thermal plants)
= PUB + PRI + IND (Output from publicly-operated + privately-operated utilities + industrial establishments)
TOT
HYD
PUB
PRI
IND
PRI
THM
10 Thousand million kwh.
1 Thousand million kwh.
100 million kwh.
Semi-Logarithmic
1956
7
8
9
1960
1
2
3
4
5
6
7
8

APP. II. 1d Ontario

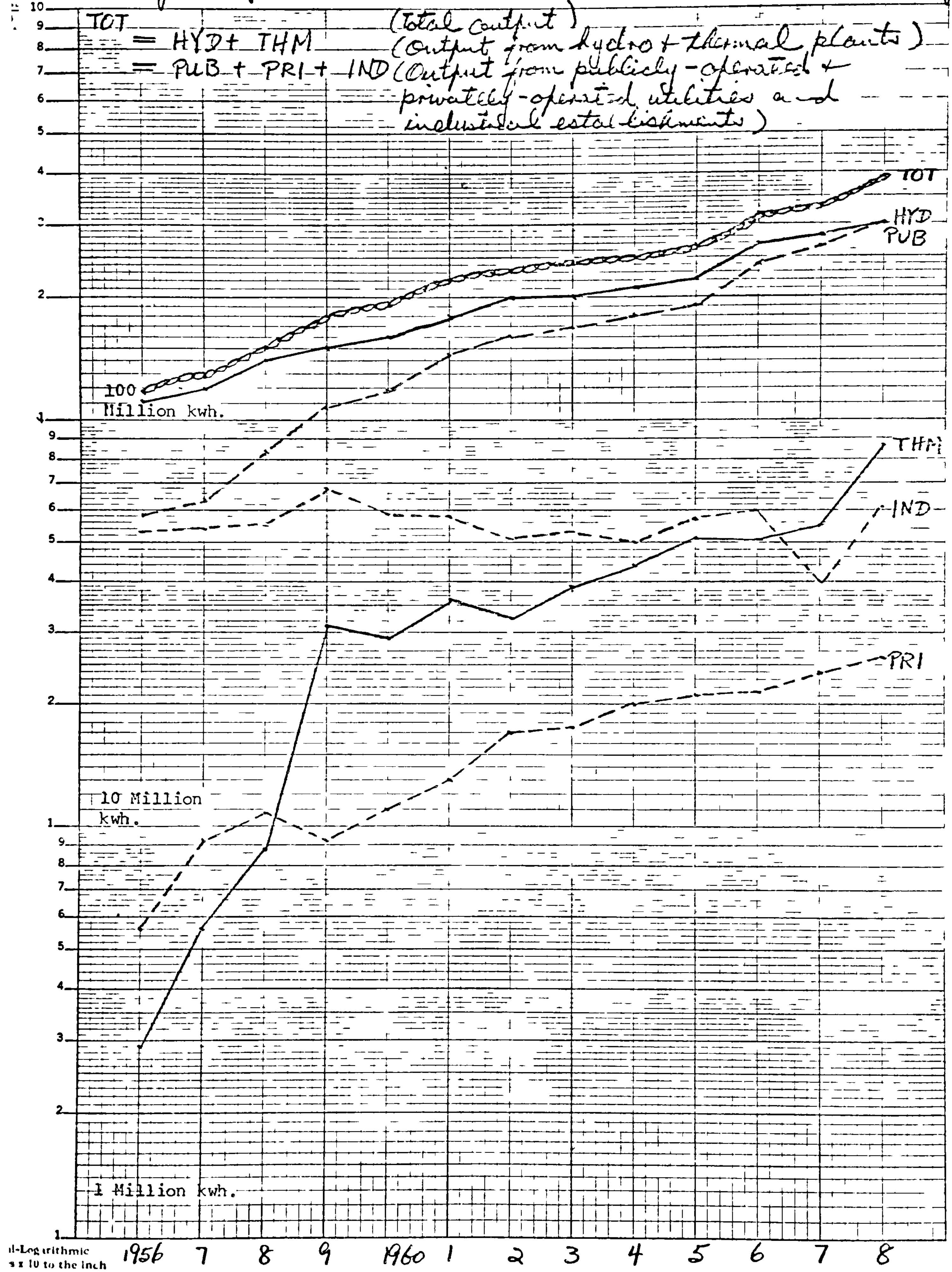


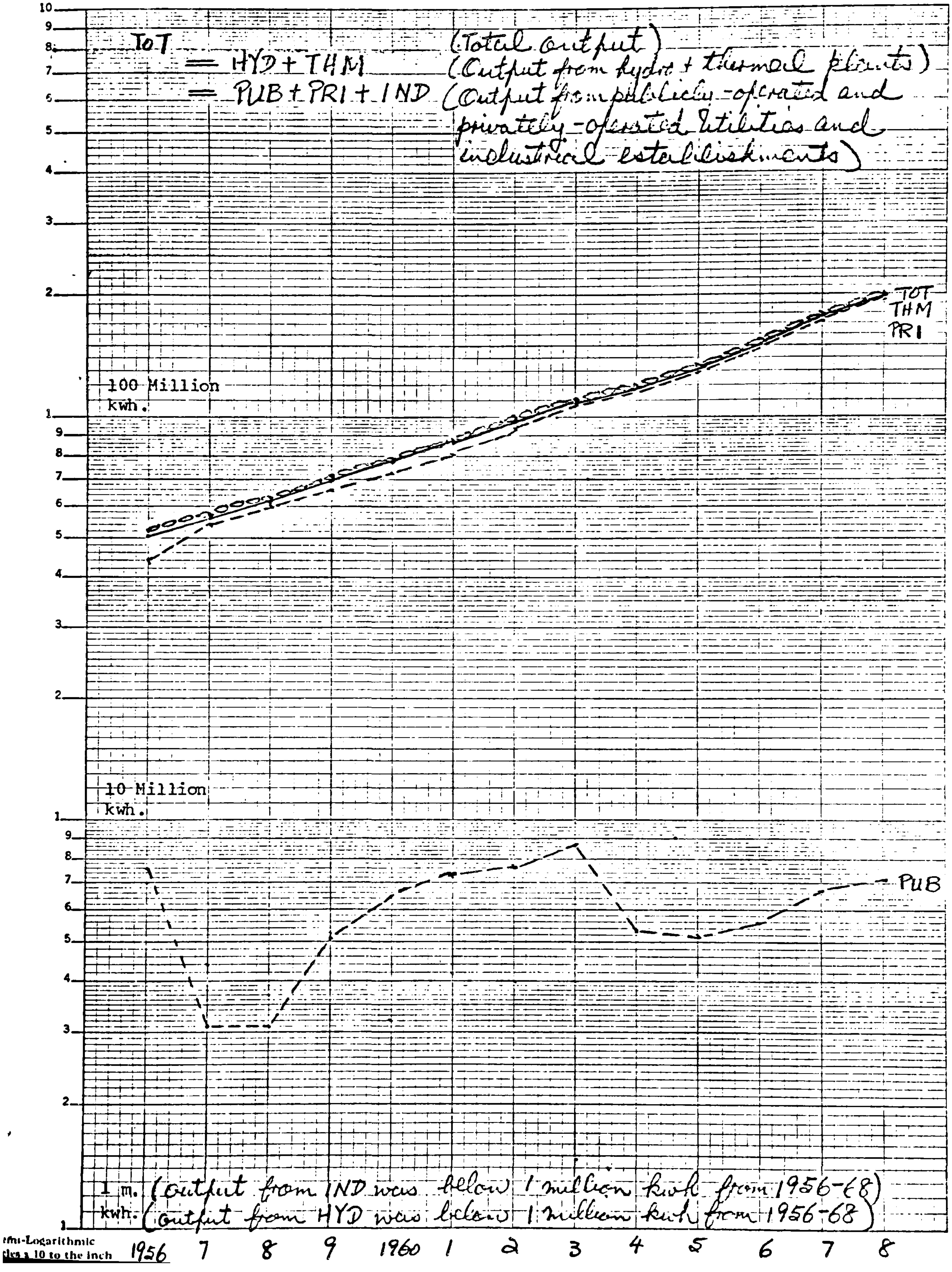
ATT. II.1e *Manitoba*



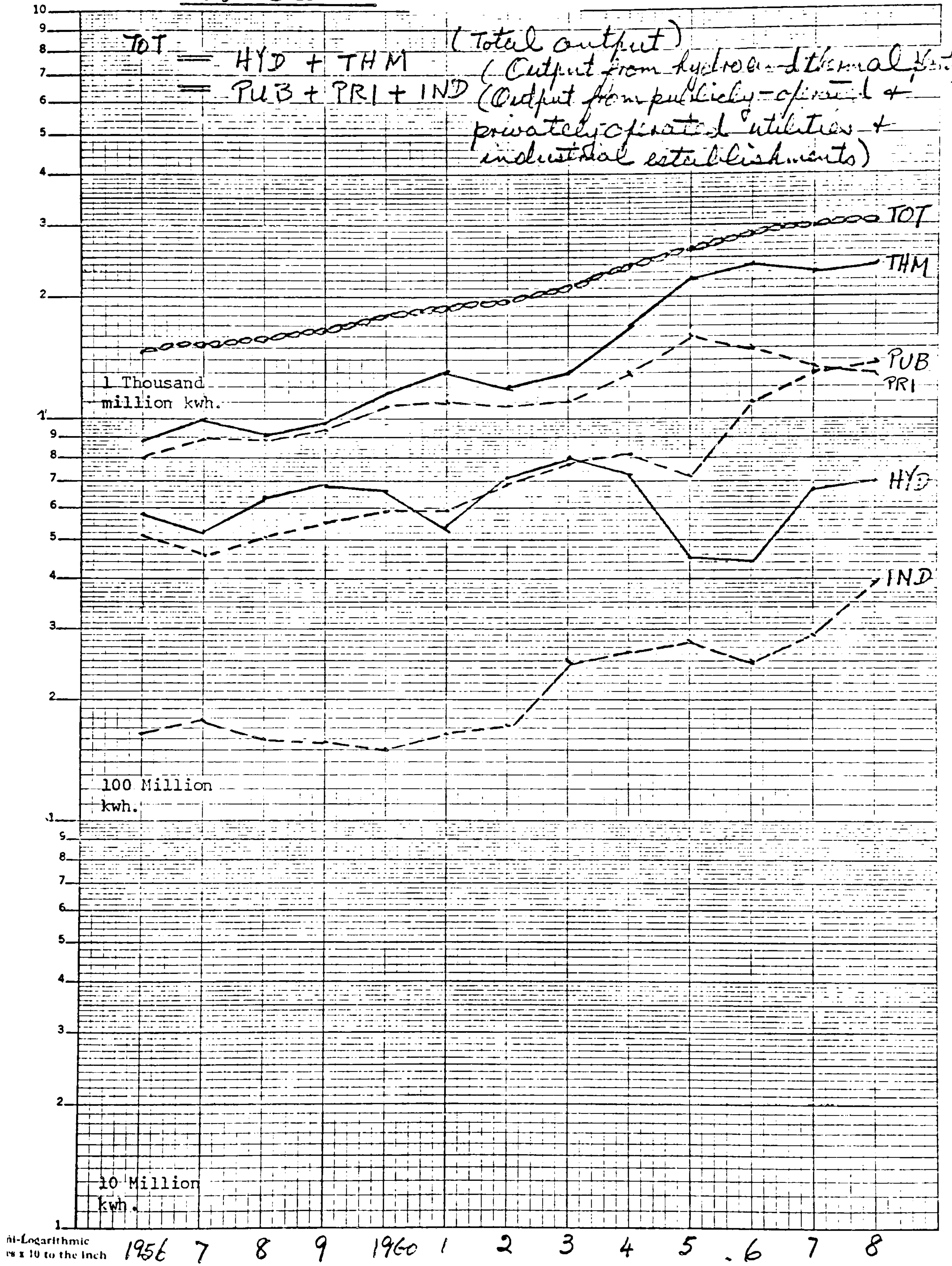

TOT
= HYD + THM
= PUB + PRI + IND
(Total output)
(Output from hydro + thermal plants)
(Output from publicly-operated & privately-operated utilities and industrial establishments)
10 Thousand million kwh.
1 Thousand million kwh.
100 Million kwh.
TOT
HYD
PUB
IND
THM
PRI
IND
1956
7
8
9
1960
1
2
3
4
5
6
7
8
Semi-Logarithmic
...les x 10 to the inch

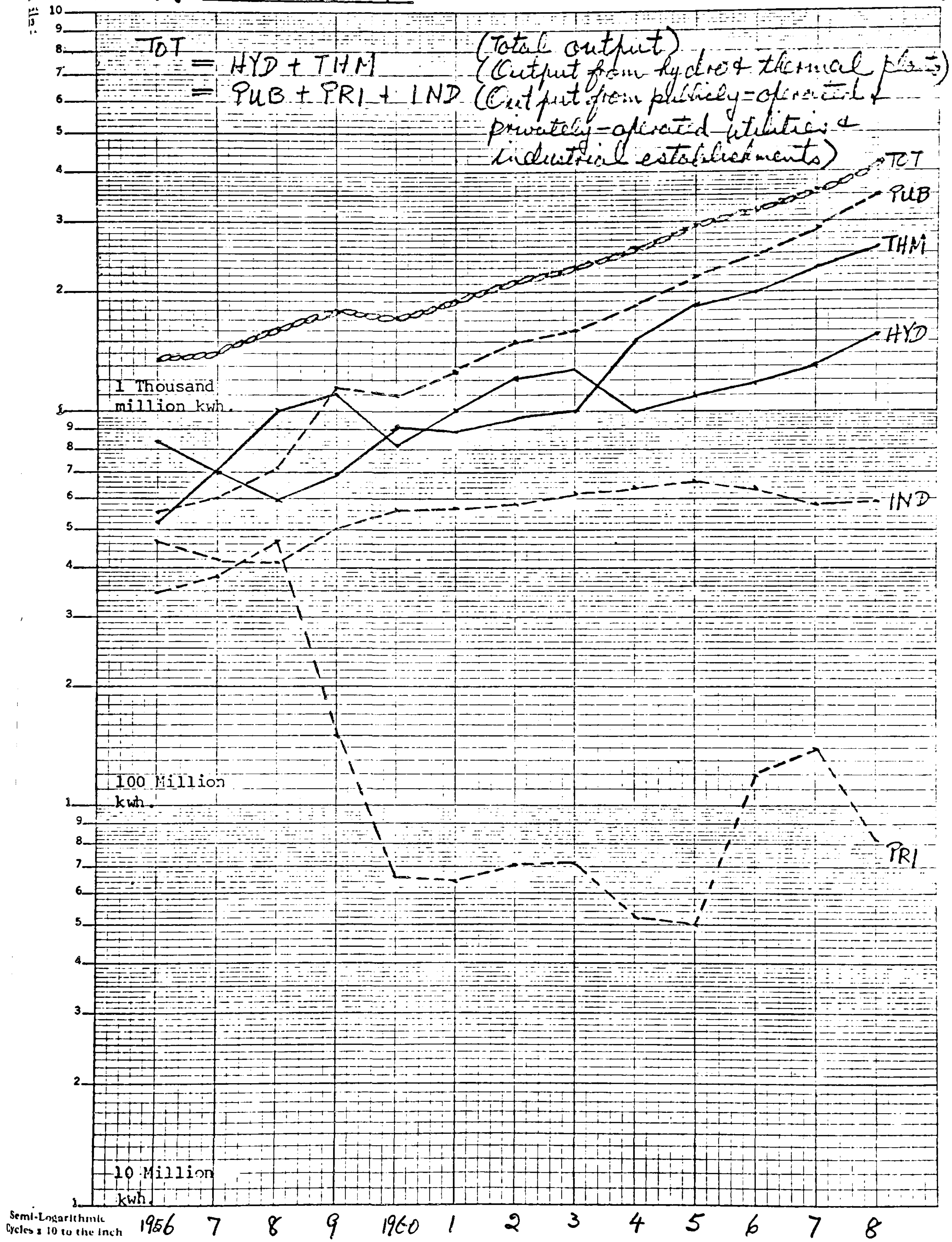
APP. II. 1g The Yukon & Northwest Territories

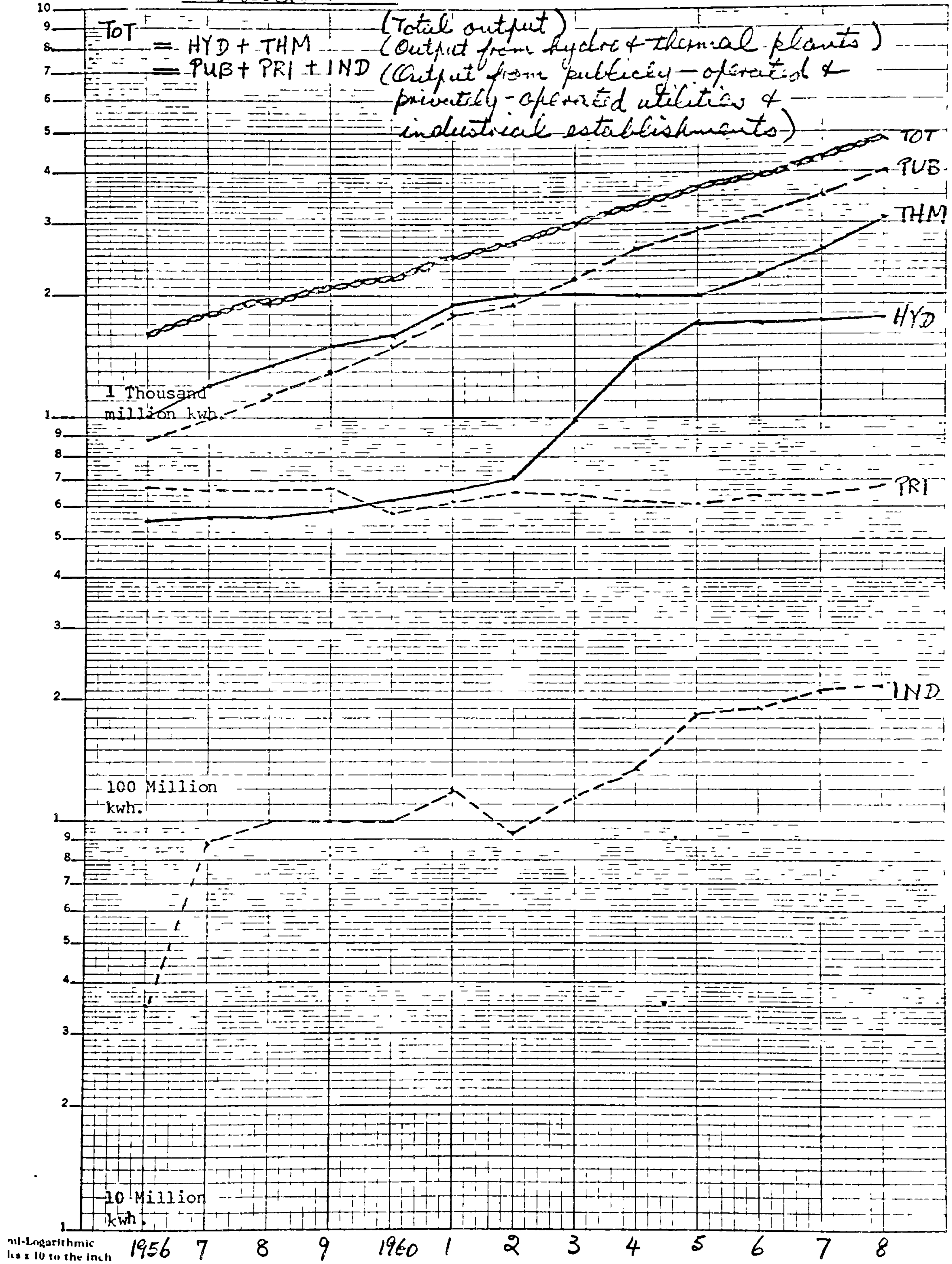


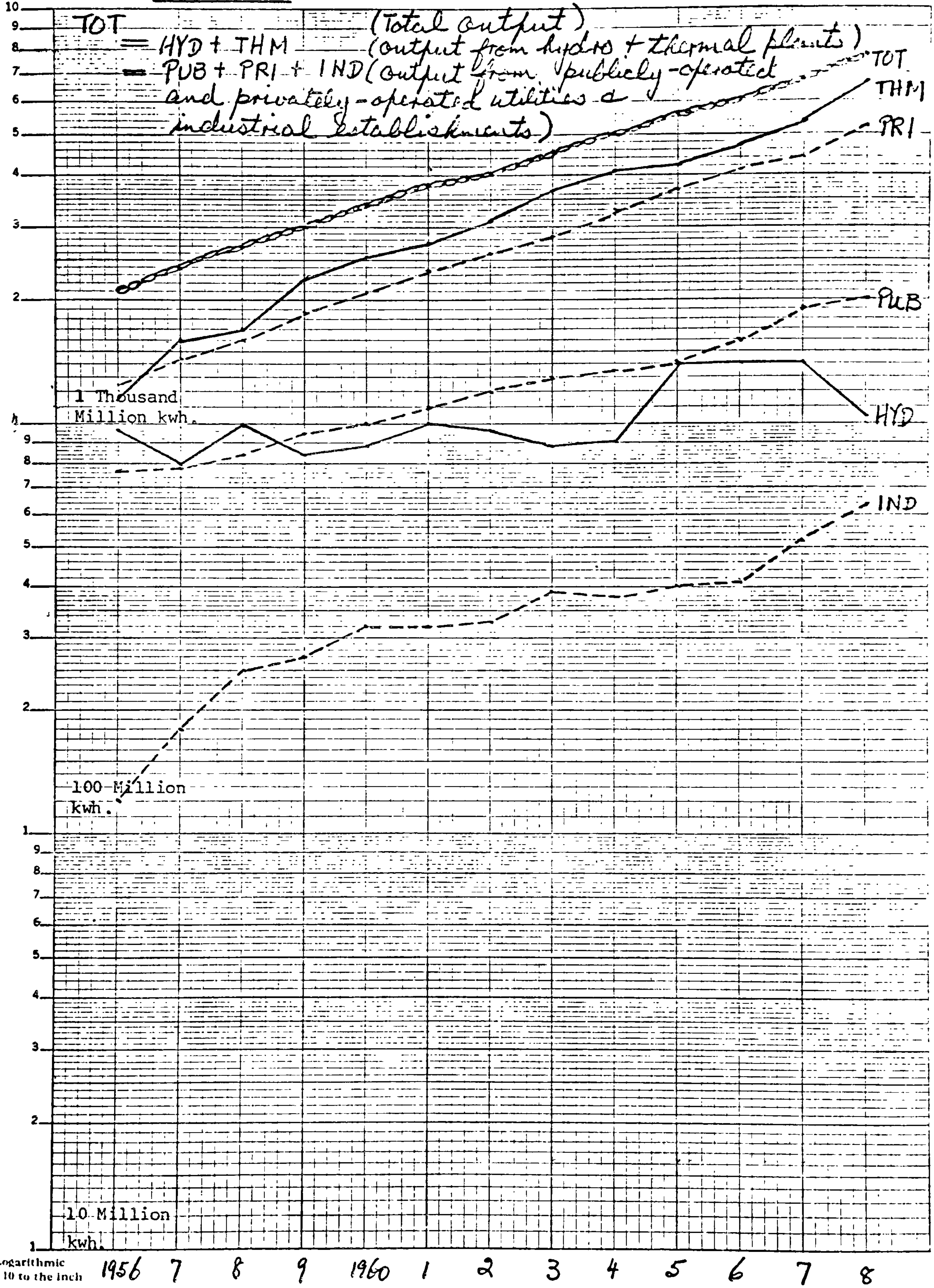

TOT (Total output)
= HYD + THM (Output from hydro + thermal plants)
= PUB + PRI + IND (Output from publicly-operated and privately-operated utilities and industrial establishments)
100 Million kwh.
10 Million kwh.
1 m. kwh.
(output from IND was below 1 million kwh from 1956-68)
(output from HYD was below 1 million kwh from 1956-68)
TOT
THM
PRI
PUB
1956
7
8
9
1960
1
2
3
4
5
6
7
8
Semi-Logarithmic
Cycles x 10 to the inch

ATT. II.1C Nova Scotia




TOT = HYD + THM
= PUB + PRI + IND
(Total output)
(Output from hydro & thermal plants)
(Output from publicly-operated & privately-operated utilities & industrial establishments)
TOT
PUB
THM
HYD
IND
PRI
1 Thousand million kwh.
100 Million kwh.
10 Million kwh.
1956
7
8
9
1960
1
2
3
4
5
6
7
8
Semi-Logarithmic
Cycles x 10 to the inch


TOT (Total output)
= HYD + THM (Output from hydro & thermal plants)
= PUB + PRI + IND (Output from publicly-operated & privately-operated utilities & industrial establishments)
TOT
PUB
THM
HYD
PRI
IND
1 Thousand million kwh.
100 Million kwh.
10 Million kwh.
1956 7 8 9 1960 1 2 3 4 5 6 7 8
Semi-Logarithmic
...ks x 10 to the inch



emi-Logarithmic
cles x 10 to the inch

AVERAGE REVENUES FROM ELECTRIC-POWER SOLD IN CANADA

($per 10^3 kwh)[a]

Year	(1) Firm Power	(2) Secondary Power	(3) Domestic & Farm	(4) Commercial	(5) Street Lighting
1956	6.6	1.8	16.4	20.4	23.7
7	6.8	1.7	16.2	19.6	23.4
8	7.3	1.7	16.1	18.2	23.8
9	7.2	1.6	16.1	17.6	24.6
1960	7.3	1.6	16.0	17.2	24.6
1	7.2	1.6	15.7	19.2	24.7
2	7.2	1.4	15.4	18.8	24.6
3	7.2	2.0	15.2	18.6	24.8
4	7.8	2.4	14.6	18.4	25.2
5	7.8	2.5	14.3	18.6	25.6
6	7.8	2.5	14.2	18.4	26.3
7	7.8	3.0	14.5	17.0	26.5
8	8.1	3.5	14.8	16.6	26.6

---

a $per 10^3 kwh means $ per one thousand kilowatt hours.

Source : Parts of Computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956 -68).

Note : See p.35.

APPENDIX II.3

AVERAGE REVENUE AND PERCENTAGE OF TOTAL CONSUMPTION
(for major groups of consumers)

Hydro Prov.[c]	Total Consumption 1968 (Index 1956 100)	1956 (t.kwh)[a]	Firm Power (% of total) 1968	1956	$ per 10^3 kwh[b] 1968	1956
Canada	213	83,074,435	32.3	43.7	8.1	6.6
Newfoundland	273	1,364,550	34.5	56.2	5.9	5.8
Quebec	189	32,093,357	34.5	45.2	7.5	5.2
Ontario	207	29,520,363	36.3	50.8	7.8	6.7
Manitoba	191	3,804,231	37.2	49.3	7.8	4.9
British Columbia	243	10,074,059	16.6	15.4	7.0	9.9
Yukon & N.W.T.	332	117,597	36.2	39.0	14.6	22.6
Thermal Prov.[c]						
Prince Ed. Isd.	384	51,803	6.5	15.6	21.0	28.9
Nova Scotia	218	1,472,994	16.2	47.8	15.4	12.7
New Brunswick	271	1,370,811	27.9	40.1	12.5	10.6
Saskatchewan	426	1,032,685	41.2	29.6	14.2	17.6
Alberta	357	2,171,985	30.6	47.1	10.9	12.6

Hydro Prov.[c]	Commercial Users (% of total) 1968	1956	$per 10^3 kwh[b] 1968	1956	Domestic and farm users (% of total) 1968	1956	$per 10^3 kwh[b] 1968	1956
Canada	11.1	6.4	16.6	20.4	21.4	17.3	14.8	16.4
Newfoundland	9.8	2.4	22.6	31.2	10.5	8.9	20.6	24.2
Quebec	7.7	4.4	16.4	18.9	17.8	9.7	13.8	16.1
Ontario	13.1	8.2	13.3	15.5	25.5	23.9	13.3	13.6
Manitoba	12.5	7.3	15.6	19.1	29.0	30.8	12.6	11.5
British Columbia	11.0	5.5	19.4	28.1	16.4	14.3	16.2	21.0
Yukon & N.W.T.	14.3	22.8	52.5	66.4	7.4	11.4	34.2	51.0
Thermal Prov.[c]								
Prince Ed. Isd.	28.5	30.6	33.3	38.4	41.1	36.6	31.4	48.6
Nova Scotia	21.8	7.5	38.1	24.4	27.9	21.7	22.0	27.2
New Brunswick	10.1	6.2	19.8	31.6	17.9	14.3	26.0	37.5
Saskatchewan	9.1	15.3	24.4	36.8	31.5	38.8	21.8	31.7
Alberta	18.2	11.3	21.5	35.3	24.2	23.1	17.9	25.1

---

a t.kwh mean thousand kilowatt hours.

b \$per 10^3 kwh mean \$ per one thousand kilowatt hours.

c A province that generates over 50% of the total electricity output in the province from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output in the province from thermal plants is listed under thermal provinces.

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

APPENDIX II.4

a. INTERNATIONAL TRANSFER ($ per 10^3 kwh)[a]

Hydro Prov.[c]	Average Revenues from Expt. to U.S. Firm Power 1968	Firm Power 1956	Secondary Power 1968	Secondary Power 1956	Average Charges for Impt. from U.S. 1968	1964[b]
Canada	6.7	3.3	0.8	3.3	1.4	0.9
Quebec	12.5	1.4	5.6	5.9	2.1	2.2
Ontario	5.5	3.2	0.9	3.3	1.2	0.8
Manitoba	83.3(1962)	45.5(1957)	-	-	-	-
British Col.	0.2	3.8	.03(1965)	76.9(1957)	1.7	2.2
Thermal Prov.[c]						
New Brunswick	8.3	6.8	7.5	6.6	3.6	10.4
Saskatchewan	-	-	-	-	22.2	39.6
Alberta	-	-	-	-	10.5	11.0

b. INTERPROVINCIAL TRANSFERS ($ per 10^3 kwh)[a]

Atlantic Prov.	Average Revenue from Transfers to other Provinces Firm Power 1968	Firm Power 1956	Secondary Power 1968	Secondary Power 1956	Average Charges for Transfers in from other Provinces 1968	1964[b]
Newfoundland	4.0	4.2(1959)	-	-	-	-
Nova Scotia	6.9(1966)	19.3	6.3	2.0(1962)	3.4	3.3
New Brunswick	4.2(1967)	1.7(1960)	4.2	2.5(1963)	7.3	7.7
Central Canada						
Quebec	2.1	2.8	1.8	2.5	1.4	4.1
Ontario	4.0	8.5	3.8	1.7	2.4	2.7
Prairie & Western Prov.						
Manitoba	5.1	16.5	0.4	3.3	1.8	2.0
Saskatchewan	2.0	2.3	0.5(1964)	0.7(1963)	5.5	3.4
Alberta	7.6	6.8(1958)	-	-	2.0	7.8
British Col.	2.0	3.2	7.4(1964)	16.8(1959)	6.3	35.7(1965)

---

a $per 10^3 kwh means $ per 1,000 kilowatt hour.

b Value of imports from the U.S. and transfers in from other provinces started to be published in 1964. One figure is given for value of firm and secondary power.

c A province that generates over 50% of the total electricity output in the province from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output in the province from thermal plants is listed under thermal provinces.

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

APPENDIX II.5

OUTPUT, CONSUMPTION AND POPULATION

	Population		Output				Consumption			
	1968 (%)	1956 (%)	1968 (%)	1956 (%)	1968 per capita[a]	1956 per capita[a]	1968 (%)	1956 (%)	1968 per capita[a]	1956 per capita[a]
Canada	100[b]	100[b]	100[c]	100[c]	8.5	5.5	100[d]	100[d]	8.52	5.2
Hydro Prov.[e]										
Newfoundland	2.4	2.6	2.2	1.6	7.5	3.4	2.1	1.6	7.4	3.3
Quebec	28.6	28.8	36.9	42.4	11.0	8.1	34.2	38.6	10.2	6.9
Ontario	35.2	33.6	32.0	33.0	7.7	6.4	34.6	35.5	8.4	5.5
Manitoba	4.7	5.3	3.8	3.8	7.0	4.0	4.1	4.6	7.5	4.5
British Col.	9.7	8.7	13.4	11.5	11.8	7.2	13.9	12.1	12.2	7.2
Yukon & N.W.T.	0.22	0.2	0.2	0.1	8.5	3.8	0.2	0.1	8.5	3.8
Thermal Prov.[e]										
Prince Ed. Isd.	0.5	0.6	0.1	0.06	1.8	0.5	0.1	0.06	1.8	0.5
Nova Scotia	3.7	4.3	1.7	1.68	4.0	2.1	1.8	1.77	4.2	2.1
New Brunswick	3.0	3.5	2.4	1.6	6.7	2.5	2.1	1.7	6.0	2.5
Saskatchewan	4.6	5.5	2.8	1.8	5.1	1.8	2.5	1.2	4.6	1.2
Alberta	7.4	7.0	4.4	2.4	5.1	1.9	4.4	2.6	5.1	1.9

a Output per capita and consumption per capita are in thousand kilowatt hours.

b The actual population in Canada was 20,744,000 in 1968 and 16,081,000 in 1956.

c The actual output in Canada was 176,378,280 t.kwh in 1968 and 87,938,931 t.kwh in 1956. (t.kwh means thousand kilowatt hours).

d The actual consumption in Canada was 176,841,205 t. kwh in 1968 and 83,074,435 t.kwh in 1956. (Consumption included "losses").

e A province that generates over 50% of the total electricity output in the province from hydro plants is listed under hydro provinces. Similarly a province that generates over 50% of the total electricity output in the province from thermal plants is listed under thermal provinces.

Source : Parts of Computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

APPENDIX III.1

PERCENTAGE OF OUTPUT FROM HYDRO PLANTS TO TOTAL OUTPUT

(publicly and privately-operated utilities only)

Year	Manitoba	Nfd.	Quebec	Ontario	B.C.	Y&NWT
1956	99.90	99.71	99.92	96.51	96.52	97.07
7	99.73	98.72	99.97	94.77	96.56	94.21
8	95.84	99.13	99.97	97.77	96.86	92.16
9	98.39	96.59	99.92	98.88	96.73	90.01
1960	97.94	95.65	99.90	99.46	96.46	86.14
1	93.41	91.52	99.93	98.38	96.09	83.55
2	96.78	94.50	99.85	88.84	95.05	83.52
3	97.75	95.75	99.86	78.01	94.88	82.41
4	96.34	95.50	99.72	76.78	90.84	81.60
5	95.90	91.60	98.49	74.28	75.95	81.78
6	97.96	89.87	99.66	77.16	74.12	85.90
7	98.73	93.90	97.56	73.28	76.37	84.78
8	95.45	96.40	93.56	68.72	77.22	84.18
Total	1264.12	1238.84	1288.31	1122.84	1163.65	1127.31
Mean	97.24	95.30	99.10	86.37	89.51	86.72

Year	N.B.	PEI	Alberta	N.S.	Sask.
1956	50.72	0.85	48.46	42.16	35.82
7	64.51	0.65	35.88	36.76	32.54
8	79.68	0.85	40.04	43.32	30.29
9	80.45	0.48	29.76	42.88	28.13
1960	64.10	0.52	28.36	37.26	27.86
1	71.64	0.46	29.49	30.21	25.60
2	70.98	0.40	25.38	38.12	25.03
3	70.98	0	21.28	40.71	31.70
4	50.48	0	19.28	32.00	40.29
5	45.43	0.23	27.33	17.98	45.71
6	43.61	0.19	24.83	16.02	42.79
7	41.10	0	22.85	23.88	39.83
8	42.24	0	14.94	24.85	35.83
Total	775.92	4.63	367.88	426.15	441.42
Mean	59.69	0.36	28.30	32.78	33.96

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

APPENDIX III.2

(1) Quebec (Data)

Year	Cost ($'000)	Output (10^6 kwh)	Wage Rate ($)per year	Rental Rate on Cap.Equip. (Est.Index)	Fuel Price ($per 10^7 B.t.u.)
1956	62,554	27,266	3,399	2.02	13.99
7	71,274	28,538	3,608	2.09	10.38
8	83,175	32,037	4,010	2.24	11.47
9	86,141	33,292	4,142	2.33	11.77
1960	86,363	36,188	4,201	2.48	9.67
1	100,658	36,070	4,370	2.26	9.56
2	117,400	36,325	4,842	2.71	9.80
3	131,391	33,169	4,786	3.10	11.72
4	157,244	38,153	5,141	3.38	7.52
5	191,454	37,775	5,450	3.38	4.76
6	222,293	45,660	7,249	3.39	5.62
7	196,304	47,038	6,858	3.51	4.53
8	227,851	49,117	8,307	3.65	3.81

(2) Manitoba (Data)

Year	Cost ($'000)	Output (10^6 kwh)	Wage Rate ($)per year	Rental Rate on Cap.Equip. (Est.Index)	Fuel Price ($per 10^7 B.t.u.)
1956	18,065	3,334	3,461	3.11	9.99
7	19,209	3,341	3,411	2.82	6.53
8	22,039	3,214	3,626	2.82	3.60
9	22,785	3,598	4,009	2.80	3.77
1960	26,809	3,690	4,324	2.93	3.97
1	29,779	3,786	4,417	3.42	2.55
2	30,854	4,305	4,477	3.23	3.39
3	33,001	4,785	4,636	3.10	5.99
4	33,214	4,915	4,497	2.93	4.23
5	40,975	5,417	5,026	3.58	3.73
6	45,549	6,102	5,372	4.57	5.45
7	46,893	6,499	6,146	4.07	6.85
8	50,814	6,706	6,975	3.70	4.09

Source: Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, *Electric Power Statistics*, Vol.II 1956-68).

(3) Newfoundland (Data)

Year	Cost	Output	Wage Rate	Rental Rate on Cap. Equip.	Fuel Price
	($'000)	(10^6 kwh)	($) per yr.	(Est.Index)	($per 10^7 B.t.u.)
1956	4,325	1,012	2,504	1.94	9.30
7	4,881	982	2,927	1.88	17.03
8	4,617	992	2,967	1.87	6.26
9	5,358	1,046	3,300	2.02	4.84
1960	5,766	1,084	3,294	2.27	4.22
1	6,200	1,023	3,562	2.38	4.43
2	6,537	1,224	3,466	2.30	7.72
3	9,647	1,621	3,557	2.42	6.13
4	10,903	1,961	3,172	3.09	5.10
5	12,270	2,265	4,301	2.68	4.99
6	13,534	2,367	4,440	2.57	4.82
7	16,013	2,658	6,077	1.70	6.28
8	15,103	3,421	5,163	1.29	7.57

(4) British Columbia (Data)

Year	Cost	Output	Wage Rate	Rental Rate on Cap. Equip.	Fuel Price
	($'000)	(10^6 kwh)	($)per yr.	(Est.Index)	($per 10^7 B.t.u.)
1956	30,230	4,222	4,253	1.93	11.45
7	36,068	4,265	3,749	2.13	9.72
8	46,048	5,481	4,231	2.61	6.37
9	51,617	5,377	5,474	2.85	5.43
1960	57,849	6,205	5,832	3.18	5.39
1	67,099	6,558	6,147	3.78	4.86
2	77,138	7,132	5,762	4.56	3.68
3	70,599	7,542	5,885	4.26	4.71
4	74,934	8,391	6,048	4.12	4.48
5	80,889	9,450	6,519	3.42	3.17
6	89,352	10,900	7,051	2.93	3.36
7	95,611	11,341	7,415	2.58	3.39
8	109,340	12,624	8,139	2.88	2.77

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

(5) The Yukon & N.W.T. (Data)

Year	Cost ($'000)	Output (10^6 kwh)	Wage Rate ($) per year	Rental Rate on Cap.Equip (Est.Index)	Fuel Price ($ per 10^7 B.t.u.)
1956	877	64	3,739	2.87	14.25
7	559	73	4,083	1.62	15.45
8	726	96	4,353	1.09	14.70
9	1,231	117	4,563	1.54	14.73
1960	1,529	130	4,960	1.87	16.32
1	2,997	160	5,482	2.96	12.76
2	2,804	180	5,103	2.91	15.00
3	2,953	186	5,121	2.51	15.11
4	3,516	202	5,152	2,07	18.95
5	3,548	211	6,000	1.81	17.89
6	4,136	261	6,781	3.38	15.08
7	4,855	292	7,339	3.03	9.42
8	5,393	329	7,861	2.91	9.85

(6) Ontario (Data)

Year	Cost ($'000)	Output (10^6 kwh)	Wage Rate ($) per yr.	Rental Rate on Cap.Equip. (Est.Index)	Fuel Price ($ per 10^7 B.t.u.)
1956	118,749	26,909	4,017	2.93	3.55
7	141,071	28,000	4,344	2.99	3.59
8	151,482	27,191	4,556	3.08	3.72
9	163,682	31,321	4,864	3.22	3.74
1960	171,243	33,637	4,632	3.32	4.12
1	183,552	32,795	5,250	3.38	3.27
2	204,564	33,103	5,659	3.39	3.54
3	224,792	35,502	5,774	3.42	3.58
4	237,257	37,250	5,989	3.43	3.49
5	247,262	42,161	6,228	3.46	3.47
6	269,019	45,857	6,635	3.39	3.42
7	305,001	49,146	7,204	3.50	3.42
8	339,454	53,438	7,870	3.67	3.41

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

(7) New Brunswick (Data)

Year	Cost	Output	Wage Rate	Rental Rate On Cap.Equip	Fuel Price
	($'000)	(10^6kwh)	($)per yr.	(Est.Index)	($per 10^7B.t.u.)
1956	9,833	896	3,284	2.57	4.28
7	7,277	983	3,184	2.15	4.38
8	10,992	1,198	3,234	3.52	4.46
9	13,201	1,306	3,296	3.92	4.53
1960	14,112	1,173	3,585	3.73	4.17
1	14,504	1,339	3,638	4.13	4.14
2	16,186	1,590	3,689	4.14	3.70
3	17,922	1,683	3,377	4.04	3.75
4	21,327	1,908	3,415	4.10	3.63
5	25,030	2,297	5,183	3.88	3.63
6	24,870	2,583	5,480	2.94	3.50
7	27,550	3,045	5,271	2.88	3.37
8	36,335	3,605	6,831	4.52	3.32

(8) Saskatchewan (Data)

Year	Cost	Output	Wage Rate	Rental Rate On Cap.Equip	Fuel Price
	($'000)	(10^6kwh)	($)per yr.	(Est.Index)	(per10^7$B.t.u.)
1956	15,571	1,551	3,960	3.06	2.73
7	17,958	1,678	3,349	3.27	2.73
8	22,142	1,810	4,569	3.15	2.46
9	25,377	1,998	4,530	3.11	1.94
1960	29,356	2,103	5,250	3.94	1.75
1	32,195	2,422	5,402	3.70	1.65
2	30,293	2,594	4,609	3.22	1.66
3	35,516	2,875	6,026	3.77	1.72
4	40,425	3,202	6,137	4.52	1.70
5	38,966	3,548	5,938	3.63	1.45
6	39,719	3,752	7,317	3.75	1.75
7	41,991	4,151	7,166	3.48	1.85
8	44,298	4,660	7,943	3.21	1.71

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II. 1956-68).

(9) Nova Scotia (Data)

Year	Cost	Output	Wage Rate	Rental Rate on Cap.Equip.	Fuel Price
	($'000)	(10^6 kwh)	($) per yr.	(Est.Index)	($per 10^7 B.t.u.)
1956	13,029	1,316	2,839	2.63	3.98
7	15,296	1,355	3,136	2.61	4.37
8	15,328	1,399	3,500	2.71	4.36
9	16,434	1,493	3,685	2.57	4.25
1960	17,712	1,661	3,862	2.74	4.27
1	19,444	1,696	4,153	3.00	3.99
2	19,583	1,775	4,386	3.17	4.10
3	20,463	1,885	4,133	3.00	4.13
4	22,943	2,138	4,508	2.70	3.99
5	24,832	2,349	4,598	2.46	3.62
6	27,647	2,620	4,879	2.88	3.50
7	30,420	2,665	5,458	3.30	4.15
8	31,592	2,667	6,442	3.10	3.47

(10) Alberta (Data)

Year	Cost	Output	Wage Rate	Rental Rate on Cap.Equip.	Fuel Price
	($'000)	(10^6 kwh)	($) per yr.	(Est.Index)	($per 10^7 B.t.u.)
1956	11,568	2,021	3,547	1.83	1.30
7	14,141	2,249	4,208	1.97	1.12
8	17,326	2,474	4,561	2.19	1.10
9	20,275	2,830	4,665	2.39	1.15
1960	20,425	3,126	5,233	2.23	1.25
1	23,300	3,451	5,127	2.28	1.41
2	25,347	3,767	5,329	2.29	1.43
3	28,147	4,141	5,368	2.34	1.40
4	30,252	4,645	5,540	2.44	1.33
5	32,709	5,189	5,767	2.42	1.30
6	34,845	5,739	6,362	2.08	1.30
7	37,870	6,284	6,838	1.83	1.33
8	44,948	7,119	7,031	2.18	1.27

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

(11) Prince Edward Island (Data)

Year	Cost	Output	Wage Rate	Rental Rate on Cap. Equip.	Fuel Price
	($'000)	(10^6 kwh)	($) per yr.	(Est.Index)	($per 10^7 B.t.u.)
1956	948	52	2,264	1.54	4.59
7	1,112	57	2,368	1.56	4.59
8	1,286	63	2,634	1.58	3.92
9	1,324	71	2,897	1.66	3.76
1960	1,519	79	3,309	1.49	3.60
1	1,700	89	3,472	1.70	3.65
2	1,864	102	3,824	1.62	3.66
3	1,972	111	3,961	1.70	3.65
4	2,244	124	4,019	2.25	3.54
5	2,354	137	4,538	2.18	3.59
6	2,492	156	4,257	2.01	3.61
7	2,803	182	5,365	1.78	3.64
8	3,026	199	6,083	2.28	3.64

Source : Parts of Computer Results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

a. EACH KIND OF FUEL USED
(as % of total)

Fuels	Canada 1968	Canada 1956	Nfd. 1968	Nfd. 1956	Quebec 1968	Quebec 1956	Ontario 1968	Ontario 1956	Manitoba 1968	Manitoba 1956	B.C. 1968	B.C. 1956
COALBC[a]	10.8	25.5	-	-	-	-	11.8	-	0.1	6.0	-	1.3
COALBI[b]	35.1	18.2	-	-	-	-	86.6	98.6	-	-	-	-
COALSL[c]	4.9	4.9	-	-	-	-	-	-	60.5	16.7	-	-
FURNL[d]	0.5	0.2	-	4.5	0.6	-	1.1	0.7	1.3	-	0.1	-
FURNH[e]	17.4	10.1	50.5	86.3	97.0	-	-	-	-	-	19.4	-
DIESEL[f]	1.3	3.5	49.5	9.2	2.4	100	0.4	0.6	13.6	77.3	4.2	77.2
PETROO[g]	0.01	6.2	-	-	-	-	-	-	0.1	-	0.1	8.8
GASN[h]	20.0	25.7	-	-	-	-	0.2	-	24.5	-	76.3	12.7
PROPAN[i]	0.02	-	-	-	-	-	-	-	-	-	0.3	-

Fuels	Yukon&NWT 1968	Yukon&NWT 1956	PEI 1968	PEI 1956	N.S. 1968	N.S. 1956	N.B. 1968	N.B. 1956	Sask. 1968	Sask. 1956	Alberta 1968	Alberta 1956
COALBC	-	-	-	-	65.0	84.3	26.2	94.6	-	-	0.2	0.2
COALSB[j]	-	-	-	-	-	-	-	-	7.9	12.5	50.3	8.6
COALSL	-	-	-	-	-	-	-	-	39.8	20.2	-	-
COALO[k]	-	-	-	-	-	-	-	-	-	2.5	-	-
FURNL	-	-	-	-	0.1	0.1	0.4	-	-	-	-	-
FURNH	28.9	-	99.5	-	34.4	15.4	73.0	3.2	2.9	28.6	1.6	0.3
DIESEL	71.1	100	0.5	11.0	0.6	0.2	0.5	1.0	0.8	1.9	0.4	0.7
PETROO	-	-	-	89.0	-	-	-	1.3	-	19.1	-	-
GASN	-	-	-	-	-	-	-	-	48.6	15.2	47.6	90.3

a COALBC means Canadian Bituminous Coal

b COALBI means Imported Bituminous Coal

c COALSL means Saskatchewan Lignite Coal

d FURNL means Light Furnace Fuel Oil

e FURNH means Heavy Furnace Fuel Oil

f DIESEL means Diesel Fuel Oil

g PETROO means Other Petroleum Fuel

h GASN means Natural Gas

i PROPAN means Other Fuels (Propane)

j COALSB means Sub-bituminous Coal (Canada : 10% used in 1968 and 5.2% used in 1956)

k COALO means Other Coal (Canada : 0.6% used in 1956)

Source : Parts of Computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68)

D. AVERAGE PRICE OF FUEL

($per 10^7 B.t.u.)

Fuels	Canada 1968	Canada 1956	Nfd. 1968	Nfd. 1956	Quebec 1968	Quebec 1956	Ontario 1968	Ontario 1956	Manitoba 1968	Manitoba 1956	B.C. 1968	B.C. 1956
COALBC[a]	3.4	4.0	-	-	-	-	3.4	-	5.7	4.4	-	5.0
COALBI[b]	3.3	3.5	-	-	-	-	3.3	3.5	-	-	-	-
COALSL[c]	1.4	1.0	-	-	-	-	-	-	3.0	3.4	-	-
FURNL[d]	7.8	9.4	-	12.2	6.2	-	7.9	9.1	8.4	-	0.1	-
FURNH[e]	3.5	3.2	3.7	8.7	3.7	-	-	-	-	-	3.7	-
DIESEL[f]	10.7	12.7	11.5	13.7	9.1	14.0	11.8	13.4	11.2	11.9	10.4	13.4
PETROO[g]	7.0	4.0	-	-	-	-	-	-	13.3	-	5.9	4.5
GASN[h]	1.9	1.5	-	-	-	-	3.6	-	2.5	-	2.1	4.8
PROPAN[i]	3.8	-	-	-	-	-	-	-	-	-	3.8	-
Average Price :	2.9	3.2	7.6	9.3	3.8	14.0	3.4	3.6	4.1	10.0	2.8	11.5

Fuels	Yukon&NWT 1968	Yukon&NWT 1956	PEI 1968	PEI 1956	N.S. 1968	N.S. 1956	N.B. 1968	N.B. 1956	Sask. 1968	Sask. 1956	Alberta 1968	Alberta 1956
COALBC	-	-	-	-	3.5	4.0	3.6	4.2	-	-	1.8	2.4
COALSB[j]	-	-	-	-	-	-	-	-	1.9	2.6	0.7	0.8
COALSL	-	-	-	-	-	-	-	-	1.2	0.9	-	-
COALO[k]	-	-	-	-	-	-	-	-	-	2.5	-	-
FURNL	-	-	-	-	8.0	9.6	8.2	-	-	-	-	-
FURNH	10.0	-	3.6	-	3.4	3.8	3.2	4.6	2.7	2.8	2.3	3.2
DIESEL	9.8	14.3	8.1	11.2	9.1	12.2	9.1	12.3	4.2	9.2	10.3	12.0
PETROO	-	-	-	3.8	-	-	-	6.2	-	3.9	-	-
GASN	-	-	-	-	-	-	-	-	2.0	2.8	1.7	1.3
Average Price :	9.9	14.3	3.6	4.6	3.5	4.0	3.3	4.3	1.7	2.7	1.27	1.30

a COALBC means Canadian Bituminous Coal

b COALBI means Imported Bituminous Coal

c COALSL means Saskatchewan Lignite Coal

d FURNL means Light Furnace Fuel Oil

e FURNH means Heavy Furnace Fuel Oil

f DIESEL means Diesel Fuel Oil

g PETROO means Other Petroleum Fuel

h GASN means Natural Gas

i PROPAN means Other Fuels (Propane)

j COALSB means Sub-bituminous Coal (Canada : $0.8 in 1968 and $1.9 in 1956)

k COALO means Other Coal (Canada : $2.5 in 1956)

Source : Parts of Computer results (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

MATRIX OF CORRELATION COEFFICIENTS

	Y and P_1 (Output and Wage Rate)	Y and P_2 (Output and Cap. Price)	P_1 and P_2 (Wage Rate & Cap. Price)
Time Series Data			
Hydro Prov.[a]			
Quebec	.9376	.9089	.9878
Manitoba	.4099	.2787	.9567
Newfoundland	.5517	.0752	.7312
British Columbia	.9601	.8130	.9165
The Yukon & N.W.T.	.7684	.5423	.7789
Ontario	.9207	.8081	.9512
New Brunswick	.9429	.6554	.5329
Thermal Prov.[a]			
Saskatchewan	.9133	.6767	.8638
Nova Scotia	.9483	.7897	.8594
Alberta	.8172	-.1988	.1541
P.E.I.	.9664	.8649	.8740
Time Series and Cross Section Data			
Canada (all prov. pooled)	.3183	.3532	.9202
All hydro prov.	.5353	.5030	.9028
All thermal prov.	.7278	.8192	.9171
Selected hydro Prov.[b]	.2802	.0757	.8835
Selected thermal prov.[c]	.8464	.6192	.9096

a Hydro provinces and thermal provinces are classified according to the mean percentage of output from hydro plants to total output generated by publicly and privately-operated utilities. For further information please see Appendix III.1

b The Yukon and N.W.T. are excluded.

c Prince Edward Island is excluded.

Source : Parts of Computers (worked out from raw data published in D.B.S. 57-202, Electric Power Statistics, Vol.II 1956-68).

COVARIANCE ANALYSIS

		F	D.F.
(1)	Test of overall homogeneity		
a)	All provinces pooled together	21.9	(40,99)
b)	Between hydro and thermal prov.	1.65	(52,87)
c)	All hydro prov. [a]	13.1	(24,63)
d)	All thermal prov.[b]	8.49	(12,36)
(2)	Test of differential slope vectors		
a)	All hydro prov.[a]	4.6	(18,63)
b)	Selected hydro prov. [c]	2.8	(15,54)
c)	All thermal prov.[b]	7.1	(9,36)
d)	Selected thermal prov.[d]	4.6	(6,27)

Note : All above are rejected at 5% and also at 1% level of significant. However we need not to reject (2b) and (2d) at .1% level of significant.

---

a All hydro provinces include Quebec, Manitoba, Newfoundland British Columbia, The Yukon & N.W.T., Ontario and New Brunswick.

b All thermal provinces include Saskatchewan, Nova Scotia, Alberta and Prince Edward Island.

c Quebec, Manitoba, Newfoundland, British Columbia, Ontario and New Brunswick are included.

d Saskatchewan, Nova Scotia and Alberta are included.

Source : Based on Regressions Results, the coefficients of which are presented in tables 3.1, 3.2 and 3.3.

A SURVEY OF THE PREVIOUS STUDIES ON ELECTRICITY GENERATION

(1) Nordin's Study on Light Plants' Cost Curves (1947-UK) (82)

This short run time-series study attempted to find the form of functional relation between fuel cost and output in one steam-electric light and power plant. Nordin believed that a broader knowledge of such a relationship should be useful in discussion of light-plant economies. For example, the extent to which the rate schedule should encourage consumption depended partly on the shape of the cost curves. The data used were from light plant records for a period of about six months including 541 eight-hour shifts in 1941. It was found that

$$C = 16.68 + 0.125\ Y + 0.00439\ Y^2$$

where C = total fuel cost for an 8-hr. period
Y = 8-hr total output in per cent of capacity.

The fuel cost function and the marginal fuel cost derived from it were represented in the following diagrams :

Fig. A.1a Fuel Cost Function

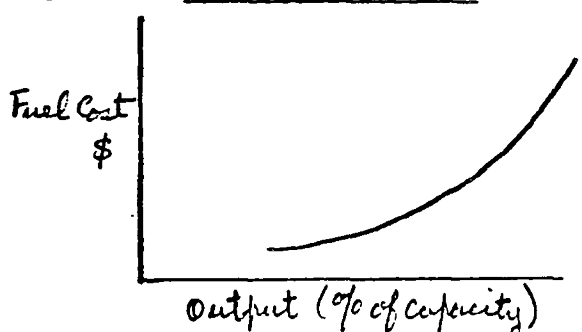
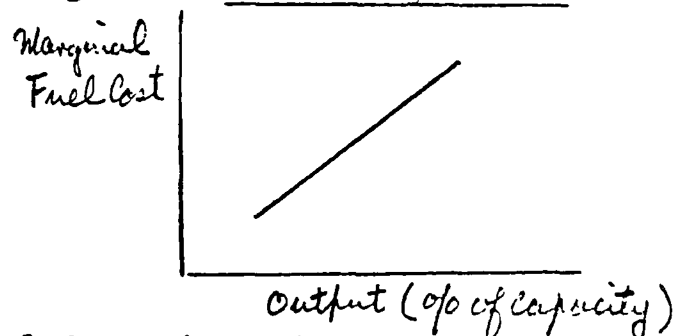


Fig. A.1b Derived Marginal Cost



This means that in the short run, if only fuel cost is considered while capacity is kept constant, the more the output the higher the marginal fuel cost for an extra additional unit of electricity generated.

(2) Lomax's Cost Curves (1952-UK) (68)

This study used cross-sectional data, relating to costs in different generating stations where there were steam-electric plants operating for more than 6600 hours in 1947-48 in two regions of the United Kingdom. The results were :

North-East : $Y \propto X_1^{-0.12} X_2^{-0.41}$

South-East : $Y \propto X_1^{-0.15} X_2^{-0.70}$

where $Y =$ working costs per unit generated
$X_1 =$ capacity of generators in kilowatts
$X_2 =$ load factor

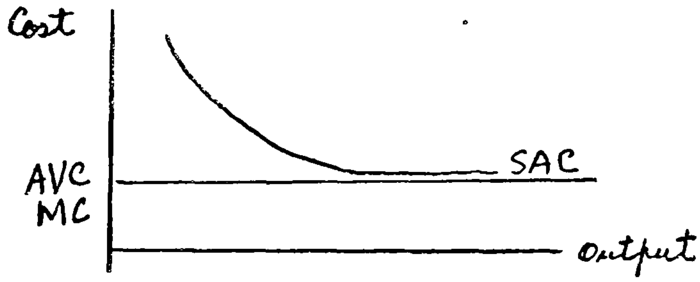
The results showed that for a given load pattern unit costs fell as the size of the plant increased and, similarly, for any given size of plant, unit costs fell as the load factor increased. Therefore it was concluded that, in the long run, there would be increasing returns to scale of operation.
(to higher load factor)

(3) Johnston's Short-period Analysis (1960-UK) (55)

This study used multiple correlation analysis with the usual statistical tests of significance in order to choose between alternative regressions. Time-series data from 17 steam-electric plants whose size of capital equipment remained constant throughout 1928-47 were collected and it was assumed that there was no technical change during this period. Data of cost (including three categories of fuel, salaries and wages, repairs and maintenance, oil, water and stores) were deflated with an appropriate price index number so as to remove the influence upon costs of all factors other than output. It was based on two assumptions that the changes in relative factor prices had not resulted in any substitution between factors in the productive process and that changes in the firm's output had not had any influence upon factor prices.

From the regression analysis he concluded that the short-period results tended to support the idea that the total cost function is linear in output Y. Average variable cost (AVC) and marginal cost (MC) functions were constant. In the following figure AVC and MC coincided and became one horizontal line .

Fig. A.2 Constant Average Variable and Marginal Costs



Furthermore a time variable T was added to the equation so as to represent the shifts in the cost function as a result of obsolescence of plant, changed management techniques and production methods. One of the equations Johnston found was :

$$Y = 18.8 + 0.889\ X - 0.639\ T$$

where $Y =$ deflated working expenses
$X =$ annual output
$T =$ time

(4) Johnston's Long-period Analysis (1960-UK) (55)

Similarly an analysis for 23 firms, whose capital equipment had not remained constant during the 1928-47 period was carried out. Both time-series analysis for 23 plants as well as cross-sections analysis for 40 plants in 1946-47 and 33 plants in 1938-39 supported the linear relationship between total cost and output. One of the equations Johnston found was :

$$Y = 46.3 + 0.499\ X + 1.155T$$

Where Y = deflated working expenses
X = annual output
T = time

However Johnston said that the estimation of long run average cost was much more dubious owing to the severe defects of the available data on capital costs. He concluded that after an initial fall, average working costs were approximately constant over the rest of the output range and the capital cost data tended to support a similar thesis with respect to average fixed cost.

(5) Iulo's Electric Utilities Costs (1961-US) (52)

This was not an econometric study to find the production function nor the cost function of electricity generation. It collected data from firms which bought electricity from other producers and which generated electricity in hydro-electric works. It only attempted to explain the relation of unit cost of electricity to some historical, operating and market characteristics.

(6) Komiya's Production Function (1962-US) (63)

Komiya critized the idea that most empirical studies on production functions were based on time series data but they seldom distinguished the importance between the shift in the production function and the movement along it. As a result they either assumed that there was no shift in the function or the shift was represented simply by a uniformly continuous change in the constant term. Another point he made was that since capital equipment in the electricity industry lasted as long as 20 to 30 years, during this time interval technology changed rapidly, plants operating at a certain point of time but built at different points of time would be in different technological strata. Therefore it was not appropriate to fit one production function for all plants, but a production function was fitted to those plants built in one period and a separate one to those built in the next period. Furthermore the plants in one group were classified by fuel type into two sub-groups of coal and non-coal (using natural gas or oil).

He collected data for 235 plants built in periods of 1930-45, 1946-56, 1951-53 and 1954-56 and used the limitational model akin to a Leontief-type fixed proportion production function. Three input functions relating the fuel, capital and labor requirements to the level of output or capacity are :

$$X_f = A_f \; Y_1^{\beta_f}$$
$$X_c = A_c \; Y_1^{\beta_c} \; Y_2^{\mu_c}$$
$$X_l = A_l \; Y_1^{\beta_l} \; Y_2^{\mu_l}$$

Where X_f = fuel input per generating unit in terms of B.t.u. per hr.
X_c = capital cost of equipment in constant dollar (1947) per generating unit (the cost of construction and land were excluded)
X_l = average number of employees during the year, per generating unit
Y_1 = average size of generating unit in megawatts
Y_2 = number of generating units on the same plant

In order to analyse the process of technological change, first, a long-run cross-section type production function of input-output relationship was fitted to the observation and second, the shift in the production function over time was examined by statistical tests. The purpose was to find out how much of the decline in the input requirements was due to economies of scale, factor substitution and the shift in the production function. The results were :

(1) Scale effect was high : capital (β^c=.85), fuel (β^f= .80) and labour (β^l= from .50 to .60).

(2) Substitution was possible and more capital was used while the use of fuel and labor declined especially in coal plants.

(3) Technical progress in the electricity industry was a cause of the possibility of building larger generating units to enjoy the increasing returns to scale.

Finally he concluded that in steam power generation the scale effect was a far more important factor in the process of technological progress than factor substitution.

(7) Nerlove's Returns to Scale (1963-US) (81)

Nerlove was interested in finding the returns to scale at only the firm level because he was concerned primarily with the general question of public regulation and investment decisions In view of the technological and institutional characteristics of the electric power industry in the United States he made two assumptions in his model building :

1) The output of a firm and the prices it paid for the factors of production were exogenous even though the industry did not operate in perfectly competitive markets.

2) Each individual firm tries to minimize the total costs of production of a given output subject to the production function and the prices it must pay for factors of production.

He believed that the traditional estimation of a production function from cross-section data on inputs and output was not correct.

Nerlove assumed that the electric power firms in the U.S. had production functions of a generalized Cobb-Douglas type :

$$y = a_o x_1^{a_1} x_2^{a_2} x_3^{a_3} u \qquad (1)$$

Where $y =$ output (measured in kwh)
$x_1 =$ labour input
$x_2 =$ capital input
$x_3 =$ fuel input
$u =$ a residual expressing neutral variations in efficiency among firms. This means that increased efficiency increases the amount of output obtainable from a given input combination proportionately for all factor proportions i.e. only constant term of the function varies from firm to firm, but not the elasticities of output with respect to the various inputs (79).

To minimize cost :

$$c = p_1 x_1 + p_2 x_2 + p_3 x_3 \qquad (2)$$

implied that the familiar marginal productivity conditions were satisfied:

$$(p_1 x_1 / a_1) = (p_2 x_2 / a_2) = (p_3 x_3 / a_3) \qquad (3)$$

Where $p_1 =$ wage rate
$p_2 =$ capital price
$p_3 =$ fuel price
$c =$ total production costs

The cost function which is the reduced form of the production function depends on the level of output and factor prices. It is derived in the following method :

From (3) : $X_1 = \frac{p_3 X_3 a_1}{a_3 p_1}$ and $X_2 = \frac{p_3 X_3 a_2}{a_3 p_2}$ (5)

Sub. (5) in (1) : $y = a_0 \left(\frac{p_3 X_3 a_1}{a_3 p_1}\right)^{a_1} \left(\frac{p_3 X_3 a_2}{a_3 p_2}\right)^{a_2} X_3^{a_3} u$

$$= \frac{a_0 p_3^{a_1+a_2} X_3^{a_1+a_2+a_3} a_1^{a_1} a_3^{a_2} u}{a_3^{a_1+a_2} p_1^{a_1} p_2^{a_2}}$$

Therefore $X_3^{a_1+a_2+a_3} = \frac{y a_3^{a_1+a_2} p_1^{a_1} p_2^{a_2} p_3^{a_3}}{a_0 p_3^{a_1+a_2+a_3} a_1^{a_1} a_2^{a_2} u}$

Therefore $X_3 = \frac{k_3 y^{1/r} p_1^{a_1/r} p_2^{a_2/r} p_3^{a_3/r} u^{-1/r}}{p_3}$ (6)

where $r = a_1 + a_2 + a_3$

$k_3 = a_0^{-1} a_1^{-a_1} a_2^{-a_2} a_3^{a_1+a_2} = (a_0 a_1^{a_1} a_2^{a_2} a_3^{a_3})^{-1} a_3^{r}$

Therefore $k_3' = k_3^{1/r} = a_3 (a_0 a_1^{a_1} a_2^{a_2} a_3^{a_3})^{-1/r}$ (7)

Similarly $X_1 = \frac{k_1 y^{1/r} p_1^{a_1/r} p_2^{a_2/r} p_3^{a_3/r} u^{-1/r}}{p_1}$ (8)

$X_2 = \frac{k_2 y^{1/r} p_1^{a_1/r} p_2^{a_2/r} p_3^{a_3/r} u^{-1/r}}{p_2}$ (9)

Sub. (6), (8), (9) in (2) : $C = y^{1/r} p_1^{a_1/r} p_2^{a_2/r} p_3^{a_3/r} u^{-1/r} \left(\frac{p_1 k_1}{p_1} + \frac{p_2 k_2}{p_2} + \frac{p_3 k_3}{p_3}\right)$

$$= k y^{1/r} p_1^{a_1/r} p_2^{a_2/r} p_3^{a_3/r} v \quad (10)$$

where $k = k_1 + k_2 + k_3$ and $v = u^{-1/r}$

There were two reasons why Nerlove decided to use the generalized Cobb-Douglas function for electric power. Firstly it led to a cost function which was linear in the logarithms of the variables and it would be easy to estimate. The function became : (Capital letters represent logarithm of the small letters) :-

$$C = K + (1/r)Y + (a_1/r)\ P_1 + (a_2/r)\ P_2 + (a_3/r)\ P_3 + V \qquad (11)$$

Secondly it was possible to find a single estimate of returns to scale by working out the reciprocal of the coefficient of the output in logarithm.

By using cross-section data from 145 privately owned firms operating in 44 states in 1955 Nerlove tested the following models: -

Model A [a]

To impose a restriction that the coefficients of the prices must add up to one, the proper method was to take one of the prices (for example, fuel price) as the divisor and divide the cost and two of the remaining prices by it.

$$C-P_3 = K + (1/r)\ Y + (a_1/r)(P_1-P_3) + (a_2/r)(P_2-P_3) + V$$

Model B [a]

If there were not relevant data on the capital price and if it was assumed that capital price was the same for all firms, then

$$C = K' + (1/r)\ Y + (a_1/r)\ P_1 + (a_3/r)\ P_3 + V$$

Where $K' = K + (a_o/r)\ P_2$

---

a Nerlove also tested two other models on the assumption that returns to scale depend on the size of output. In our study, similar models have been tested but the results are not satisfactory. Presumably this is due to the use of time series data .

Finally he concluded there was evidence of a marked degree of increasing returns to scale at the firm level, but the degree varied inversely with output. This means that long run average cost excluding transmission costs declines. The variation in returns to scale was neutral in character so that the scale of operation did not affect the marginal rates of substitution between factors of production. When the transmission costs were considered,the returns to scale might be greater or less than one depending on the elasticity of transmission cost with respect to output and the elasticity with respect to number of plants. If transmission costs decrease with a larger number of plants, there would be increasing returns to scale. However, if transmission losses were considered the returns to scale at the firm level would be less than at the plant level depending on the ratio of losses to the quantity of power actually delivered.

(8) Barzel's Productivity (1963-US) (7)

It was not an econometric study. Barzel investigated the output per unit of input technique as a measure of productivity because it required very little prior knowledge of the production process. On the assumption that there were no economies or diseconomies of scale in the industry, the production function was homogeneous of first degree.

$$O = \sum I_i \, MP_i$$

Where O = output
I = input
MP = input marginal productivity.

Another assumption was that the industry operated competitively so that factors of production were paid according to the value of their marginal product. Therefore $0 = \sum I_i p_i$ where $p =$ price of input. If the inputs in year 2 were assigned MP proportional to their prices in period 1, the expected output would be $0_2^* \sim \sum I_{i2} p_{i1}$. But 0_2 was the output actually produced in period 2 under the technical conditions which were different from those of year 1. Therefore the productivity index was :

$$0_{12} = 0_2 / 0_2^* = (0_2 \sum I_{i1} p_{i1}) / (0_1 \sum I_{i2} p_{i1})$$

Finally he found that from a time-series study the factor productivity in the electric power industry in 1955 was 2.83 times that in 1929. His study showed that this figure could be represented as a product of four distinct factors :

1) 1.48 was due to the increase of the average amount of electricity purchased by customers in both the residential and commercial classes.
2) 1.23 was due to the increased average size of plant.
3) 1.18 was due to higher average load factor.
4) 1.32 (the residual) was due to pure technical advance in this industry over the period 1929-55.

(9) <u>Barzel's Production Function (1964-US)</u> (8)

Barzel criticized the general Cobb-Douglas type of production function ($Y = A \prod_i^k X_i^{a_i}$) for severely limiting the number of variables to be estimated. When it was applied to the steam-power industry it would have serious statistical drawback because the conventional inputs were not sufficient for describing the production function of this industry.

He introduced two additional variables (l = load factor, and s = size of the unit) into the production function such that :

$$Y = A \prod_{i=1}^{n=3} X_i^{a_i} \, l^{a_4} s^{a_5}$$

The load factor was introduced because output was a function not only of the capacity of the plant but also of the extent to which this plant was used. The size factor was used because it was believed that this industry enjoyed substantial economies of scale.

However, instead of testing this explicit Cobb-Dougals model Barzel used an alternative approach to study the production function through the implicit demand for a factor of production, which was a function of three sets of forces, namely the demand for the final product, relative prices, and the state of arts (depending on technical coefficients).

The estimated fuel equation in logarithm was :-

$$y_f = 0.896\, x_1 + 0.848\, x_2 + 0.893\, x_3 - 0.040\, x_4 - 0.074\, x_5 - 0.013\, x_6 + \text{constant} + \text{dummy variables}$$

and the estimated labour equation in logarithm was :-

$$y_l = 0.626\, x_1 + 0.169\, x_2 + 0.054\, x_3 - 0.267\, x_4 - 0.259\, x_5 + 0.010\, x_6 + \text{constant} + \text{dummy variables}$$

Where x_1 = plant size measured by the number of kilowatts of installed capacity

x_2 = anticipated average load of plant measured by the observed load factor in the first full year of operation

x_3 = a within plant index of x_2 over time

x_4 = anticipated average input price ratio measured as the ratio of the average price of fuel per B.t.u. to the average labour cost per man-year in the first year of operation of the plant

x_5 = a within-plant index of x_4 over time

x_6 = age of plant defined as the accumulated number of hours of operation

The estimated capital function in logarithm was :

$$K = 0.815\, z_1 + 0.271\, z_2 + 0.186\, z_3 + 0.116\, z_4 + \text{dummies}$$

Where $z_1 =$ size $\quad z_2 =$ labour price
$z_3 =$ fuel price $\quad z_4 =$ load factor

Using time-series study from 1941 to 1959 finally he found that there were substantial economies of scale in the steam power industry and they were not uniform over all factors of production. It was highest for labor, less for capital and even less for fuel. Increasing returns to scale was even more obvious in the more intensive use of the available plants, not only capital was saved but also labour . Even the proportional increase of fuel used was less than that of output when the plants were used more intensively.

When prices information was considered, factor substitution was made not only in the long run but also for existing plants. The increase in fuel efficiency was partly due to technical advance and partly due to economies of scale. The increase in labour efficiency was much more than that of fuel, probably because of the improvement in the quality of labor. Although the results showed that capital requirements fell over time, it was difficult to evaluate the magnitude of these changes.

(10) Dhrymes and Kurz's Scale in Electricity Generation (1964-US) (34)

This study used the Neoclassical model of production by employing a generalized version of the constant-elasticity-of-substitution production function. Their method was to combine the cost minimization hypothesis of Nerlove's "Return to Scale" and the sample stratification technique of

Komiya's "Production Function". In the analysis the sample consisting of 362 newly constructed plants built in 1937-59 was stratified according to technological period (1937-45, 1946-50, 1951-54, 1955-59) and size of plants. The capacity of a plant was accepted as an index of the capital but corrected for the fraction of the time during which the generator was actively engaged in generating electricity. Their purpose was to isolate the impact of technological progress on steam power generation so as to investigate the question of returns to scale in electricity supply, assess the effects of technological change on returns to scale, and to evaluate the degree of factor substitution in this industry.

Like Komiya and Barzel, Dhrymes and Kurz did not try to test the explicit production function (CES in this case). Neither do they test the cost function derived from it. However, they tested three explicit reduced demand functions for labour, fuel and capital. The demand functions could be written in logarithm form as :-

$$\ln X_i = \frac{1}{\beta_i - 1} \ln \frac{\alpha_n \beta_n}{\alpha_i \beta_i} + \frac{1}{\beta_i - 1} \ln \frac{P_i}{P_n} + \frac{\beta_n - 1}{\beta_i - 1} \ln X_n$$

Where $X_i =$ one of the input e.g. fuel $\quad P_i =$ price of X_i
$X_n =$ another input e.g. capital $\quad P_n =$ price of X_n

When these demand functions were substituted to the original production function :

$$Y = A \left(\sum_{i=1}^{n} \alpha_i X_i^{\beta_i} \right)^{1/r}$$

the implicit relation between the price ratios p_i/p_n and output Y, which were exogenous, and the n^{th} input X_n could be derived as :

$$\ln X_n = a_o + \sum_{i=1}^{n-1} a_i \ln \frac{p_i}{p_n} + a_n \ln Y$$

A two-stage least squares had to be performed before the necessary parameters could be obtained. In this case the equations for labour and fuel were :

$$\ln L = \delta_0 + \delta_1 \ln (P_L/P_K) + \delta_2 \ln (\dot{K}^*)$$

$$\ln F = \delta_0 + \delta_1 \ln (P_F/P_K) + \delta_2 \ln (K^*)$$

Where $(\dot{K}^*)$ was the estimate of the nonstochastic part of ln (K), capital function in the first-stage.

The final results were that increasing returns to scale were the prevailing phenomenon in steam electric generation and the degree of returns to scale with respect to fuel and capital was less than that of labour. Technical change had not been neutral in this industry because it had significant impact on the elasticity of substitution. However, the neutral component was equally significant in its size because the estimated A in the production function had a monotone increasing behaviour.

(11) <u>Ling's Economies of Scale (1964-US)</u> (66)

Ling also used cost minimization principle to estimate an average cost function reduced from a Cobb-Douglas function. A set of data were constructed from ex-ante engineering considerations relating to systems of between 2500MW and 13700MW which operated at varying system loads and they were used to fit the average cost function. The equation was as follows :

$$C_a = 5534\, S^{-0.1688} \quad \lambda^{-1.8406 + 0.1428 \ln \lambda}$$

Where C_a = annual average generating cost in mills per KWH
S = system installed capacity in megawatts
λ = system load factor in per cent.

Furthermore this function was tested with ex-post data from four utility systems operating in the U.S. between 1938 and 1958. The results showed that for any given system load factor average generating costs decreased as the size of system increased.

(12) <u>Galatin's Economies of Scale (1968-US)</u> (41)

Galatin criticized that most of the studies on electricity generation were carried out on plant or firm level rather than machines in the plant. This gave no allowance to the machine mix of plants. Some studies did not consider separately the effects of technological change and economies of scale while some studies did not used the programming technique for minimising variable cost in a plant. Those studies that took minimisation of cost principle into consideration did not have the proper assumed minimisation behaviour for the firms in the electric-power industry. Two particular characteristics in this industry that most of the studies were not aware of were : (1) the instantaneous nature of the production process in terms of fuel input, and therefore did not consider the implications of using annual data to estimate instantaneous parameters; and (2) the varied degree of capacity utilisation of machines as a result of fluctuation of demand due to on-peak and off-peak phenomena.

Galatin used Komiya's stratification technique but not his limitational models which, Galatin believed, was defective owing to the problem of machine-mix. Time-series and cross-section data on plant operation from 1938 to 1953 were collected and they were stratified according to coal, non-coal and mixed plants and according to vintage of machines (1920-24), (1925-29), (1930-34), (1935-39), (1940-44), (1945-50), (1951-53).

For coal plants of vintage 1945-50 the estimated fuel function was:

$$a_{it} = 96591.2\ (X_{it}/X_{iK})^{-1} + 25087.1\ (X_{iK})^{-1} + 10181.6$$

Where a_{it} = input of fuel per kilowatthour for machine i during the period t

(X_{it}/X_{iK}) = the degree of capacity utilisation for the same machine

X_{iK} = size of the machine in megawatts

The capital input function was :

$$C_T/N = 5372.9\ N - 3437.7\ N^2 + 462.7\ N^3 + 137.8\ X_{iK}$$

Where C_T = total capital cost of a plant

N = the number of machines in the plant

X_K = size of each machine

The labour input function was :

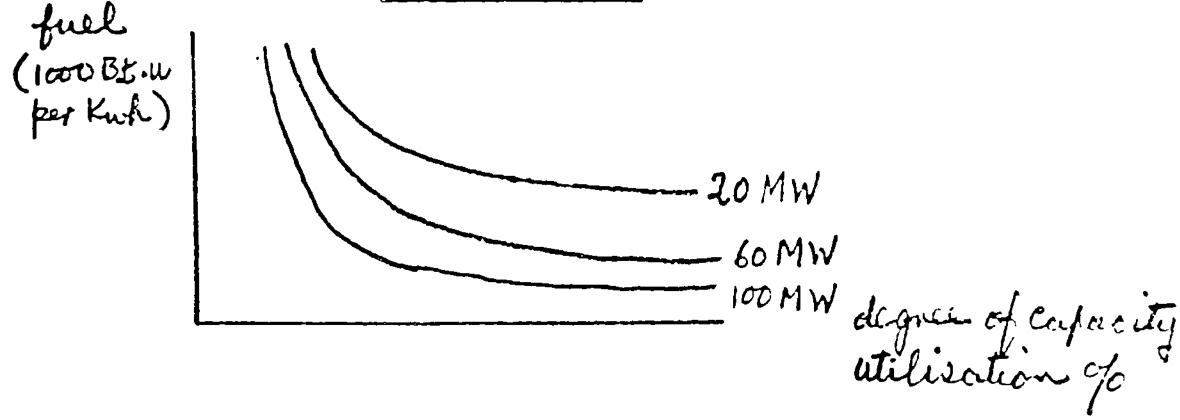
$$L = -38.538 + 20.644\ N + 0.837\ X_{iK} + 0.330PF^*$$

Where L = labour input

PF^* = the adjusted plant factor

The results for fuel were that the input of fuel per unit of output was less for bigger machines and also less if the machines were used more intensively. This can be represented in the following diagram :

Fig. A.3 Fuel Requirement



When the machine operated at the level of full capacity there were important economies of scale for fuel. Technological change was in favour of saving on fuel input especially in coal and mixed machines but for relatively smaller size machines.

Economies of capital were present especially in coal plants. There were economies in labour use in each vintage for plants of a given machine size. Technical change had contributed to a reduction in labour requirements for plants of the same size and same number of machines. The degree of capacity utilization also had an influence on labour input but the effect was small for small changes in capacity.

Having attempted to use a time variable to represent "technical change" in each province, but having found negative coefficients for some output variables, another attempt was made to use a dummy variable. From the estimated total cost of production; output and shift from "hydro" to "thermal" or "thermal" to "hydro"; major construction projects in each province, presumably major technical change occurred in Ontario and Alberta in 1962; in Newfoundland, Quebec, Saskatchewan and New Brunswick in 1963; Manitoba, British Columbia and Nova Scotia in 1965. The major construction projects in each province were as follows:-

1962 : Ontario - Not only the first nuclear power plant started in operation but also a 300,000 kilowatts steam unit at Lakeview generating station was placed in service.

Alberta - The Calgary Power Company completed an additional unit of 150,000 kilowatts at Wabamun steam plant.

1963 : Newfoundland - Two hydro generators of total 93,600 kilowatts were added on Unknown River in Labrador.

Quebec - Six additional units of total 280,500 kilowatts were added to the Carillon hydraulic project.

Saskatchewan - For the first time hydro-electric power generated in Saskatchewan was fed into Saskatchewan Power Corporation system. Also four units of total 134,000 kilowatts were installed at Squaw Rapids generating station. (hydro)

New Brunswick - A unit of 60,000 kilowatts was added to Grand Lake No.2 (thermal).

1965 : Manitoba - Three units of total 327,750 kilowatts were added to Hydro's Grand Rapids generating stations.

British Columbia - An additional unit of 150,000 kilowatts was added to Burrard station (thermal).

<u>Nova Scotia</u> - A 100,000 kilowatts steam unit was completed at Tuft's cove generating station.

The results of the regressions using dummy variable are in the attached Table A.1 (0 : before the change; 1 : after the change)

The coefficient for output in each province is positive. They are all less than 1. Therefore the reciprocal of these figures will be greater than 1 which means increasing returns to scale.

As to the coefficient for the dummy variable, only the coefficient for Newfoundland is significant and positive. The coefficients for Quebec, Ontario and Nova Scotia are not too far from significant and positive. The coefficient for Saskatchewan is significant and negative while the coefficient for Manitoba is not too far from significant and negative. The coefficients for British Columbia, New Brunswick and Alberta are far from significant.

Table A.1

Results from Regressions Based on Time Series data from 1956 to 1968 with an additional dummy variable for "technical change"

The equation in logarithmic form:

$$C - P_3 = K + (1/r)\,Y + (a_1/r)\,(P_1^1 - P_3) + (a_2/r)\,(P_2^2 - P_3) + \beta D \qquad R^2 \ (\bar{R}^2) \quad DW \quad F$$

Constant, Coefficients, (standard errors), ((t-values)), and other statistics

	K	Y	$P_1^1-P_3$	$P_2^2-P_3$	D	R^2 ($\bar{R}^2$)	DW	F
Quebec	4.450	0.270	0.455	0.688	0.068	.993	1.663	1179
	(3.018)	(0.418)	(0.330)	(0.360)	(0.046)	(.990)		
	((1.5))	((0.6))	((1.4))	((1.9))	((1.5))			
Manitoba	0.770	0.689	0.622	0.526	-0.042	.993	1.839	1179
	(0.785)	(0.145)	(0.157)	(0.173)	(0.031)	(.990)		
	((1.0))	((4.7))	((4.0))	((3.0))	((-1.4))			
Newfoundland	1.048	0.529	0.672	0.313	0.093	.999	1.950	3626
	(0.532)	(0.109)	(0.061)	(0.054)	(0.034)	(.997)		
	((2.0))	((4.8))	((11.0))	((5.8))	((2.8))			
British Columbia	1.888	0.531	0.515	0.446	0.044	.994	1.708	1393
	(1.909)	(0.298)	(0.233)	(0.147)	(0.051)	(.991)		
	((1.0))	((1.8))	((2.2))	((3.0))	((0.9))			
Ontario	1.790	0.484	0.744	0.293	0.032	.991	1.453	861
	(1.065)	(0.163)	(0.332)	(0.478)	(0.019)	(.986)		
	((1.7))	((3.0))	((2.2))	((0.6))	((1.7))			
New Brunswick	0.877	0.698	0.462	0.513	-0.010	.972	1.685	282
	(1.950)	(0.280)	(0.428)	(0.230)	(0.114)	(.959)		
	((0.4))	((2.5))	((1.1))	((2.2))	((-0.1))			
Saskatchewan	1.798	0.657	0.400	0.784	-0.072	.989	1.863	696
	(1.066)	(0.220)	(0.210)	(0.170)	(0.036)	(.983)		
	((1.7))	((3.0))	((1.9))	((4.6))	((-2.0))			
Nova Scotia	0.309	0.633	0.513	0.048	0.029	.994	2.836	1331
	(0.761)	(0.126)	(0.127)	(0.145)	(0.016)	(.991)		
	((0.4))	((5.0))	((4.0))	((0.3))	((1.8))			
Alberta	0.707	0.687	0.552	0.473	0.005	.995	2.364	1522
	(0.370)	(0.086)	(0.128)	(0.097)	(0.018)	(.992)		
	((1.9))	((8.0))	((4.3))	((4.9))	((0.3))			

A further attempt was to include two more dummy variables in the regression for Ontario. The Hydro-Electric Power Commission of Ontario Annual Report (1958) showed that there was the greatest addition to power sources in the Commission's fifty-two year history. New generating stations totalled more than 800,000 kilowatts of capacity placed in service during the year 1958. Hydraulic developments included Sir Adam Beck-Niagara Generating Station No.2; Whitedog Falls Generating Station; Caribou Falls Generating Station; Robert H. Saunders-St. Lawrence Generating Station; Extensions were made to Cameron Falls, Alexander and Mauitou Falls Generating Stations, Otter Rapids on the Abitibi River and Red Rock Falls on the Mississagi River.

In 1962 the report said that early in the year the Commission began the actual construction of the first major 500-kv line on the North American continent. In April commissioning tests were completed for the first 300-mw unit at Lakeview Generating Station, and in June the first power was delivered to the Commission's East System from the Nuclear Power Demonstration plant situated at Rolphton on the Ottawa River.

In 1967 the interconnections with neighbouring utility systems were fully demonstrated. In the same year a highlight was the production of electric energy from Canada's first commercial nuclear generating station at Douglas Point.

The results of the regression are as follows:

$$
\begin{array}{lllllll}
C - P_3 = & 2.005 & + 0.401\,Y & + 0.807\,(P_1 - P_3) & + 0.141\,(P_2 - P_3) & + 0.032\,D_1\,(1958) \\
 & (1.186) & (0.144) & (0.330) & (0.464) & (0.014) \\
 & ((1.7)) & ((2.8)) & ((2.4)) & ((0.3)) & ((2.2))
\end{array}
$$

$$
\begin{array}{ll}
+ 0.031\,D_2\,(1962) & + 0.006\,D_3\,(1967)^{a} \\
(0.019) & (0.021) \\
((1.6)) & ((0.3))
\end{array}
$$

$$R^2 = 0.995 \qquad \bar{R}^2 = 0.990 \qquad DW = 2.4487 \qquad F = 1198$$

Having noticed that fuel price variable could be excluded from the regressions for hydro provinces, new sets of equations for these provinces were estimated. The results are shown in the attached Table A.2. Moreover regressions using dummy variable to represent technical progress were also estimated and the results are shown in the attached Table A.3.

On the whole the significance of the coefficient for output in each province is improved. However, the magnitude of the coefficient of determination of each regression was smaller than the original estimation.

---

a. Theoretically we expect a negative coefficient for the technical change variable (D) since the total cost should be reduced as a result of technical advance. When the coefficient may be positive we guess that the utility company takes advantage of technical advance by building more plants at the same time and also total cost is inflated. On the other hand we expect average cost to decrease faster, that is, the coefficient for output (Y) in the equation is smaller than that in a equation where (D) is excluded. However, if we compare the Ontario equations on p.157 and p.88 we are disappointed to find that the coefficient for Y on p.157 is greater than that on p.88. This may be due to the shift from building new hydro plants to thermal plants in Ontario as a result of shortage of appropriate hydro sites. On the other hand, if we compare the new equation using three dummies and the equation on p.88 we find that coefficient for Y in this new equation is smaller. The $\bar{R}^2$ in this equation is the greatest among all the $\bar{R}^2$s in the three equations, even though the number of independent variables is increased by the three dummies.

Table A.2

(A new set of equations in which fuel price variable is not used)

The equation in logarithmic form :

$$C - P_2 = K + (1/r)\ Y + (a_1/r)(P_1 - P_2)$$

Constant, Coefficients, (standard errors), ((t-values)), and other statistics

	K	(1/r) Y	$(a_1/r)(P_1-P_2)$	R^2 ($\bar{R}^2$)	DW	F
Ontario	1.092	0.434	1.062	0.977	1.175	424
	(0.554)	(0.167)	(0.256)	(.972)		
	((2.0))	((2.6))	((4.2))			
Newfoundland	-0.284	0.801	0.589	0.993	2.312	1319
	(0.201)	(0.042)	(0.050)	(.991)		
	((-1.4))	((19.1))	((11.8))			
Quebec	-1.618	1.259	-0.078	0.822	1.737	46
	(1.363)	(0.234)	(0.353)	(0.787)		
	((-1.2))	((5.4))	((-0.2))			
Manitoba	0.811	0.542	0.814	0.912	0.910	103
	(0.607)	(0.101)	(0.195)	(.894)		
	((1.3))	((5.4))	((4.2))			
British Col.	1.437	0.542	0.661	0.959	1.888	232
	(0.403)	(0.064)	(0.087)	(.950)		
	((3.6))	((8.5))	((7.6))			
New Brunswick	1.128	0.666	0.461	0.944	1.705	169
	(0.429)	(0.077)	(0.109)	(.933)		
	((2.6))	((8.7))	((4.2))			
Yukon & NWT	-0.904	1.052	0.420	0.917	1.352	110
	(0.784)	(0.106)	(0.185)	(.900)		
	((-1.2))	((9.9))	((2.3))			
Selected Hydro Provinces	0.599[a]	0.690	0.585	0.9942		11961
	(0.198)	(0.038)	(0.052)	(.9936)		
	((3.0))	((18.0))	((11.2))			

Note a. D.K for provinces other than New Brunswick are :
Manitoba : -0.055 ((-2.6)) Newfoundland : -0.183 ((10.0))
Quebec : -0.075 ((-1.5)) Ontario : 0.090 ((1.8))
British Columbia : 0.070 ((2.7))

Table A.3

(Another new set of equations in which fuel price variable is not used but an additional dummy variable is used for technical change (a))

The equation in logarithmic form :

$C - P_2 = K + (1/r)\,Y + (a_1/r)(P_1 - P_2) + \beta D$

Constant, Coefficients, (standard errors), ((t-values)), and other statistics

	K	(1/r) Y	$(a_1/r)(P_1-P_2)$	βD	R^2 ($\bar{R}^2$)	DW	F
Ontario	1.652	0.483	0.767	0.032	0.983	1.418	523
	(0.590)	(0.154)	(0.283)	(0.018)	(.977)		
	((2.8))	((3.1))	((2.7))	((1.8))			
Newfoundland	1.095	0.519	0.688	0.093	0.996	2.067	2281
	(0.504)	(0.103)	(0.051)	(0.032)	(.995)		
	((2.2))	((5.0))	((13.4))	((2.9))			
Quebec	1.754	0.574	0.463	0.099	0.906	1.827	86
	(1.590)	(0.302)	(0.332)	(0.035)	(.874)		
	((1.1))	((1.9))	((1.4))	((2.8))			
Manitoba	0.184	0.667	0.752	-0.030	0.916	1.175	98
	(1.110)	(0.211)	(0.220)	(0.044)	(0.888)		
	((0.2))	((3.2))	((3.4))	((-0.7))			
British Col.	2.323	0.456	0.567	0.046	0.962	1.759	231
	(1.019)	(0.111)	(0.133)	(0.048)	(.950)		
	((2.3))	((4.1))	((4.3))	((0.9))			
New Brunswick	0.939	0.686	0.483	-0.013	0.944	1.687	152
	(1.550)	(0.176)	(0.212)	(0.100)	(.926)		
	((0.6))	((3.9))	((2.3))	((-0.1))			

Another Equation for Ontario

$$C - P_2 = \underset{\substack{(0.769)\\((2.9))}}{2.218} + \underset{\substack{(0.134)\\((3.0))}}{0.404}\,Y + \underset{\substack{(0.269)\\((2.9))}}{0.768}\,(P_1 - P_2) + \underset{\substack{(0.013)\\((2.4))}}{0.032}\,D_1\,(1958) + \underset{\substack{(0.018)\\((1.7))}}{0.031}\,D_2\,(1962) + \underset{\substack{(0.019)\\((0.4))}}{0.007}\,D_3\,(1967)$$

$R^2 = 0.991$ $\bar{R}^2 = 0.984$ $DW = 2.445$ $F = 751$

Note a. See p.155 above.