THE EFFECT OF DEMAND UNCERTAINTY ON PLANNING: THE STEEL INDUSTRY IN ARGENTINA

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(ABSTRACT)

The traditional method for conducting sensitivity analysis is to repeatedly solve a model while varying the parameters. The solution is then obtained as some average of these optimal solutions under those different conditions or states of the world. The present work presents results of conducting sensitivity analysis using a method more firmly ground in mathematical programming theory. The present analysis models the investment decisions in a case with large uncertainty in demand: the steel industry in Argentina. Special emphasis is devoted to the recent history, where a recent shift in economic policy (1976-1981) towards allowing free competition with imported products resulted in a severe crisis for the steel industry and its trading partners. An increase in exports was observed during this period which is not likely to continue if there is a recovery process. In the first sections, the relation of steel production and economic

growth is analyzed in the context of the world situation of the industry, setting the background for the analysis of the Argentinian industry as a case study. The results of the present model adequately describe the existence of unutilized capacity observed in the industry, as well as the recent increase in exports. The most important conclusion of the model is that the traditional method of conducting sensitivity analysis results in significant inefficiency of the reached decissions, involving large losses for a case such as the steel industry considered here.

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1.0 INTRODUCTION

1.1 STEEL, DEVELOPMENT, AND DEMAND UNCERTAINTY

The pattern of steel production and consumption has undergone important changes in recent years. Newly industrialized nations now account for a large share of the steel products market. A similar trend is seen in production (1). In particular, Latin America accounts for half of the new capacity to be installed by 1985 in newly developing nations. It is therefore important to analyze the future prospects of the Latin American steel industries. The present work deals with the Argentinian steel sector as a case study. The Argentinian case represents an industry in an intermediate stage of growth. It is not as developed as that of Brazil, but it has achieved a certain degree of self sufficiency and has recently started to increase exports (2). The evolution of steel industries in developing countries is very complex due to the number of factors that have to be considered. These factors include the availability of raw materials and resources, the possibility of financing for steel development, the technological capability of the industry, and government policy toward steel. This last factor is of the utmost importance, since government may consider steel as essential to the security and independence of the nation and decide to subsidize steel for this reason. Subsidies may also result from political pressure to avoid unemployment. In recent years (1976-1981) Argentina experienced the effects of a significant change in government policy, mainly as a result of a high parity of the national currency against the dollar, and a loosening of import tariffs. The effects of this change in policy on the development of the steel industry are very significant, as will be shown in the present analysis. The technological level of the steel industry is also known to have strong effects on the development of the sector, especially in the possibility of competing for the international market. For example it has been shown that a correlation exists between the speed of adoption of oxygen steelmaking technology and the development of exports (3). Other economic particularities of the steel industry are the close relationship of steel with other important sectors of the economy. Technical particularities refer to the role of energy, raw materials and technological innovation. The industry is undergoing important changes at the international level, partly due to technological innovations which result in a transformation of the traditional patterns of comparative advantage. In this new setting the developing nations are in a stronger position to achieve self sufficiency in steel and even to compete for a share of the international market (1). The present paper discusses some aspects of the evolution of the steel industry in Argentina in recent years, with the goal of identifying the most important factors that affect development and growth of the steel sector. Special consideration is given to the technological level and the effect of government policy. Since these factors are of the utmost importance in the planning decisions, which are the main interest of this work.

1.2 THE INTERNATIONAL SITUATION OF THE STEEL INDUSTRY

Statistics show that in the last ten years, steel production in the world has not increased significantly. Furthermore between 1973 and 1983 it has decreased (4). It is well known that the industry is in a crisis, mainly due to wrong projections on demand growth. The unutilized capacity is now more that 30%. However, if these facts are to be interpreted correctly, one should point out that a certain quantity of steel in 1973 is not equivalent to the same amount nowadays. This is partly due to technical change that allows a more efficient use of the ton of steel in the making of finished products. Furthermore the better quality allows production of final steel consuming goods with less amount of steel. Despite these facts, the industry in a great majority is reporting losses. The fact is that current demand values are much lower than projected. Several consequences may be pointed out from this situation. The first consequence is of course massive layoffs in most countries, including Japan. The second consequence is that protection to the industry is growing in most producing countries. Thirdly, government subsidies to steel industries are widespread. Finally the fact that there is unused capacity results in the dumping phenomenon, distorting international prices. Within this grim picture there are some interesting points to be noticed. One is that the smaller minimills, in particular those that produce high quality, specialty steels, are in general not reporting losses. The developing countries are not only increasing their self sufficiency rate but in several cases are exporting significant amounts (i.e. Brazil in Latin America) (1).

1.3 PLANNING UNDER UNCERTAINTY

The above discussion suggests that there may be a relation between planning methodology and the current problems facing the international steel industry in general, and the Argentinian case in particular. Certainly, we will argue in forthcoming chapters that the Argentinian case is an example of extreme uncertainty in demand. The question arises then of using the correct planning models to account for the effects of uncertainty. We will apply therefore different methodologies and compare the results. Analyzing the current literature, it is difficult to find methodological recommendations for conducting sensitivity analysis in general, and under uncertainty in particular. The traditional methodology consists in solving the problem under certainty conditions repeatedly, varying the parameters that are uncertain. The final solution is then obtained as some average of the solutions. As we will argue in the course of this work It is clear that this method is not mathematically correct. In the present work we will concentrate in a small number of possible states of the world. We will also assume validity of the expected utility theorem or Bernoulli principle. With this assumptions it turns out that a simple formalism can be devised to account for uncertainty in a mathematically sound way. We will also obtain the solutions using the traditional method in order to fully asses the consequences of using traditional methods. The conclusions of such a comparison of methodologies will also be relevant for other applications of programming models.

2.0 STEEL AND INDUSTRIALIZATION IN ARGENTINA

The process of industrialization in Argentina began in the 1930's with import substitution. The process was accelerated in the 1940's and 50,s, when the steel industry began to develop as well. It began with heavy protection, subsidies and foreign capital. Table 1 shows the foreign financing received by the industry compared to other countries. Table 2 shows the importance of government ownership compared to other countries (6). In very broad terms it followed the general pattern of other latin american countries, namely Brazil (The Brazilian case is analyzed in detail by Baer) (7). This pattern is characterized as a process that started as a response to the needs of the initial phase of the import substitution industrial development. However, the local private sector lacked the financial and technological resources to respond to these needs, and the industry developed under government control, subsidies, and foreign capital. The International Iron and Steel Institute has developed a model that predicts the self sufficiency rate of a country in terms of steel consumption (as a measure). The average curves and the data for the development of the Argentinian steel industry are shown in Fig. 1 (8).

Table 1. U.S. Government and International Agency Financial Assistance to Foreign Steel Industries

Country	Year	Eximbank	IBRD	IADB	IFC	AID and predecessor programs	Total
Argentina	1955	$60.00					$60.00
	1958	.09					.09
	1959	2.41					2.41
	1960	21.33			$3.66		24.99
	1961	.41					.41
	1962	.69					.69
	1964			$0.20			.20
	1965	22.48					22.48
Total		107.40		.20	3.66		111.26
Brazil	1950	25.00					25.00
	1952	2.19					2.19
	1955	5.06					5.05
	1956	35.13					35.13
	1957	4.88					4.88
	1958	12.50					12.50
	1961					6.83	6.83
	1964			30.10		7.09	37.19
	1965	6.00		.20	5.05		11.25
Total		90.74		30.30	5.05	13.92	140.01
Mexico	1948	1.50					1.50
	1951	5.00					5.00
	1952	8.10					8.10
	1955	3.40					3.40
	1956	46.51					46.51
	1957	16.00					16.00
	1960	6.87			.28		7.15
	1961	1.57					1.57
	1962	1.85			5.07		6.92
	1963	16.90					16.90
	1964	28.00			6.45		34.45
	1966				5.88		5.86
Total		135.70			17.68		153.38

Table 2. Government Ownership of Steel Industry in Latin America

Country	Company	Latest annual raw steel production, net tons	Percent of national production
Argentina	Sociedad Mixta Siderurgia Argentina (SOMISA)	880,000	58
	Altos Hornos de Zapla	170,000	11
Brazil	Acos Finos Piratini S/A	46,000	[1]
	Companhia Ferro e Aco de Vitoria	110,000	9
	Usinas Siderurgicas de Minas Gerais S.A. (USIMINAS)	670,000	26
	Companhia Siderurgica Nacional—Volta Redonda	1,385,000	42
	Cia. Siderurgica Belgo Mineira	500,000	15
	Companhia Siderurgica Paulista (COSIPA)	175,000	15
Chile	Compania de Acero del Pacifico	600,000	83
Colombia	Acerias Paz del Rio, S.A.	225,500	84
Mexico	Altos Hornos de Mexico, S.A.	1,300,000	48
	Toyoda de Mexico, S.A.	[1]	[1]
Peru	Corporacion Peruana del Santa "Chimbote"	100,000	97
Venezuela	CVG Siderurgica del Orinoco C.A. (Sider)	600,000	87

It is seen that Argentina fits the general curve. A more detailed analysis of the particular characteristics of the Argentinian case up to 1976 shows a poorly integrated industry, heavily dependent on imported raw materials and averaging a positive, but low level of profits up to 1973 (9). The IISI model indicates that the growth of the steel industry is linked to the global growth of the economy, independently of the particular country is question. It may be expected that since Argentina has followed the general model in the past it will also follow the pattern in the future. However, this does not address the fundamental question of the mechanism by which steel development influences economic growth or viceversa. The IISI model does not allow prediction of future growth rates. The model only establishes a correlation between GNP growth and steel development, which is followed by a great majority of countries. To summarize, there appears to be a predicted rate of self sufficiency in steel corresponding to a given stage of growth. The other significant feature of the relation of steel to the industrialization process is the conflict between the demand for steel created by the general industrialization process and the lack of financing resources and technology. This explains the reliance on foreign capital and government enterprises to develop steel firms. The question that arises is the nature of the correlation between steel and growth. The second

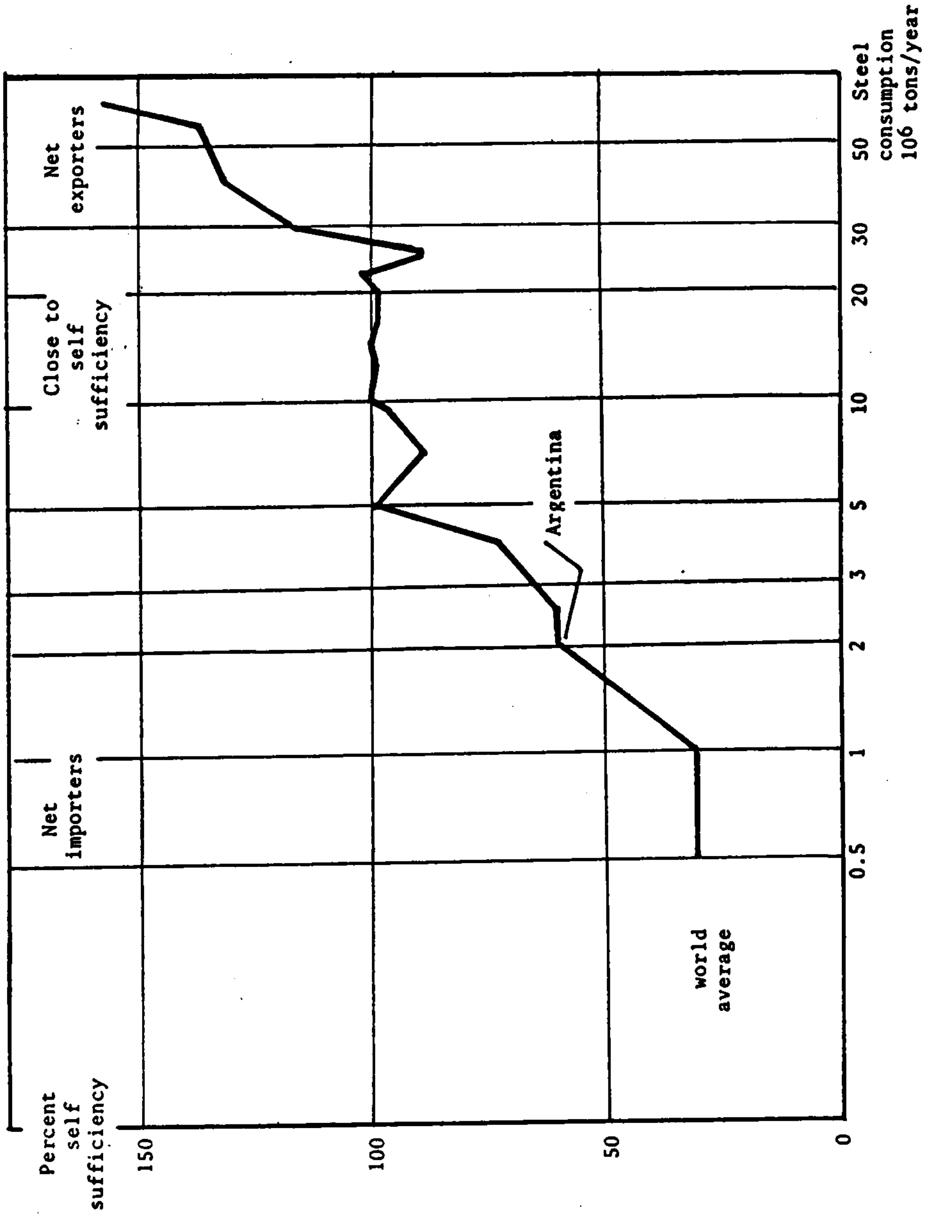


Figure 1. Relation Between GNP and Steel Production

question is the possibilities of the steel industry in developing nations to be profitable for the local private sector without government subsidies and foreign financing. This question will be explored further in terms of the forward and backward linkages of the industry and its technological possibilities.

2.1 THE GROWTH OF STEEL DEMAND, THE FORWARD LINKAGES OF ARGENTINIAN STEEL INDUSTRY

There has been a large amount of work in forecasting steel demand in developing countries (8). This is due to the importance of the accuracy in forecasting demand needed for planning decisions. The steel industry requires a large investment, has long capital rotation times and has to work at high levels of utilization of installed capacity. For the Argentinian industry general equations are available for the total consumption as a function of GNP and percent change in GNP (8). These equations reflect the forward linkages with the most important sectors of the economy. The most important of these are agricultural machinery auto industry, construction, and oil exploration (9). The recent crisis is an example of the importance of these linkages. Due to the changes in economic policy (1976-1981) demand fell by as much as 20% in a year (1980-1981). Demand is strongly influenced by government policy, and political instability. It is not simple to incorporate this uncertainty factor in planning given the long times and high costs involved in a steel plant this is a major problem and requires further study. It is possible that the attitude towards this risk results in a particular pattern of industrial decisions. Even if domestic demand is the main component of total markets the prospects for exports should also be analyzed. During 1981-1982 the large drop in domestic consumption resulted in a large increase in exports and in 1982 they accounted for 44% of total sales. Prices in the international market have been lower than internal prices in most producing countries due to the general crisis of the industry. International prices in 1982 were 30% less than those of 1981 and 48% less than those of 1975. This is due to the decrease of demand in the developed countries and the subsidies that the steel industry is receiving from the government in several producing countries (20-30% in France, up to 40% in the UK). With this distorted price structure price comparison is very difficult It may be that the most meaningful comparison is that of internal prices in Argentina with internal prices in other countries (9). Currently internal prices for Argentinian steel are lower than in most producing countries, even if the prices of many finished products containing steel are higher. This is the case for the auto industry or home appliances for example (2). Exports appear to be increasing and there are possibilities for further expansion. This is a factor to be considered, but it is not likely to be a key factor in the near future, as it probably is in Brazil. There is insufficient data to determine how much the government has been subsidizing exports, but it appears that the recent increase is due to the decrease in local demand and will not continue if the national economy recovers in the near future.

3.0 TECHNOLOGICAL CONSIDERATIONS

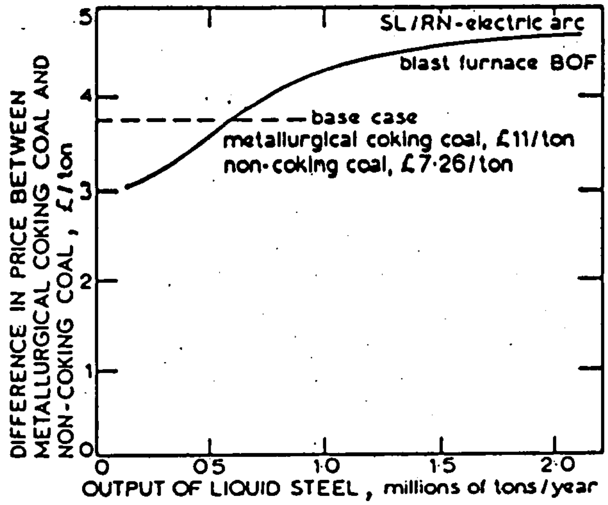
3.1 ALTERNATIVE ROUTES TO STEEL MAKING

As a background for any analysis of the steel industry it is necessary to discuss the possible steelmaking alternatives, their relative advantages, raw material requirements, and technological complexity. This will be done in a very brief way in this section. The factors that influence the choice of technology will be briefly analyzed.

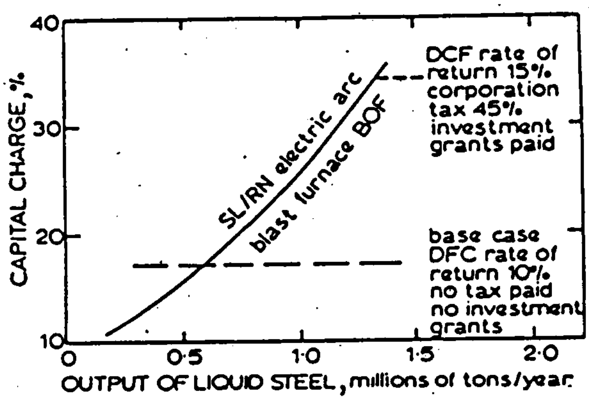
In recent years several technological innovations have been introduced in the iron and steel industry. The most important of these are the basic oxygen furnace (BOF or LD process), direct reduction of iron (DRI), and continuous casting. BOF was first introduced in Austria in 1952. The process has clear advantages over the traditional open hearth furnace. Capital investment is about one half that required for an open hearth (OH) plant of the same size. It allows economy of labor and space. In the last 20 years the process has been developed to include many variants and it now accounts for 60% of the world's production. It is interesting to note that a recent survey by Gale (10) and other reports (11) indicate that the recent and planned future expansion of the world BOF capacity is contributed almost exclusively by less developed nations. The Blast furnace-BOF route is also the most adequate route for large scale production and accounts for 80% of the steel produced in large scale plants (10). Direct reduction processes were first introduced in Mexico as an alternative to blast furnaces, in 1957. Several variants have been developed since then both gas based and coal based. The gas based processes do not require metallurgical coal and use natural gas instead. These processes are of interest to developing countries because they are adequate for small scale production. However, it is also being considered in industrialized countries to achieve high product quality and low pollution control costs (12). The process of continuous casting is technologically more complex. It involves the continuous production of slab, thereby saving labor and energy. It was not used industrially until the middle 1960's. Further advantages are the reductions in space and operating costs, as well as improvement in surface quality. It should be noted that the advantages of adopting continuous casting depend strongly on the level of integration of the plant. It is difficult to state which route is more economical in a particular country without considering all the factors involved. Johnston and Mills analyzed the choices in different situations (13). In a schematic way the factors considered are the price of natural gas, the desired output of steel and the capital charge. The blast furnace-BOF route is favored for large output, low capital charge, and high price of gas. Coal based direct reduction (SL/RN) is favored for low output high capital charge and high price of gas. Finally gas based direct reduction (HYL process) is favored for low price of natural gas. This is schematically shown in Fig. 2.

Raw materials and energy requirements for the steel industry are strongly dependent on the process chosen for steel production. The most important inputs required are iron ore, coke, scrap, electric power, and natural gas. Almost all the iron ore consumed by the Argentinian steel industry is imported. The sources for 1982 were Brazil (88%), Peru (8%), and Venezuela (4%) (9). This means that even if ore is not available nationally, it is provided largely by neighboring countries at low transport costs. It should also be noted that the cooperation between latin american countries in steel production is important, as shown by the reports of the Latin American Iron and Steel Institute (ILAFA) (14). In recent years new steel plants are usually located close to the source of energy, labor and the market. This is different from the traditional pattern that associated comparative advantage with the availability of iron ore and coke. All the metallurgical coke that the steel industry in Argentina con-

Sensitivity of process selection to coal prices



Sensitivity of process selection to charge on capital



Sensitivity of process selection to price of gas

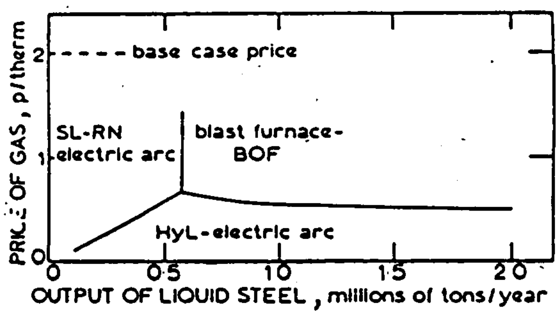


Figure 2. Alternative Routes to Steel Production.

sumes is locally produced but from imported mineral. In this case the sources are USA (67%), Australia (13%), Poland (12%), Canada (6%), and Colombia (2%) (9). This is a major factor in the cost of steel produced by the blast furnace BOF route. There is a large direct reduction capacity installed that uses natural gas. The industry currently uses 750 million cubic meters, which only represents one thousandth of the known reserves (9). Direct reduction processes also use a larger percentage of scrap. Scrap is available nationally, and the metallic charge of steel furnaces is 99.6 % local. This situation would indicate a comparative advantage in favor of direct reduction gas based technology. It is not clear whether the technology choices made so far in the sector have been adequate to the raw materials situation. This problem is related to the concept of "appropriate technology" for developing countries which will be further explored below. From the point of view of raw materials it can be said that there is no clear comparative advantage for the steel industry in Argentina. However, it is possible by the choice of technology to use resources that are available either nationally or at a low import cost. The cooperation with other latin american countries is important in this respect. It is possible that on an overall basis the industry can be competitive in the international market. However, this fact is strongly dependent on the choice of technologies available to the industry.

3.2 THE TECHNOLOGICAL LEVEL OF THE ARGENTINIAN STEEL INDUSTRY

To determine the technological possibilities for the future it is necessary to analyze the past development, in particular the speed of adoption of the recent technologies. Two types of indicators have been used in the past to measure the diffusion speed of a new process (11). One is the percentage output produced using the new process and the other is the percentage of newly installed capacity that uses the new technique. It has been argued that the latter indicator is more representative of the situation in the steel industry. For example in the case of BOF technology it is clear that the costs for a new BOF plant are lower than for an open hearth plant. The cost analysis will not generally be favorable for a replacement of an existing open hearth plant (11). Table 3 shows steel production by process in several countries. These data show that for all latin american countries the level of adoption of BOF technology has been much slower than in industrialized nations. On the other hand the adoption of direct reduction processes has been more widespread. This share is quite large for Argentina and Mexico. This is contrasted to the case of Brazil.

Table 3. Crude Steel Production by Process in Selected Countries, 1976-79
(percentage of total production)

Country	1976			1977			1978			1979		
	Oxygen	Open-hearth	Electric	Oxygen	Open-hearth	Electric	Oxygen	Open-hearth	Electric	Oxygen	Open-hearth	Electric
Argentina	19.5	45.0	33.7	10.6	47.5	38.6	18.4	34.9	44.5	23.7	24.7	49.0
Austria	81.8	6.2	11.9	82.6	3.8	13.6	82.9	4.3	12.8	84.0	3.3	12.7
Belgium	92.7	0.9	4.4	95.5	0.3	4.2	95.6	-	4.4	95.7	-	4.3
Brazil	46.2	27.1	26.5	56.1	19.6	24.1	62.1	14.4	23.4	63.4	11.8	24.7
France	68.4	5.6	14.2	73.5	3.1	14.5	78.2	2.0	15.1	79.7	1.7	15.3
Germany, Fed. Rep. of	71.9	14.3	12.4	74.4	12.6	13.0	74.6	11.0	14.4	76.1	9.9	14.0
India	21.4	65.3	13.3	22.2	63.9	13.9	20.7	59.9	19.4	24.2	56.0	18.0
Italy	45.6	8.4	46.0	44.8	6.8	48.4	43.2	6.2	50.6	42.0	4.7	53.3
Japan	80.9	0.5	18.6	80.5	0.4	19.1	78.1	-	21.9	76.4	-	23.6
Korea, Rep. of	61.0	1.4	37.6	59.6	2.3	38.1	57.2	2.1	40.7	69.7	0.1	30.2
Luxembourg	86.2	-	1.9	98.9	-	0.7	99.8	-	0.2	100.0	-	-
Mexico	13.0	41.5	45.5	27.1	29.2	43.7	36.9	21.6	41.5	38.2	20.8	41.0
Netherlands	93.1	0.3	6.6	93.8	-	6.2	94.5	-	5.5	94.5	-	5.4
Poland	22.4	66.6	11.0	21.5	64.0	14.5	34.7	51.0	14.3	39.5	47.5	13.0
Spain	54.2	8.4	37.4	53.1	8.6	38.3	52.4	5.3	42.3	48.5	5.3	46.2
Sweden	44.2	13.1	42.7	47.2	10.4	42.4	48.9	7.9	43.1	52.6	6.0	41.2
Turkey	43.0	30.9	26.1	43.0	30.9	26.1	30.4	43.2	26.4	54.7	24.3	21.0
USSR	24.6	64.7	9.9	26.0	63.4	9.9	28.1	61.3	10.0			
United Kingdom	51.5	18.1	30.3	53.1	16.1	30.7	69.8	6.5	22.8	60.2	5.4	34.2
United States	62.5	18.3	19.2	62.1	16.1	21.8	61.1	15.6	23.3	61.3	14.1	24.6

Source: EUROSTAT, Quarterly iron and steel bulletin; OECD, The iron and steel industry; IISI, World steel in figures.

This is probably due to the fact that the Brazilian steel industry is at a further stage of development and requires more large-scale production methods. It is important to characterize the alternative routes to steelmaking in the framework of the theories of technology in developing countries. One of these theories is known as the appropriate technology movement (15). The concept originated in Shumpeter's term "intermediate technology", but also the technology that has specific characteristics. These characteristics include being labor intensive, and low capital cost per workplace. It seems that according to this definition direct reduction- electric arc furnace is the "appropriate" route for steelmaking in developing countries, at least those countries that have low cost natural gas and electric energy. This fact has been recognized in a recent report on the international iron and steel industry (16). It seems that these considerations apply to the case of the Argentinian steel industry. However, if large-scale production is required, the validity of this concept is subject to serious objections, since the Blast furnace-BOF route is known to be more efficient. It is also necessary to adopt continuous casting technology if the industry is to be competitive in semi-finished products.

Another important factor in determining the technological choice is the indigenous research capability. A comparison of research and development effort in ferrous metals in various countries shows that Japan is now world leader in terms of research and development employment and expenditure, corresponding to the leading role of the Japanese steel industry in the world market (17). The role of local research capability is related to the need to adapt the international technology to local conditions, as discussed below. It should be noted that Argentina has one of the strongest scientific systems of the developing world (18), and therefore, this is a factor that could favorably influence the future possibilities for technological development of the steel sector. Another important consideration regarding the technological possibilities in developing countries is technology transfer. There are different views on the technology transfer problem. Latin American scholars, the most prominent of which are Celso Furtado and Osvaldo Sunkel, picture the process as interrelated forces where the prime movers are the more developed countries. Foreign investment is attracted and technology is transferred with an insufficient adaptation to local needs and market sizes. This tends to favor wealthier groups, stimulating foreign investment again and the cycle perpetuates itself (19). On the other hand there are the advocates of the multinational enterprise as a vehicle of technology transfer. They argue that protectionism and governmental policies play an important role in technological backwardness. Free entry of foreign products and technology would stimulate competition in the national enterprises and result in the introduction of innovations. This was the rationale behind the economic policy in Argentina during the late 1970's. In addition, the question of licensing payments, patents, the critical mass of scientific structure required, and the necessity of adapting the high technology to local conditions have to be taken into account. In principle, multinational enterprises can play a key role in technology diffusion. A technologically oriented company which is large enough will make an attempt to locate abroad. This will contribute to the global transfer of the technology developed by this company. The problems of this process are related to the need of understanding and adapting the technology contained in the product produced by the multinational enterprise. The research capabilities needed to imitate and adapt a given technology may be comparable to those needed to develop it. The third alternative that a multinational enterprise has is licensing or turn-key agreements. Licensing provides an income and avoids the risk associated with establishing new markets. It may also be more convenient in terms of capital, time, and energy. The innovating company is thus saved the effort of establishing a subsidiary abroad. However in some cases licensing may not be an attractive prospective for a company selling goods with high innovational content. These are the cases where it may invite future competition. The agreement in these cases could upgrade the licensee's technology. From the point of view of the multinational company the three alternatives, exports, overseas location and licensing are complementary strategies that are used in different cases, according to the particular conditions. This is specially true for a subsidiary that can stimulate the imports needed in the host economy. Companies selling knowledge may effectively loose control on the area of technology concerned. This makes companies cautious and sell licences only for discoveries which are peripheral to their main areas of activity. It should be noted that the alternative of licensing is the one that has been selected in the steel industry. It is also possible that the production of low grade steel products is becoming a secondary area of activity for most large steel multinational enterprises. The production of stainless and specialty steels requires a more advanced technology and is increasingly regarded as the main potential of large steel companies, specially in the United States (4).

There are several studies related to technology transfer in the steel industry. Herbert and Rufing (20) point out that in the steel industry there has been a flow of technology from semi-industrialized countries to industrialized ones (HYL, SL/RN processes). On the other hand an analysis of the tendering projects in developing countries shows that the turn-key contracts are the most common type, as supplied by a consortium of international companies (21). The study also shows that consortiums tend to use equipment from their country disregarding indigenous availability of the equipment. This appear to be the case for BOF. Ono (22) studied the adaptation of BOF technology to Brazilian needs, as compared to the adaptation process in the early Japanese steelworks. The study shows that in the Brazilian case technological fixity resulted in the use of non-adapted borrowed processes. This is in contrast to the Japanese emphasis on adaptation and subsequent development of local processes. These findings probably carry over to the Argentinian industry and to the process of continuous casting. However, no studies are reported in these areas.

4.0 THE EFFECT OF GOVERNMENT POLICY

There are various ways in which government can subsidize the steel industry. These include direct investment, measures to attract foreign financing, tariff protection, buying national products for state enterprises, etc. In Argentina the government owns a large fraction of the steel sector (60%), and therefore has a strong direct influence. It also controls through government enterprises 40% of the economy. The generally held view is that in newly industrializing nations like Argentina that are in the process of consolidating the steel industry government policies strongly favor the steel sector. There are several possible reasons why governments would choose to favor the steel sector in developing countries (south). Two of the most relevant are discussed here.

4.1 HECKSCHER-OHLIN THEORY APPLIED TO THE STEEL INDUSTRY

First, consider a simple two good two factor model with two regions, north and south. The two goods are B, the basic good, and I, the luxury-investment good. Heckscher-Ohlin theory predicts that the region relatively more endowed in capital (the north) will export the capital intensive good I, whereas the labor endowed south will export the labor intensive good B. This takes place under the assumption of similar preferences in the north and south (23). It follows that, in this simple model unless K increases there is no reason for the south to increase its production of steel, which is a capital intensive good. The reasons for the observed pattern of changes have to be found in other motives to establish and subsidize steel development for governments in the south. A more complete analysis may be obtained by considering the Heckscher-Ohlin model in a three good three factor situation. Let the assumption of equal preferences in the north and south hold and let the three factors be labor, capital, and the endowment of scientific and technical capabilities, denoted L, K, and T. Let the three goods be the basic good, labor intensive, the investment good, capital intensive and the luxury good U, which is technology intensive. As in the two good case the south is labor endowed, whereas the north is endowed in both capital and technology. It seems reasonable to assume that the north is relatively more endowed in technology than in capital. This is expressed in the following conditions:

$$K/L)^N > K/L)^S \quad ; \quad T/L)^N > T/L)^S$$

but $$T/K)^N > T/K)^S \,.$$

Under these assumptions and in autarky the model will yield relative prices in both regions, in analogy to the two good two factor case. These will be:

$$P_I/P_B)^N < P_I/P_B)^S \quad ;$$

$$P_U/P_B)^N < P_U/P_B)^S \quad ;$$

and $$P_U/P_I)^N < P_U/P_I)^S$$

These price relations can be derived from a construction as shown in Fig. 3.

The assumption of equal preferences means that the demand curves will be equal in the south and in the north. In each of the curves of Fig. 3 the quantity of one of the goods is held constant. These conditions mean that the north will export goods I and U. The price differential is higher for good U than for good I. This means that the majority of the gains from trade will be associated with good U. It may even seem possible that in the north there will be a tendency to use capital in the production of good U. This may set the

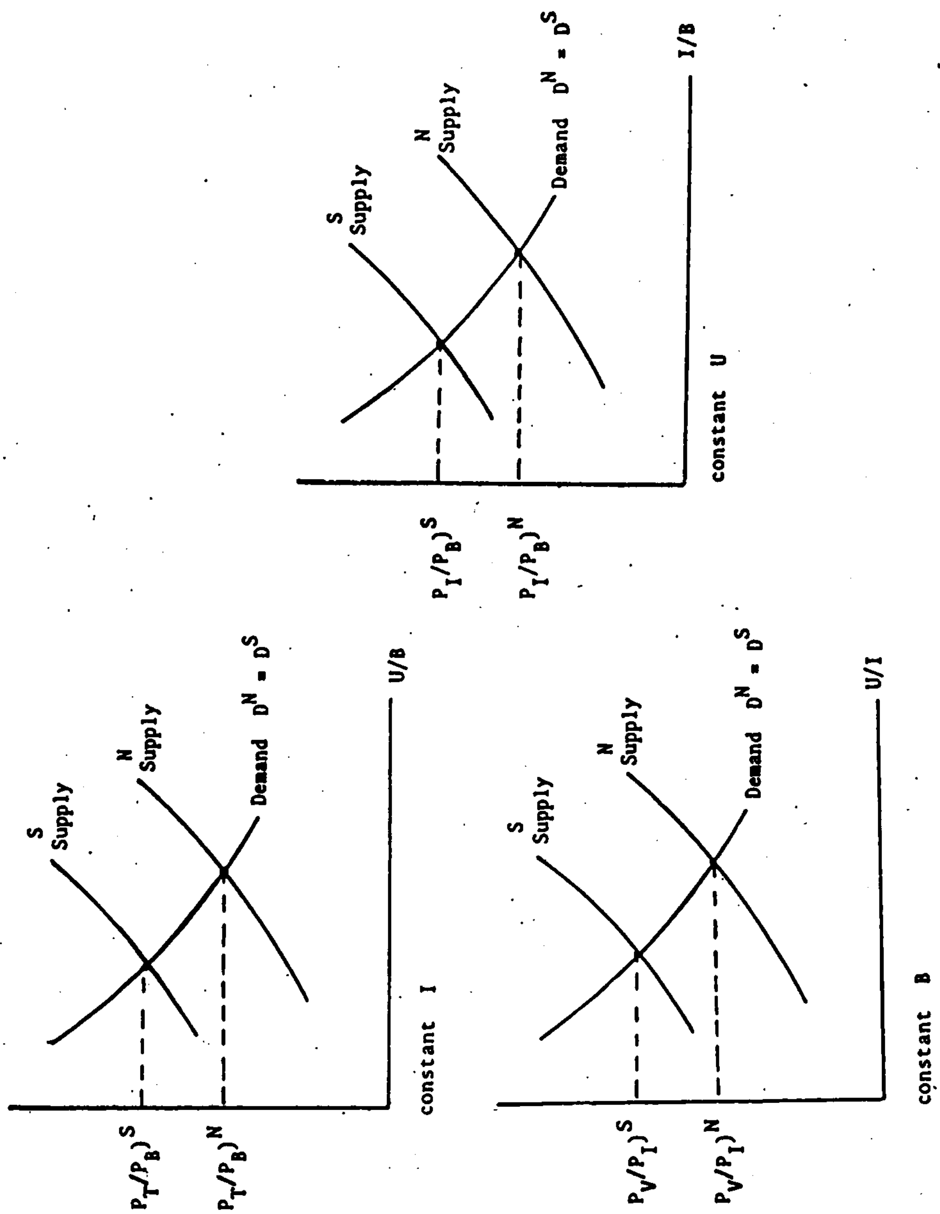


Figure 3. Heckscher-Ohlin Theory Applied to the Steel Industry

world equilibrium price of good I only slightly above that in the south. The south then has the opportunity of adopting measures to develop its own production of good I, at a relatively low cost. This model, however does not explain why the south would be engaged in such a policy. It only indicates that the existence of other goods that are relatively more technology intensive makes the cost of establishing a steel industry relatively lower. If this is true one should find that in developing countries prices of steel relative to other steel-containing products is lower than in the developed countries. This is indeed true, and is shown in reference 9 in a comparison of relative prices in Argentina and the U.S.

It should also be true that the steel exports of developing countries are constituted by low value added products in large percentages. Furthermore the developing nations that are relatively more capable technically should exhibit larger amounts of high value added exports. To test this hypothesis the type of steel products exported by developing nations was analyzed according to the OECD classification and divided in three types. These are low, medium, and high value added steel products. The fraction of these types of products exported by the three main Latin American exporters are shown in Fig. 4. It is seen from these data that indeed Latin America exports low and medium value added steel products.

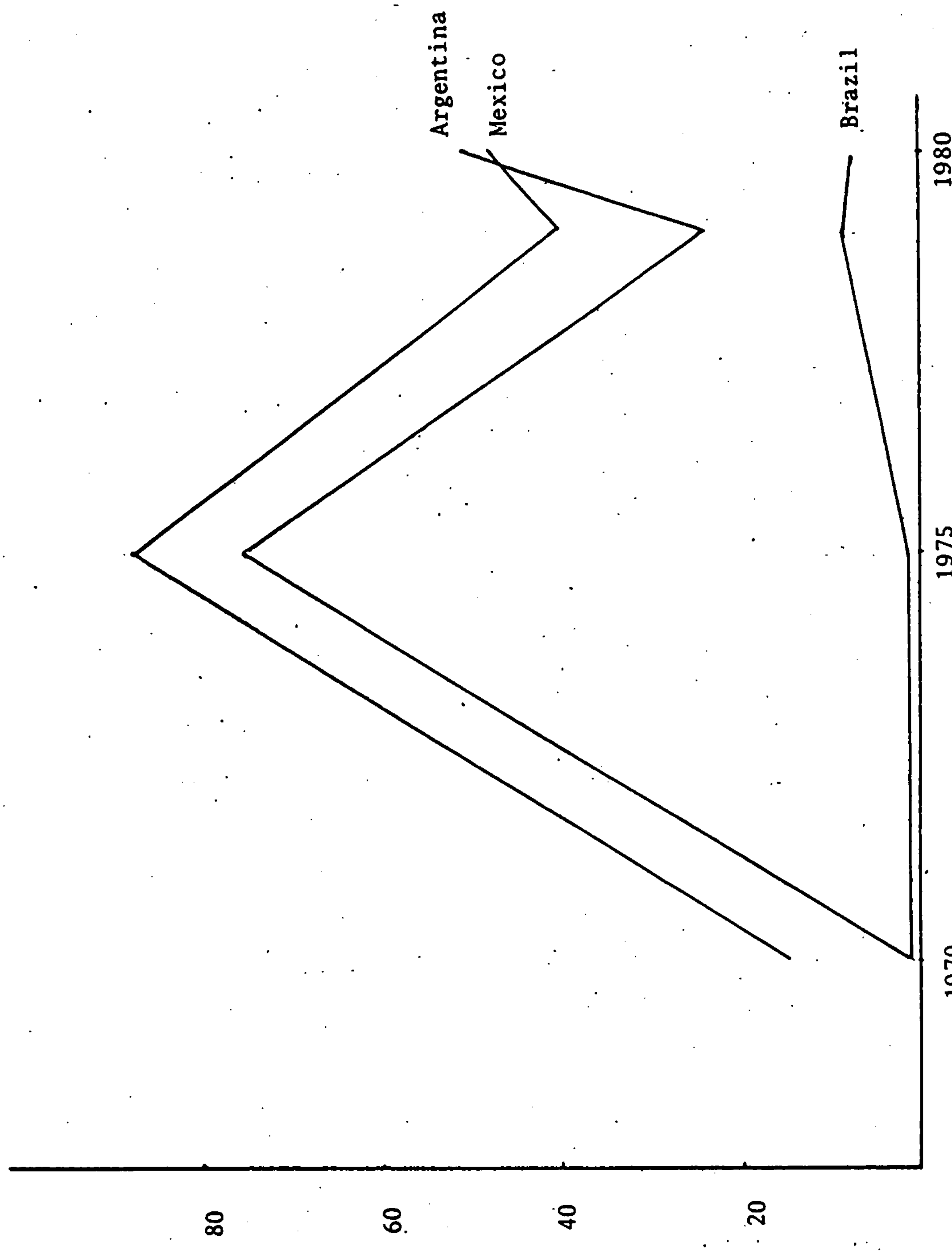


Figure 4. Fraction of High Value Added Steel Exports.

Note that Argentina is the country with the highest fraction of high value added, corresponding to its higher endowment of scientific and technical capability.

4.2 THE FOREIGN DEBT AND THE TRANSFER PROBLEM.

In this section the increasing steel production in the south is analyzed in its relation to the foreign debt problem, which affects several countries in Latin America. In particular the largest foreign debts are held by the largest steel producing countries in the region, Brazil, Argentina, and Mexico. The problem should be analyzed in two different cases (24). Periods when the south is receiving foreign aid, that is a net transfer from north to south, and periods when the south is paying the foreign debt, that is a net transfer from south to north. For simplicity this problem will be analyzed in a two good two factor framework. Consider a case where the south does not produce the capital intensive good at all, whereas the north specializes in the investment-luxury good. In this case it can be shown that there is a secondary burden for the paying country. During periods when the south receives loans this means that the terms of trade worsen for the north. During the period when the south pays the foreign debt the terms of trade will worsen for the south. To avoid this secondary burden the south may try to establish production of the capital intensive good. As mentioned in the previous section the steel industry is a case where this can be done at a relatively low cost. It should be noted that most developing nations that are now increasing steel production have gone through the situation of nearly specializing in basic goods. In the actual case, the north does not specialize in investment-luxury goods. The mathematical analysis of the transfer problem with one country specializing and the other not is rather long and will not be discusses here. Intuitively it may be suggested that for most conditions if the south specializes it will have to pay a secondary burden during the periods when it pays back its foreign debt. However, one showed be careful in interpreting this analysis, since skilled labor is usually more abundant in the north. This may give rise to a situation similar to the Leontief paradox.

4.3 THE ARGENTINIAN CASE :1976-1983

The preceding considerations support the view that governments generally favor the steel industry in developing nations. This view is not supported by the recent developments in Argentina. The main problem of the steel sector has been the low level of general economic activity. As discussed earlier this affects the industry very strongly through the forward linkages. It is also apparent that this is a direct consequence of the government policy that started in 1976 and was reversed in 1981-1982 due to the pressures of national industry and the foreign debt. The nature of the changes of 1976 is clearly discussed in a study by the Business International Corporation (25). The study evaluates business prospects in the new setting of 1978. The reform was aimed at forcing the national industry to compete with international markets and therefore raise their standards. The above mentioned report states that this policy would lead Argentina to the road to recovery. However, the exchange rate was maintained artificially high and industry could not compete with foreign products. Most sectors suffered severe losses, including the steel industry and its most important customers. The crisis has resulted in record levels of unutilized capacity (26), The foreign debt is now four times that of 1978. Currently this policies are being reversed and the steel industry demands a series of measures to help its recovery. Basically these are measures to favor exports, bring tariffs back to 1977 levels and restrict government purchases to national products whenever possible. It therefore appears that government policy in recent years has not favored steel production. On the contrary it resulted in a severe crisis, which was not linked solely to the international problems of the industry. It can be linked to a large extent to a general crisis of the industrial sector as a whole (27). In turn this is related to a financial crisis that had a strong influence on the industrial sector.

5.0 LINEAR PROGRAMMING UNDER UNCERTAINTY

5.1 UNCERTAINTY AND THE STEEL INDUSTRY

In this section we discuss informally the role of uncertainty in the specific case of the steel industry. The main feature to be noted is that investment to increase installed capacity should be planned well before demand is actually known. Completion of steel plants takes several years until they are able to start production.

The second feature is that the fixed costs of maintenance and depreciation are a substantial part of the price of a ton of steel (more than 50%). Different technologies. These will, of course, have different variable to fixed cost ratios, and this will be reflected in the effect of uncertainty in technology choices. Internal demand, is not the only source of uncertainty of the steel industry . International prices, prices of energy and raw materials, exchanges rates, among other are possible source of uncertainty. The present work, however, focuses on only one source of uncertainty (national demand) which is particularly large in a country like Argentina. This assumption will also supply our computational work.

5.2 MAXIMIZING EXPECTED UTILITY

The most important principle regarding maximizing utility under uncertainty is the Expected Utility Theorem. This principle is also called the Bernoulli criterion. It was put forward by D. Bernoulli (29) in the 1750's, and had remained almost uncontested as the most rational criterion for decision until the 1940's. It simply states that: one decision is preferred to another if and only if the expected value of the gain (loss) of the first is greater (smaller) than that of the second. The expected utility theorem can be proved to be valid in quite general cases that assume rationality. It is widely accepted, and will be used in the present work.

As a criterion for decision, the Bernoulli principle is rather simple to apply, provided that the different probabilities involved are known. It is clear to us that the principle implies repeated trials (i.e., a repetition of the decision situation). Hence, for the practical decision maker, it can only make sense if he expects a stationary probability system. Although this criterion is the one more generally applied to problems related to uncertainty, and in particular to planning strategies (30), there are also other proposed principles, such as the principle that requires the individual to choose the strategy which minimizes his maximum loss

(31,32). The line of reasoning runs as follows: the lack of knowledge of the opponent's intentions is the major factor. Thus, large uncertainty is the common denominator in these problems, whether it be the individual facing competitors, or an individual acting on the basis of incomplete information. In the former case, the competitors are the unpredictable elements, and in the latter case we can assume that Nature is the fictitious opponent and its course of action is uncertain. Clearly, while we expect our competitors to act in opposition to our objectives, we do not expect Nature to track us down and play contrary to our wishes. The criterion is, however, not devoid of sound reasoning. If the individual plays this optimal strategy he is really merely behaving in such a way as to set an absolute lower bound to his expectation. He may feel that it is reasonable for him to act in this way, while not necessarily believes that the market will always move in the way most unfavorable to him. Simply, he is not in a position to predict the future with any accuracy, and he may want to be adequately prepared for any contingency. There may be indications that this type of behavior is expected in a case of very high uncertainty, as the one studied here. However, it seems likely that the Bernoulli criterion will be a more realistic assumption for general cases. It will therefore be used in the present modeling, thus providing our conclusions with a more general scope of validity.

5.3 SENSITIVITY ANALYSIS

Development planning models have repeatedly emphasized that sensitivity analysis forms an essential part of decision making processes. The information obtained in making sensitivity analysis is in many cases as valuable as the optimum solution itself. Nevertheless, it is difficult to find methodological recommendations for conducting sensitivity analysis.

In general the traditional methodology consists in solving the problem under certainty conditions repeatedly, varying the parameters that are uncertain. The final solution is then obtained as some average of the solutions. Although this procedure can give important information if used with virtuosity, a more precise methodology is required in most cases (33). From a mathematical point of view it is obvious that the average of optimum solutions is not a solution for the optimum of the average problem. This last problem is the one that planners should consider if the expected utility theorem is assumed valid. The inadequacy of the traditional method is specially relevant for decision models that use the "active" approach to stochastic programming, where irreversible decisions must be taken before all the necessary information is available. Then, in general, some other complementary action can be chosen. For instance, investment in steel plants has to be decided before the level of demand is known. The level of production can be determined a posteriori in the light of precise demand data. The traditional method for analyzing a model proceeds in two stages:

- first, the model is built using basic average data for the uncertain parameters and a provisional solution is computed.
- second, the optimality of this solution for the full problem is checked by varying the parameters and solving the model again. We are effectively asking a series of questions of the type "what should we do if we knew the future and it were such?" A decision is deemed optimal if it does not vary "too much" when the parameters characterizing the future vary.

The first stage of the analysis is obviously a first approximation to the problem. About the second stage, we should first note that it asks the wrong question as we really want to know "what should we do given that the future can take so many different forms?" The main difficulty is that the optimal solution to the model can vary with the parameters, and in those cases traditional sensitivity analysis cannot asses optimality.

If the expected utility theorem is assumed valid introducing uncertainty in decision models is not theoretically difficult. It has been argued that in general, it is impossible to use this approach. When the representation of uncertainty must include a large number of possible states of the world. If we can concentrate our attention on a small number of states of nature, this approach should be feasible. This should be the correct approach for the case considered here. Traditional sensitivity analysis is used as a second best method to introduce uncertainty and take it into account in decision making, while still avoiding the complications of modelling it explicitly. This presentation is generally accepted but the consequences of this approximation have never been studied.

In the present formalism we will concentrate in a small number of possible states of the world. We will also assume validity of the expected utility theorem or Bernoulli principle. With this assumptions it turns out that a simple formalism can be devised to introduce demand uncertainty in a mathematically correct way. In applying this model to a case with large uncertainty of demand, such as the

Argentinian steel industry it is clear that there may be a significant difference in the results as compared to the traditional method. We will also obtain the solutions using the traditional method in order to fully asses the consequences of using traditional methods. The conclusions of such a comparison of methodologies will also be relevant for other applications of programming models.

5.4 DESCRIPTION OF THE ALGORITHM

We will start by discussing the problem of allocation. That is, not only the one that has the has the availability of resources as its only restrictions; but also the one that has its variables constrained by additional linear equalities or inequalities. The simple allocation problem can be stated mathematically as:

$$\text{Minimize (or maximize)} \quad C = \psi\,(X_{ij}) \qquad i=1,\ldots,m$$
$$j=1,\ldots,n$$

$$\text{subject to the constraints} \quad \Sigma\, X_{ij} < a_i,$$

where X_{ij} denotes the amount of the ith resource allocated to the jth activity, and the a_i's are given constants. On the other hand, the complete programming problem can be stated as:

Minimize (or maximize) $C = \phi\ (X_{ij})$ $\quad i=1,\ldots,m$

$j=1,\ldots,n$

subject to the constraints

$$\Sigma\ a_{ij}.X_{ij} < b_j$$

$$\Sigma\ \alpha_{ij}.X_{ij} < b_i$$

where a_{ij}, α_{ij}, b_j, b_i are given constants.

Under uncertainty of demand, the general programming problem can be treated as maximization (or minimization) of the expected utility and assuming a relatively small number of states of the world, it can be written as:

Maximize or minimize

$$\psi\ (X_i) + \Sigma\ p_j\phi_j(X_{ij})$$

where p_j is the probability of state of the world j subject to:

$$\Sigma\ X_{ij} < a_j$$

where a_i is availability of ith resource and

$$\Sigma X_{ij} = b_j$$

where b_j is required production in state of the world j

In the case of our interest, we will assume that the steel industry has to meet the internal demand in all states of the world considered. The number of states of the world considered is three, corresponding to low, average, and high demand. In each of these states demand may be met by production in either of three considered technologies, or by imports. There is a maximum in the imports, due to the scarcity of foreign currency that is expected, at least in some states of the world. Also the price of imported steel is higher than that of the internal market.

In the states of the world where internal demand is lower than the installed capacity exports are allowed, at a price which is lower than that of the internal market. There is a maximum to these exports given by world demand.

Of course production will be limited for each technology by the installed capacity in all states of the world. This is a result of the investment decisions taken a priori. We will therefore minimize the cost (maximize the profits) of meeting demand in all states of the world with respect to these investment decisions, and subject to the constraints described above. Before stating this in mathematical form let us define the notation used for all the variables in question.

5.4.1 NOTATION

S : profit function to be maximized, in dollars

I_i : investment in technology i, in dollars

X_{ij} : output in technology i, state of the world j, in tons

E_j : exports in state of the world j, in tons

M_j : imports in state of the world j, in tons

C_i : already installed capacity in technology i, in tons

Q_i : new capacity per invested dollar in technology i, in tons per dollar

$Emax_j$: maximum exports in state of the world j, in tons

Max_j : maximum imports in state of the world j, in tons

F_i : fixed cost per ton in technology i, in dollars

V_i : variable cost per ton in technology i, in dollars

p_j : probability of state of the world j

P_j : price of steel in state of the world j, in dollars

D_j : Demand in state of the world j, in tons.

Px_j : export price in state of the world j, in dollars

Pm_j : import price in state of the world j, in dollars

5.4.2 STATEMENT OF THE PROGRAMMING PROBLEM

With this notation the function S to be maximized is given by:

$$S = -\Sigma\, p_j\, \Sigma\, V_i\, X_{ij} - \Sigma\, (Q_i I_i + C_i)\, F_i + \Sigma\, p_i\, \Sigma p_i\, \Sigma\, X_{ij}\, P_j -$$

$$\Sigma\, p_j\, E_j\, (P_j - Px_j) - \Sigma\, p_j\, M_j\, (Pm_j - P_j)$$

Subject to the constraints:

- meeting demand: $\Sigma\, X_{ij} + M_j - E_j = D_j$ $\quad$ j=1,3
- exports positive: $E_j > 0$ $\quad$ j=1,3
- maximum in exports: $E_j < E_{max\ j}$ $\quad$ j=1,3
- maximum in imports: $M_j < Max_j$ $\quad$ j=1,3
- installed capacity: $X_{ij} < C_i + Q_i I_i$ $\quad$ j=1,3

This simple model can take into account all the main features of the decision process for steel plant investment. In particular, phenomena like dumping (through a low export price), and the foreign exchange problem (through a maximum in imports). Also the technological problem can be treated using different variable costs and different installment costs for each technology. The most important feature that is not included in the model is the existence of economies of scale which are very important in steel plants. Taking this into account would require integer programming, which is more complex. The basic conclusions regarding the effect of uncertainty are not expected to be changed by the inclusion of economies of scale. It is not clear how will our conclusion regarding technology choices will hold if economic of scale are included.

6.0 LINEAR PROGRAMMING RESULTS

In this chapter the results of applying the described formalism are the case of the steel industry in Argentina are presented. In the following sections a description is presented of the necessary input parameters and their quantitative estimation. The effect of these parameters on the results for investment planning are described.

6.1 EVALUATION OF COSTS AND DEMAND

It is very difficult to estimate the actual costs of producing a ton of steel. The most important difficulty encountered is the existence of economies of scale. As mentioned above economies of scale are not taken into account in the present formalism. Consequently an average estimate will be used in the calculations. A second difficulty is the fact that internal prices may be strongly distorted by the effect of exchange rate fluctuation. The estimate used in the present work is an average of $ 250 per ton of steel. Note that in the present formalism constain internal prices should not affect the solution. The estimate of demand was obtained from various sources (2, 8, 9). Fig. 5 shows the values of consumption for the last years.

Consumption

Years	1978	1979	1980	1981	1982
Total (in 10^3 ton)	2,246	2,951	2,798	2,070	2,232

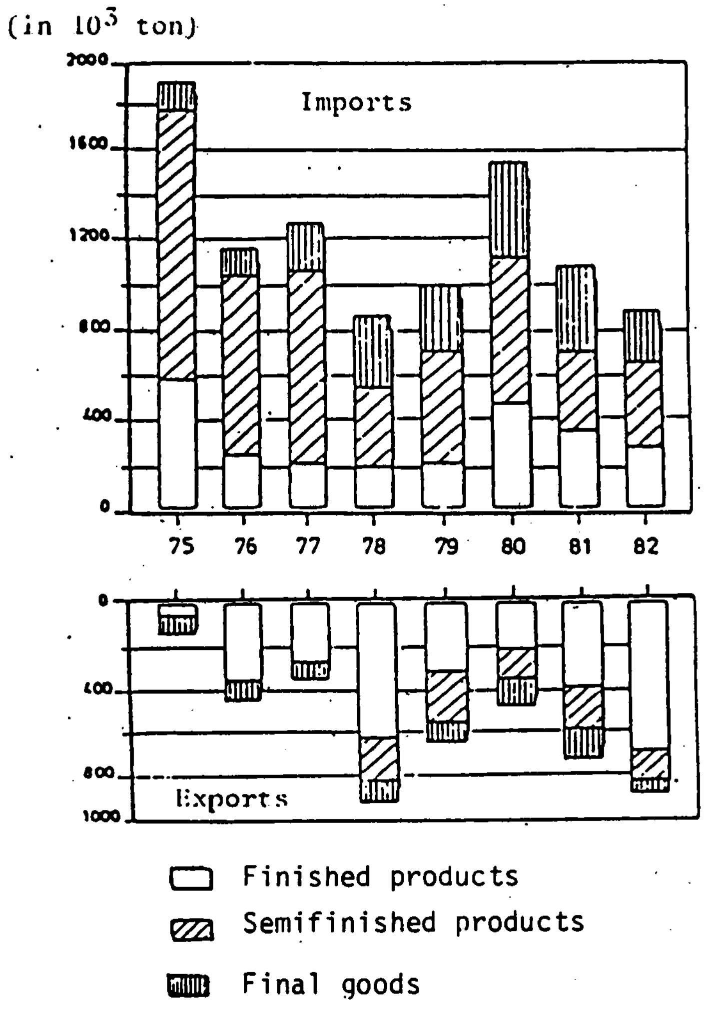


Figure 5. Consumption, Exports, and Imports in recent years.

In addition the degree of uncertainty can be estimated from these data. Demand values for the high and low states of the world were obtained by taking the maximum and minimum observed values in the previous years and increasing them according to the rate of growth of the GNP for the period considered. In this fashion approximate values were obtained of 2900, 3200, and 4700 tons per year for the different states of the world. The scatter of the data does not allow an adequate estimate of the probability distribution function based on this method. The basic data used in the present study assumes equal probabilities. The distribution was later varied , together with other variables, as described below. The values for the installed capacities were obtained from actual data for three different technologies. These are :

i) The traditional processes, mainly Siemens-Martin.

ii) The basic oxygen process, or BOF.

iii) The direct reduction-electric furnace route.

The fixed and variable cost values for the different technologies were estimated as shown in Table 4. Direct reduction (Technology 1) is clearly a more labor-intensive technology and therefore has a higher variable cost. In spite of this, it is considered to be more expensive to install. Conversely, BOF technology has a lower variable cost and is cheaper to install per ton. The total cost per ton is the same for BOF and direct reduction routes, whereas it is slightly higher for the outdated traditional route. The costs of installing traditional technology are less than for the other technologies, since it is outdated. However, its variable cost is the lowest.

The values of maximum allowed imports and exports were also obtained from data on previous years, as explained for the demand values. The data show that both import and exports take place in all years, basically due to diversity of products. Since in the present study different products are not considered the net values were used to obtain the estimates. These values are around 1000 tons for imports and 700 tons for exports. Note that in this estimation we consider only net exports or imports.

6.2 EFFECT OF IMPORT AND EXPORT PRICES

It was not possible to obtain meaningful values for import and export prices from the available data. The best estimates indicate that they may be up to 25% higher and 40% lower than the internal prices, respectively. These estimates complete the set of necessary data for the present formalism and the basic results are shown in Table 5. Table 6 shows the optimum decisions reached using traditional sensitivity analysis.

It is seen in these results that the basic features of the Argentinian steel industry are reproduced, namely the existence on unutilized capacity, the losses experienced in the states of the world with low demand, and the correspondence of the these states with higher exports. As argued in previous chapters the internal crisis leading to low demand appears to be the main reason for the recent increase in exports.

The data were then varied in consistent patterns to investigate the effect on the obtained decisions. Import and export prices determined in our model the basic investment decisions. The first series of calculations was done varying the export price and maintaining other variables constant. In this way a critical value for the export price was found that led to investment decisions. The maximum in exports and imports strongly influences these results. The example of this is shown in Tables 7 and 8. Table 9 also shows for comparison the investment values obtained using the traditional method of sensitivity analysis. Note that they are generally higher than those obtained using the more accurate method.

6.3 EFFECT OF TECHNOLOGICAL VARIABLES

The decision on the choice of technology is determined by two factors: the ratios of variable to fixed cost, and the cost of installment per ton. Since in all the cases considered there is unutilized capacity in the low state of the world, technologies with low fixed cost are favored. This effect can be balanced by the installment cost, as shown in the examples of Table 10 to 12. Investment in traditional technology was of course never predicted. It is interesting to note that for similar installment costs the technology with lowest variable cost was favored. This is despite the fact that the direct reduction-route is the "appropriate" technology for a country like Argentina. This findings suggest that the uncertainty present in demand actually leads to investment decisions in a technology which would, otherwise, not be the most efficient.

6.4 EFFECT OF UNCERTAINTY LEVEL AND CORRELATION AMONG DATA

In this series of calculations the effects of uncertainty level, distribution, and correlation properties were investigated. The data shown in Tables 13 to 15 show the effect of increasing the relative weight of the extreme states of the world. It is seen from these tables that the effects of uncertainty are indeed magnified in this case.

In the next series of model calculations the data are chosen to be correlated with the imput value for demand in each state of the world. For example, in a state of the world of low demand the maximum in exports is expected to be lower, since the crisis may be linked to the international situation of the industry. Similar considerations hold for import and export prices (Table 16). This again magnifies the effect of uncertainty, as shown in Tables 17 and 18.

6.5 COMPARISON OF DIFFERENT METHODS OF SENSITIVITY ANALYSIS

To compare the results of the present formalism with the traditional method of sensitivity analysis the cost in dollars of using the standard method was calculated for the different cases analyzed. As shown above for the basic set of data used this cost can be quite high for the steel industry. The effect of varying the different data on this cost was also calculated, and is shown in graphic form in Table 19. In this figure a horizontal arrow indicates no or little influence, whereas arrows up and down indicate increases and decreases of this cost, respectively.

Table 4. Input Values

STATE OF THE WORLD	PROB.	DEMAND	PRICE	MAX. IMPORT	MAX. EXPORT	IMPORT PRICE	EXPORT PRICE
1	0.333	4700	250	1000	750	312	200
2	0.333	3200	250	1000	750	312	200
3	0.333	2900	250	1000	750	312	200

TECH.	OLD CAP.	COST OF NEW CAP.	FIXED COST	VAR. COST
1	860	1250	150	100
2	1010	1111	170	80
3	1605	769	180	72

Table 5. Output Values

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT
1	860	1235	1605	1000	0
2	860	1235	1605	0	500
3	810	1235	1605	0	750
INVEST ×1000$	0	250	0		
PROFIT in $	-47790	% of total sales	-5.3 %		

Table 6. Output Values

Traditional Sensitvity Analysis

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT	INVEST ×1000$	PROFIT ×1000$
1	860	2235	1605	0	0	1361	-3
2	860	1010	1605	0	275	0	-17
3	860	1010	1605	0	575	0	-32
Loss due to uncertainty		30341	% of total sales	3.3 %			
Loss due to incorrect planning		51567	% of total sales	5.6 %			

Table 7. Input Values

STATE OF THE WORLD	PROB.	DEMAND	PRICE	MAX. IMPORT	MAX. EXPORT	IMPORT PRICE	EXPORT PRICE
1	0.333	4700	250	1000	750	450	230
2	0.333	3200	250	1000	750	450	230
3	0.333	2900	250	1000	750	450	230

TECH.	OLD CAP.	COST OF NEW CAP.	FIXED COST	VAR. COST
1	860	1250	150	100
2	1010	1111	170	80
3	1605	769	180	72

Table 8. Output Values

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT
1	860	1485	1605	750	0
2	860	1485	1605	0	750
3	560	1485	1605	0	750
INVEST ×1000$	0	528	0		
PROFIT in $	-78,802	% of total sales	-8.7 %		

Table 9. Output Values

Traditional Sensitvity Analysis

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT	INVEST ×1000$	PROFIT ×1000$
1	860	2235	1605	0	0	1361	-3
2	860	1010	1605	0	275	0	-9
3	860	1010	1605	0	275	0	-15
Loss due to uncertainty		69935	% of total sales	7.8 %			
Loss due to incorrect planning		51567	% of total sales	2.8 %			

Table 10. Input Values

STATE OF THE WORLD	PROB.	DEMAND	PRICE	MAX. IMPORT	MAX. EXPORT	IMPORT PRICE	EXPORT PRICE
1	0.4	5000	250	1000	750	312	200
2	0.2	3200	250	1000	750	312	200
3	0.4	2600	250	1000	750	312	200

TECH.	OLD CAP.	COST OF NEW CAP.	FIXED COST	VAR. COST
1	860	1250	150	100
2	1010	1111	170	80
3	1605	769	180	72

Table 11. Output Values

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT
1	860	1010	2130	1000	0
2	860	960	2130	0	750
3	860	360	2130	0	750
INVEST ×1000$	0	250	0		
PROFIT in $	-42412	% of total sales	-4.7 %		

Table 12. Output Values

Traditional Sensitvity Analysis

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT	INVEST ×1000$	PROFIT ×1000$
1	860	2535	1605	0	0	1694	-3
2	860	1010	1605	0	275	0	-17
3	735	1010	1605	0	750	0	-59
Loss due to uncertainty		13952	% of total sales	1.6 %			
Loss due to incorrect planning		120888	% of total sales	13.3 %			

Table 13. Input Values

STATE OF THE WORLD	PROB.	DEMAND	PRICE	MAX. IMPORT	MAX. EXPORT	IMPORT PRICE	EXPORT PRICE
1	0.333	4700	250	1000	750	312	200
2	0.333	3200	250	1000	750	312	200
3	0.333	2900	250	1000	750	312	200

TECH.	OLD CAP.	COST OF NEW CAP.	FIXED COST	VAR. COST
1	860	1111	140	110
2	1010	1111	170	80
3	1605	769	180	72

Table 14. Output Values

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT
1	1085	1010	1605	1000	0
2	1085	1010	1605	0	500
3	1035	1010	1605	0	750
INVEST ×1000$	250	0	0		
PROFIT in $	-47,609	% of total sales	-5.3 %		

Table 15. Output Values

Traditional Sensitvity Analysis

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT	INVEST ×1000$	PROFIT ×1000$
1	2085	1010	1605	0	0	1361	-3
2	860	1010	1605	0	275	0	-17
3	810	1235	1605	0	575	0	-32
Loss due to uncertainty		30250	% of total sales	3.3 %			
Loss due to incorrect planning		4187	% of total sales	0.4 %			

Table 16. Input Values

STATE OF THE WORLD	PROB.	DEMAND	PRICE	MAX. IMPORT	MAX. EXPORT	IMPORT PRICE	EXPORT PRICE
1	0.333	4700	260	1100	900	312	200
2	0.333	3200	250	1000	750	312	200
3	0.333	2900	240	900	600	312	200

TECH.	OLD CAP.	COST OF NEW CAP.	FIXED COST	VAR. COST
1	860	1250	150	100
2	1010	1111	170	80
3	1605	769	180	72

Table 17. Output Values

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT
1	985	1010	1605	1100	0
2	985	1010	1605	0	400
3	885	1010	1605	0	600
INVEST ×1000$	156	0	0		
PROFIT in $	-49037	% of total sales	-5.4 %		

Table 18. Output Values

Traditional Sensitvity Analysis

STATE OF THE WORLD	OUTPUT TECH 1	OUTPUT TECH 2	OUTPUT TECH 3	IMPORT	EXPORT	INVEST ×1000$	PROFIT ×1000$
1	860	2235	1605	0	0	1361	44
2	860	1010	1605	0	275	0	-17
3	860	1010	1605	0	575	0	-61
Loss due to uncertainty		37672	% of total sales	4.2 %			
Loss due to incorrect planning		4020	% of total sales	0.4 %			

Table 19. Summary of Results

	EFFECT ON				
VARIABLE INCREASED	UNUSED CAPACITY	INVEST	PROFIT	LOSS DUE TO UN-CERTAINTY	COST OF INCORRECT PLANNING
Import Price	↑	↑	↓	↑	→
Export Price	↓	↓	↑	↓	→
Maximum Imports	↓	↓	↑	↓	↓
Maximum Exports	↓	↑	↑	↓	↓
Uncertainty Level	↑	↑	↓	↑ ↓ *	↑
Uncertainty Distribution (to sides)	↑	→	→	↑ ↓ *	↑
Fixed Cost	→	→	→	↑	↑
Variable Cost	→	→	→	↓	↓
Cost of New Capacity	→	→	→	↑	→
Data Correlation	→	→	→	↑	↑ ↓ *

* increase or decrease, depending on maximun values for imports and exports

7.0 CONCLUSIONS

The situation of the steel industry in Argentina can be modeled on the basis of planning and investment decisions. The model has, as a main feature the uncertainty in demand and the possible choice of three alternative routes to steel production. The results of the present modeling enable a series of conclusions regarding the interpretation of the current crisis of the industry, as well as certain predictions for the future.

In the first place, it is seen that uncertainty in demand is the main reason for the losses experienced by the industry in the recent years. Unutilized capacity results from this uncertainty and given the large fixed cost of steel this results in severe losses in states of the world with low demand. It should be emphasized that if uncertainty is not taken into consideration in the correct way planning decisions result in larger investment and even larger losses when demand is low.

The second important conclusion is that the recent increase in exports is only connected with the occurrence of the low demand state of the world. This was generated by the economic policy carried out by the government in the years 1976-1981, which resulted in a severe crisis not only for the steel industry but for the whole national economy. This policy is currently being reversed and the increase in exports will not continue if the current measures succeed in reactivating the industrial system.

A third conclusion is related to the technological problem. The present analysis suggests that the direct reduction-electric furnace route is the most appropriate for the Argentinian steel industry. This followed arguments of different types. In the first place the availability of local resources in natural gas that could be utilized by this technology. Also, it is more labor intensive, small scale, and therefore appropriate for a developing country. Note that this technology was developed in Mexico. In spite of these facts our planning models show that a labor intensive technology will not necessarily be favored under conditions of uncertainty in demand. This is because the labor intensive technology may be costlier to install. In our model the choice of technology is determined by the product of fixed cost times the coefficient Q, that is new installed capacity per dollar. If uncertainty is not present this will not affect technology choices at all. This choices would be made solely on the basis of resource price to minimize total cost.

Uncertainty thus results in the selection of an inefficient technology.

Regarding the planning methods, the present results show that in most cases the loss incurred because of the use of incorrect sensitivity analysis is similar or larger that that due to the uncertainty itself. In some cases it may be much larger, as shown in Table 12, where the uncertainty level was increased. If this is computed as a percent of the total sales of the industry it is seen that this effect is quite significant, and can reach about 10% of sales.

Finally, the results of the present model adequately describe the existence of unutilized capacity observed in the industry. The most important conclusion of the model is that the traditional method of conducting sensitivity analysis results in significant inefficiency of the reached decisions, involving large losses for the industry.

7.1 HOW SHOULD YOU DO SENSITIVITY ANALYSIS?

This work has presented a mathematical program where uncertainty is modeled explicitly, based on the expected utility theorem. The method generates a solution for optimality for a case with a small number of possible states of nature.

Comparing the results with traditional methods the cost of simplifying the problem in the manner of traditional sensitivity analysis were assesed. Those results also provide insights on the type of data which could be treated by models using the traditional approach. As was discussed in the course of the work, prediction models that include actions which should be taken in the present, are the ones that require the more correct present formalism. The computation of investment programs and similar problems appears to require the present type of modeling if the uncertainty is large. Practical difficulties in doing so may arise when there is a large number of possible states of the world. The present results suggest that the traditional method of sensitivity analysis tends to produce larger investment values. The generality of the present conclusions, of course, remains to be tested in a variety of other problems.

7.2 PROSPECTIVES FOR FURTHER WORK

Regarding the methods for planning under uncertainty, the most relevant continuation of the present work would be to apply computational methods similar to the one presented here to other planning problems, to confirm the present conclusions. Such other problems may include other industries in developing countries or high-risk investment programs, such as research investment planning.

From the point of view of accurate modeling of the steel industry in particular, the next step is necessarity to include the economies of scale, by way of integer programming. This may give then a realistic model for the industry, and it is expected that the agreement with actual patterns will be much improved.

REFERENCES

1. "Technology looks for new directions", J. Aylen, Iron and Steel International, Feb. 1983, p. 41
2. "Acero Argentino", Centro de Industriales Siderurgicos, Buenos Aires, 1983.
3. "The Diffusion of Innovation among Steel Firms", S. Oster, The Bell J. of Economics, 1981, p. 45.
4. "The Iron and Steel Industry", OECD annual reports.
5. "Minimills, Maxiprofits", Time , Jan. 24 1983, p.59.
6. "Steel Import Study", OECD 1968.
7. "The Steel Industry in Brazil", A. Baer, 1967.
8. "Consumption and Production of Steel in Argentina in the Framework of a General Theory", Siderurgia , April 1979, p. 49.
9. "La Siderurgia Argentina", Annual Report, Centro de Industriales Siderurgicos" , 1982-83
10. "Oxygen Steelmaking Today", W. K. V. Gale, Steel Times, Feb. 1983, p. 68.
11. "International Diffusion of Steel Technologies", K. Poznanski, Technology Forecasting and Social Change Vol. 23, 1983, p. 59.
12. "Economics of Direct Reduction", Steel Times, July 1983, p.364.

13. "Economic and Geographic Considerations Affecting the Choice of Route", G. A. Johnston and H. R. Mills,in "Alternative Routes to Steel", London, 1971.

14. Latin American Iron and Steel Institute (ILAFA), Report

15. "The Appropriate Technology Movement and its Literature", M. Hollic, Technology in Society, Vol. 4 , 1982, p. 213.

16. The Iron and Steel Commitee, International Labour Organization, Report, Geneva, 1981.

17. "Technology and Steel Industry Competitiveness", Iron and Steelmaker, Jan. 1981, p. 42.

18. "Third World Research", E. Garfield, Science and Public Policy, Vol. 10, March 1983, p. 113.

19. "Technology and Productive Structure", J. Sabato and M. Mackenzie, Interciencia Vol. 5, 1980, p. 11.

20. "Steel in Developing Countries", H. Herbert, and S. Ruffing, Materials and Society, 1981, p. 76.

21. "Tendering Projects in Developing Countries", A. K. Seth, and P. L. Laha, Iron and Steel International, Feb. 1982, p. 53.

22. "Borrowed Technology in the Iron and Steel Industry, a Comparison between Brazil, India, and Japan", A. Ono, Hitotsubashi Journal of Economics, Feb. 1981, p. 1.

23. "World Trade and Payments", R. E. Caves, and R. W. Jones Little Brown and Company, Toronto, 1980, p. 121.

24. "The Transfer Problem once Again", J. Chipman, in "Trade, Stability and Macroeconomics", G. Horwick and P. Samuelson Editors, 1974.

25. " Argentina in Prospective", Business International Corporation, 1978.

26. "Capacidades Maximas Reales de la Industria Siderurgica ", Instituto Argentino de Siderurgia, Buenos Aires, 1984.

27. "Cambios en el Liderazgo Industrial Argentino en el Periodo Martinez de Hoz", J. Schvarzer, Desarrollo Economico, Vol. 23, 1983, p. 397.

28. "La Crisis Financiera Argentina", R. B. Fernandez, Desarrollo Economico, Vol. 23, 1983, p. 89.

29. "Exposition of a New Theory on the Measurement of Risk", D. Bernoulli, English translation by Louise Sommer, Econometrica, 22, 23-26, 1954.

30. "Programming under Uncertainty", S.E.A. Elmaghraby, PhD Thesis, Cornell University, 1958

31. "The Theory of Games and Economic Behavior", J. Von Neumann and O. Morgenstern, Princeton University Press, 3rd Ed., 1953

32. "Statistical Decision Functions which Minimize the Maximum Risk", A. Wald, Ann. Math. Stat., Vol. 46, 1945.

33. "How should you do Sensitivity Analysis?", J. Cremer, Caress Working Paper #80-02.

Given below is the listing of the program 'Acero' that was used for the cost minimization under the different models for sensitivity analysis.

```
C       IN THIS PROGRAM THE COUNTRY'S DEMAND  HAS TO BE MET.
C       MINIMIZE COSTS  FOR STEEL INDUSTRY WITH 3 POSSIBLE
C       TECHNOLOGICAL PROCESSES AND THREE POSSIBLE STATES OF
C       THE WORLD
        DIMENSION P(3),D(3), VK(3),CAPLD(3),Q(3),
1       CMANT(3),VC(3),FC(3)
        DIMENSION A(20,18),B(20),C(18),AXIM(3),
1       E(3),PSOL(18),PRI(3)
        DIMENSION DX1(10),RW1(458),IW1(58)
        DIMENSION A1(8,8),B1(8),C1(8),X1(8),X(3,3)
        DIMENSION DSOL(20),RW(458),IW(58),XIMP(3),XEMP(3)
        DIMENSION DX2(8),RW2(458),IW2(58)
        DIMENSION A2(8,8),B2(8),C2(8),X2(8)
        DIMENSION DX3(8),RW3(458),IW3(58)
        DIMENSION A3(8,8),B3(8),C3(8),X3(8)
        CALL ERRSET (208,256,-1)
        READ(5,*)  (P(I), D(I), PRI(I), I=1,3)
        READ(5,*)  (CAPLD(I), Q(I) ,I=1,3)
        READ(5,*)  (FC(I), VC(I), I=1,3)
        READ(5,*)  (AXIM (I),I=1,3)
        READ(5,*) PRIMP, PREXP
C      CALCULATE FIXED COST ON INSTALLED CAPACITY
        CORR = 0
        DO 1123 I=1,3
        CORR = CORR + CAPLD(I)*FC(I)
 1123   CONTINUE
         IA=20
         N=18
         M1=15
         M2=3
C       FORM B, RIGHT HAND SIDE OF INEQUALITIES
        DO 100 I=1,3
        B(3*(I-1)+1)=CAPLD(I)
        B(3*(I-1)+2)=CAPLD(I)
        B(3*(I-1)+3)=CAPLD(I)
        B(15+I)=D(I)
        B(9+I)=AXIM(I)
```

```
      B(12+I)=0
      B(19)=0
      B(20)=0
C     FORM MATRIX A OF THE COEFFICIENTS IN INEQUALITIES
C     UNKNOWNS ARE X(1,IT),X(2,IT)....VK(IS), XIMP(IS),
C     XEMP(IS) WHERE IT REFERS TO TECH AND IS TO STATE OF
C     WORLD. VK INVESTMENT
C     FIRST ALL STATES OF WORLD, THEN TECH
 100  CONTINUE
      DO 200 I=1,20
      DO 200 J=1,18
      A(I,J) =0
 200  CONTINUE
      ICOUNT =0
      DO 300 I=1,3
      DO 300 J=1,3
      ICOUNT = ICOUNT +1
      A(ICOUNT,3*(I-1)+J)=1.
      A(ICOUNT,9+I)=-Q(I)
 250  CONTINUE
      A(15+I,3*(J-1)+I) = 1.
      A(15+I,12+I) = 1.
      A(15+I,15+I) = -1.
      A(9+I,12+I) = 1.
      A(12+I,15+I) =-1.
C     COEFFICIENT FOR THE PROFITS FUNCTION TO BE MAXIMIZED
      C(3*(I-1)+J)=P(I)*(PRI(I)-VC(I))
      C(9+I)=-Q(I) *FC(I)
      C(12+I) =(-PRIMP +PRI(I))*P(I)
      C(15+I) =(PREXP -PRI(I))*P(I)
 300  CONTINUE
      CALL ZX3LP(A,IA,B,C,N,M1,M2,S,PSOL,DSOL,RW,IW,IER)
      DO 400 I=1,3
      X(I,1)=PSOL(I)
      X(I,2)=PSOL(3+I)
      X(I,3)=PSOL(6+I)
      WRITE (5,1000) I,X(I,1)
      WRITE (5,1100) I,X(I,2)
      WRITE (5,1200) I,X(I,3)
      WRITE (5,2000) I,PSOL(9+I)
      WRITE (5,2100) I,PSOL(12+I)
      WRITE (5,2200) I,PSOL(15+I)
 400  CONTINUE
      S =S - CORR
      WRITE (5,3000) S
      WRITE (5,4000) IER
 1000 FORMAT ('OUTPUT IN TECH 1 STATE OF THE WORLD',I2,
     : F12.2)
 1010 FORMAT ('OUTPUT IN STATE OF THE WORLD 1 TECH',I2,
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     :   F12.2)
 1020    FORMAT ('OUTPUT IN STATE OF THE WORLD 2 TECH',I2,
     :   F12.2)
 1030    FORMAT ('OUTPUT IN STATE OF THE WORLD 3 TECH',I2,
     :   F12.2)
 1100    FORMAT ('OUTPUT IN TECH 2 STATE OF THE WORLD',I2,
     :   F12.2)
 1200    FORMAT ('OUTPUT IN TECH 3 STATE OF THE WORLD',I2,
     :   F12.2)
 2000    FORMAT ('INVESTMENT IN TECH',I2,F12.2)
 2100    FORMAT ('IMPORT IN STATE OF WORLD',I2,F12.2)
 2200    FORMAT ('EXPORT IN STATE OF WORLD',I2,F12.2)
 2110    FORMAT ('IMPORT IN STATE OF WORLD 1',F12.2)
 2210    FORMAT ('EXPORT IN STATE OF WORLD 1',F12.2)
 2120    FORMAT ('IMPORT IN STATE OF WORLD 2',F12.2)
 2220    FORMAT ('EXPORT IN STATE OF WORLD 2',F12.2)
 2130    FORMAT ('IMPORT IN STATE OF WORLD 3',F12.2)
 2230    FORMAT ('EXPORT IN STATE OF WORLD 3',F12.2)
 3000    FORMAT ('EXPECTED PROFITS ARE',F12.2)
 4000    FORMAT ('ERROR CODE IS ',I4///)
C        DO 600 I=1,20
C        DO 600 J=1,18
C        WRITE (5,5000) I,J,A(I,J)
 600     CONTINUE
C        WRITE (5,*) (B(I),I=1,20)
C        WRITE (5,*) (C(I),I=1,18)
 5000    FORMAT (I2,',',I2,'=',F4.1)
C        CALCULATE OPTIMUM INVESTMENT IN THE DIFFERENT STATES
C        OF WORLD
          IA1= 8
          N1=8
          M11=5
          M21=1
C        FORM B1, RIGHT HAND SIDE OF INEQUALITIES
         DO 110 I=1,3
         B1(I)=CAPLD(I)
 110    CONTINUE
         B1(6) =D(1)
         B1(4)=AXIM(1)
         B1(5)=0
         B1(7)=0
         B1(8)=0
C        FORM MATRIX A1 OF THE COEFFICIENTS IN INEQUALITIES
         DO 210 I=1,8
         DO 210 J=1,8
         A1(I,J) =0
 210     CONTINUE
         DO 310 I=1,3
         A1(I,I)=1.
```

```
      A1(I,3+I)=-Q(I)
 251  CONTINUE
      A1(6,1) = 1.
      A1(6,2) = 1.
      A1(6,3) = 1.
      A1(6,7) = 1.
      A1(6,8) = -1.
      A1(4,7) = 1.
      A1(5,8) =-1.
C     COEFFICIENT FOR THE PROFITS FUNCTION TO BE MAXIMIZED
      C1(I)=(PRI(1)-VC(I))
      C1(3+I)=-Q(I) *FC(I)
      C1(7) = -PRIMP +PRI(1)
      C1(8) = PREXP -PRI(1)
  310 CONTINUE
      CALL ZX3LP(A1,IA1,B1,C1,N1,M11,M21,S1,X1,DX1,RW1,
     : IW1,IER1)
      DO 410 I=1,3
      WRITE (5,1010) I,X1(I)
      WRITE (5,2000) I,X1(3+I)
 410  CONTINUE
      WRITE (5,2110) X1(7)
      WRITE (5,2210) X1(6)
      S1=S1- CORR
      WRITE (5,3000) S1
      WRITE (5,4000) IER1
       IA2=8
       N2=8
       M12=5
       M22=1
C     FORM B2, RIGHT HAND SIDE OF INEQUALITIES
      DO 120 I=1,3
      B2(I)=CAPLD(I)
      B2(6) =D(2)
 120  CONTINUE
      B2(4)=AXIM(2)
      B2(5)=0
      B2(7)=0
      B2(8)=0
C     FORM MATRIX A1 OF THE COEFFICIENTS IN INEQUALITIES
      DO 220 I=1,8
      DO 220 J=1,8
      A2(I,J) =0
 220  CONTINUE
      DO 320 I=1,3
      A2(I,I)=1.
      A2(I,3+I)=-Q(I)
 252  CONTINUE
      A2(6,1) = 1.
```

```
      A2(6,2) = 1.
      A2(6,3) = 1.
      A2(6,7) = 1.
      A2(6,8) = -1.
      A2(4,7) = 1.
      A2(5,8) =-1.
C     COEFFICIENT FOR THE PROFITS FUNCTION TO BE MAXIMIZED
      C2(I)=(PRI(2)-VC(I))
      C2(3+I)=-Q(I) *FC(I)
      C2(7) = -PRIMP +PRI(2)
      C2(8) = PREXP -PRI(2)
  320 CONTINUE
      CALL ZX3LP(A2,IA2,B2,C2,N2,M12,M22,S2,X2,DX2,RW2,
     : IW2,IER2)
      DO 420 I=1,3
      WRITE (5,1020) I,X2(I)
      WRITE (5,2000) I,X2(3+I)
 420  CONTINUE
      WRITE (5,2120) X2(7)
      WRITE (5,2220) X2(8)
      S2=S2- CORR
      WRITE (5,3000) S2
      WRITE (5,4000) IER2
       IA3=8
       N3=8
       M13=5
       M23=1
C     FORM B3, RIGHT HAND SIDE OF INEQUALITIES
      DO 130 I=1,3
      B3(I)=CAPLD(I)
      B3(6) =D(3)
 130  CONTINUE
      B3(4)=AXIM(3)
      B3(5)=0
      B3(7)=0
      B3(8)=0
C     FORM MATRIX A1 OF THE COEFFICIENTS IN INEQUALITIES
      DO 230 I=1,8
      DO 230 J=1,8
      A3(I,J) =0
 230  CONTINUE
      DO 330 I=1,3
      A3(I,I)=1.
      A3(I,3+I)=-Q(I)
 253  CONTINUE
      A3(6,1) = 1.
      A3(6,2) = 1.
      A3(6,3) = 1.
      A3(6,7) = 1.
```

```
      A3(6,8) = -1.
      A3(4,7) = 1.
      A3(5,8) =-1.
C     COEFFICIENT FOR THE PROFITS FUNCTION TO BE MAXIMIZED
      C3(I)=(PRI(3)-VC(I))
      C3(3+I)=-Q(I) *FC(I)
      C3(7) = -PRIMP +PRI(3)
      C3(8) = PREXP -PRI(3)
  330 CONTINUE
      CALL ZX3LP(A3,IA3,B3,C3,N3,M13,M23,S3,X3,DX3,RW3,
     : IW3,IER3)
      DO 430 I=1,3
      WRITE (5,1030) I,X3(I)
      WRITE (5,2000) I,X3(3+I)
 430  CONTINUE
      WRITE (5,2130) X3(7)
      WRITE (5,2230) X3(8)
      S3=S3- CORR
      WRITE (5,3000) S3
      WRITE (5,4000) IER3
      STOP
      END
```

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