CHAPTER 3

3.1 INTRODUCTION

The previous chapter had given the basic mathematical background for the investment-planning model developed in this thesis. The present chapter contains the details of this model. The model, to be referred to as M1, can be used for planning for investment for a sub-sector of the Indian steel industry, provided that there is an exogenously specified time-profile of demand to be met for that sub-sector. The model highlights the choice between domestic investment and imports as well as the choice within domestic investment of investing in existing plants and investing in building new plants.

3.2 DEVELOPMENT OF THE FRAMEWORK FOR M1

3.2.1 MOTIVATION AND BACKGROUND

Steel products, if categorised in terms of quality, shape and size, run into hundreds of items. However, the saleable steel items in India can be broadly classified into flat products and non-flat products. Flat products include plates, hot rolled & cold rolled coils, sheets, etc. while structurals, bars & rods and railway materials comprise the non-flat products. Flat products account for around 40 % of the finished steel consumption in India, the rest being accounted for by non-flats. There is an economy-wide demand for all these products in India, which can be met from the following two sources:

(i) imports and

(ii) domestic production.

The first source has so far been limited by the allocation of the available foreign exchange by the Government while the second is limited by the existing domestic capacity. Given that an exogenously stipulated time-profile of demand is to be met in the future, it is useful to plan for investment in the steel industry in such a way that the economy follows the optimum mix of domestic investment and imports. Assuming that no restrictions are imposed on the availability of foreign exchange, the investment planning problem deals mainly with two questions:

(i) what is the extent by which domestic capacity should be expanded; or, in other words, what is the optimal level of investment for each time-period of the planning horizon ?

(ii) what is the optimal level of imports for each time-period of the planning horizon?

In the context of the Indian steel industry, the domestic capacity for producing steel is shared by main producers and the secondary sector[1]. Mini steel plants, comprising the bulk of the secondary sector, have contributed only around 20 % to 22 % of the output of the saleable steel in India in the years 1984-85 to 1990-91 although in the very recent years their share has increased considerably. Again, the main producers consist of a few large steel plants which maintain a regular record of production, profitability and other statistics. So data for these plants are available in a systematic manner. But the unorganised secondary sector contains a large number of small production units. Accurate data for this sector can be obtained only with a full-scale survey, which is beyond the scope of the present thesis.

In view of the fact that the bulk of the steel output in India is produced by the main producers and that paucity of reliable data will hamper research on the secondary sector, it has been decided to develop M1 to plan for investment for the main producers alone.

The scope of this model has been limited in yet another way. In an integrated steel plant the shops included inthe main material-flow up to the Steel Melting Shop (along with the auxiliary service units) belong to the `primary area', while the rest of the shops for the main material-flow belong to the `rolling mills' area[2]. It is widely held that the low capacity-utilisation in the integrated steel plants originate in the primary area. Some evidence may be cited in this context. The Steel Sector Strategy Report brought out by the World Bank in 1987 focusses on the high coke rate in India as compared to the coke rate in Japan. This is shown in Table 4.8 of the report which is reproduced below in Table 1.

TABLE 1
COMPARATIVE COKE RATES : SAIL, TISCO AND JAPAN, 1983-84
(Tonnes coke consumed per tonne of hot metal produced)

PLANT	COKE RATE
Bhilai	0.82
Bokaro	0.73
Durgapur	0.94
Rourkela	0.89
IISCO	1.05
TISCO	0.78
All-India weighted average	0.83
Estmated available norm for India	0.70
Japan	0.45

Source: World Bank (1987)

As Table 1A below shows, although the coke rate has improved for most of the Indian plants over time, the present coke rates still far exceed that achieved by Japan in 1983-84.

Table 1A: COMPARATIVE COKE RATES : SAIL PLANTS & TISCO
Consumption of coke (dry) per tonne of hot metal
Unit : Kg/T

STEEL PLANT	1986-87	1987-88	1988-89	1989-90	1990-91
Bhilai	709	721	682	692	672
Bokaro	706	679	666	664	708
Durgapur	899	890	856	858	817
Rourkela	792	764	736	725	728
IISCO	1015	991	1023	1017	947
TISCO	757	744	716	714	674

Source: Steel Authority of India Ltd. (1992)

The World bank (1987) report goes on to assert that high coke rates and the deterioration in the quality of raw materials have led to lower Blast Furnace productivity. Quoting this report `To the extent that hot metal availability is thereby reduced, it means also that downstream processes show low levels of capacity utilization because of hot-metal shortage.' The Annual Statistics for a few integrated steel plants show that the capacity utilization in the rolling mills has been fairly low and has often been lower than the capacity utilization in the primary area[3]. The larger excess capacity in rolling mills relative to the primary area indicates that the bottleneck in production lies in the primary area. Therefore it is of more and immediate importance to plan for investment in the primary area.

This consideration has led to the exclusion of the rolling mills from the purview of M1, which concentrates solely on the primary area. It was also felt that since the rolling mills of an integrated steel plant involve a vast and complicated material-flow, connecting several finished products, inclusion of the rolling mills network may only make the investment-planning problem more complicated without adding much insight into the problem. M1 has therefore, been truncated at the continuous-casting stage, so that the final product is crude steel instead of rolled steel products. In simpler terms, the model concentrates on the issue of how best to produce one tonne of crude steel, but not on how best to roll it into finished steel. It may be noted, however, that the time-profile of the demand for crude steel is to be derived from a time-profile of demand for finished steel products by using appropriate yield rates.

3.2.2 INVESTMENT OPTIONS FOR THE MAIN PRODUCERS

The investment-options facing the main producers in India can be broadly classified into three groups:

a) Investment in a greenfield plant;

b) Expansion of capacity in an existing plant;

c) Augmentation of capacity in an existing plant by modernisation.

Regarding (a), it may be noted that an important feature of the production-process of steel can be brought into focus in this context. As has been discussed in Section 1.4.3 of Chapter 1, many of the processes for producing steel, particularly the BF-BOS route, exhibit scale-economies. Both the investment-cost as well as the total cost of setting up a new plant exhibit this feature. So option (a) permits the producers to take advantage of scale-economies in the production of steel.

Regarding option (b), it is well known that an integrated steel plant may often be constructed in two or more stages, building up its capacity in steps. In the Indian context, Bhilai and Bokaro are cases in point where the 2.5 m.t. plants have been expanded to 4 m.t. plants. But it must be noted that, in general, only those plants which have a built-in scope for expansion of capacity since inception, can be expanded easily. It is difficult to expand the capacity of an existing plant unless provision has already been made at the blue-print stage.

Option (c) requires some clarification as well. Many existing integrated steel plants in India have been operating at far below their rated capacities for several years. This has often been due to a decline in the quality of raw materials over time, emergence of infrastructural bottlenecks, etc. The World Bank (1987) report mentions that the washeries attached to the plant were designed to receive coal with an average ash content of 25 % and to produce washed coal of 17 % ash content, whereas the coal delivered to the washeries at present has an average ash content of 23% and varies widely from this average. This factor and the poor quality of iron ore cause the coke rate to increase leading to high costs and reduced blast furnace productivity. Table 2 gives some evidence in this regard.

TABLE 2

ASH IN BLEND COAL, COKE RATE AND BF PRODUCTIVITY

PLANTS	ASH % IN COAL CHARGED (DRY BASIS)		COKE RATE(KG) PER TONNE OF HOT METAL			BF PRODUCTIVITY TONNE/M3 OF WORKING VOLUME /DAY		
	1976-77	1980-81	1976-77	1980-81	1990-91	1976-77	1980-81	1990-91
BSP	18.99	20.1*	792	837	672	1.27	0.88	1.07
RSP	18.91	19.41**	919	875	728	0.73	0.78	0.68-0.76
DSP	20.22	21.96	896	1017	817	0.84	0.60	0.58
BOKARO	19.83	21.81	700	777	708	1.19	0.83	0.85-1.01
IISCO	19.93	21.71	1063	1136	947	0.91	0.65	0.60-0.80
TISCO	18.49	21.23	848	798	674	1.07	0.97	1.23-1.51

Source: Sengupta R.P. (1984).

* Contains a share of 11.5 % of imported coal of improved quality

** Contains a share of 8.8 % imported coal of improved quality

Note: The figures for 1990-91 have been added from Steel Authority of India Ltd. (1992)

It is this drastic change in parameters that has given rise to the concept of `attainable capacity' (attainable under changed parameters) as against that of rated capacity. Sengupta (1984) has used this concept and has shown the discrepancy between rated capacity and attainable capacity for major steel plants. Table 3 shows that the attainable capacities are below the rated capacities for all plants for hot-metal and steel-making (ingot and saleable), except for TISCO.

TABLE 3
RATED CAPACITY AND ATTAINABLE CAPACITY OF INTEGRATED STEEL PLANTS IN INDIA AS IN 1982-83
(THOUSAND T. PER YEAR)

	HOT METAL (IRON) MAKING*		COLD PIG-MAKING FOR SALE		INGOT STEEL		SALEABLE STEEL	
PLANTS	RATED	ATTAIN-ABLE	RATED	ATTAIN-ABLE	RATED	ATTAIN-ABLE	RATED	ATTAI-NABLE
BSP	3600	2793	2176	755$	2500	2334	1965	1890
RSP	1600	1539			1800	1558	1240	1057
DSP	1785	1459	1170	200	1600	1289	1250	1050
BOKARO	3647	2720		640	2500	1955	2051	1530
IISCO	1300	943		85	1000	724	800	570
TISCO	1800	1789			2000	1944	1524	1549

Source: Sengupta (1984).

* Net Metal for BSP and RSP; Gross metal for others.

$ Includes share of intermediate requirement for foundry.

Investment in balancing facilities can be undertaken to improve capacity-utilisation of existing plants in a cost-effective manner to help them achieve their rated capacities. For instance, coal washeries with improved technology can be set up to reduce the ash content of washed coal. Investment for modernisation purposes can thus improve capacity-utilisation. The following section shows how these investment-options are considered in the formulation of M1.

3.3 DESCRIPTION OF M1

3.3.1 AN OVERVIEW

This model aims at providing an optimal programme of investment (in respect of amount as well as phasing) for the integrated steel plants of the Indian steel industry, such that an exogenously stipulated time-profile of demand for steel is met at minimum cost. The model deals with actual investment-options as are faced by the existing steel plants, but does not deal with the selection of investment-projects for each shop within an integrated steel plant. So, in a sense, a steel plant is the production unit of this model. It may be noted that a given demand-profile must be met, irrespective of the output price. So the optinisation exercise here is one of cost-minimisation rather than one of profit-maximisation. Therefore the output price plays no role in the optimisation process. Details regarding the various components of the model, such as demand, cost, etc. and the steps of the actual optimisation procedure follow in the next few sections.

3.3.2 DEMAND

Demand for steel is usually projected in terms of finished steel products, which consist of a variety of items. But, as already mentioned, M1 concentrates on the primary area of steelmaking and crude steel is taken as the final output of the steel making process. So the projected demand for finished steel has been converted to an equivalent demand for crude steel using suitable yield rates for the rolling mills. In this context, the steps followed for estimating demand in the empirical exercise based on M1 (which will be discussed in detail in Chapter 4) may be mentioned in brief.

(i) Demand estimates for finished steel are obtained from the report of the Working Group for the Eighth Plan (in terms of flat and non-flat saleable mild steel products) for certain years (say, T_2, T_3 and T_4) as specified in the planning horizon of the Eighth Plan.

(ii) The above demand-estimates are converted to their crude steel equivalent by the use of suitable yield rates for the flat and non-flat products from crude steel.

(iii) The crude steel equivalent of the current annual consumption of finished steel is used as a proxy for demand in 1989-90 (say, T_1). Using this figure, and the estimated demand as obtained in (ii) for T_2, T_3 and T_4, the growth rates of demand are estimated for periods between (a) T_1 and T_2 (b) T_2 and T_3 and (c) T_3 and T_4. (iv) Suppose the entire planning horizon till T is beyond T_4. Then the above rates of growth are used for constructing the time-profile of demand for each year of the entire planning horizon as required by M1, with the help of of the process of interpolation from T_1 to T_4 and extrapolation for the years beyond T_4 to T.

Let the time-profile of demand (in terms of crude steel) for the entire economy as obtained following the steps mentioned above,be d_1, d_2,.....,d_T for the time-periods 1,2,...,T.

Given the demand-estimates by the Working Group, which are found to be increasing over time, and the method of obtaining growth rates as outlined above, the d_t's are found to be non-decreasing over time. The time-periods are not consecutive years, but have a constant gap of several years between them. This gap is taken as equal to the longest gestation lag among all the investment-projects available. The present value of the cost of investment-projects will be minimum if the investment-projects with shorter gestation periods are to start later than the projects with the longer gestation lags, such that all projects start producing output at the same time. Therefore, the present value of the costs of the investment-projects are calculated in such a way that the construction of some projects are staggered. So all investment-options produce outputs at each successive demand-stage 2.3....,T except at the initial stage.

Investment and/or import is required to meet the gap between demand and domestic availability (not including imports) of steel. The current availability of steel from the main producers is expected to continue till period T. given that no fresh investment takes place and given that replacement investment continues to take place at a rate sufficient for maintaining the current level of production. An estimate of this supply was obtained from the Plant Detailed Project Reports (DPRs) and the Working group Report for the 8th Plan. Suppose this supply is s_t^A for the tth period. The secondary sector is expected to grow in the future by undertaking new investment or by increasing capacity utilisation (it may be recalled that this sector is outside the scope of M1). Let the supply from the secondary sector be s_t^B for the tth time-period. The source of this estimate is the Working Group Report for the eigth plan. Then

$$D_t = d_t - s_t^A - s_t^B \quad \text{for } t=1,2,...,T$$

will give the additional demand (over Base Availability) facing the main producers which must be met through domestic investment and/or imports. The demand-series D_t is assumed to be monotonically non-decreasing. Before the advent of the new liberal economic policies in July, 1991, which include delicensing of the steel industry and decontrol of the steel prices & distribution, the secondary sector was not expected to increase its supply in a big way in the future because of licensing and other forms of control. This is the basis for the assumption of non-decreasing D_t's mentioned above. It may be noted that the model M1 was formulated in the pre-liberalisation period. Another assumption implicit here is that the additional demand D_T in the terminal period continues to remain at that level indefinitely in the future. This is so because otherwise the investment would have to be planned in such a way that the projects have their lifetimes ending at the terminal period (since output has no use beyond that period).

Because of indivisibilities and existence of scale-economies, there may be excess capacity in the domestic plants. This capacity could be utilised and the output exported to the international market to earn revenue which would lower the value of the objective function (since that would be a negative cost). But for the purpose of simplifying the model, export possibilities have been ignored.

3.3.3 CAPACITY-GRID AND INVESTMENT

As already mentioned, the three options for domestic investment are:

a) Investment in a greenfield plant;

b) Expansion of capacity in an existing plant;

c) Augmentation of capacity in an existing plant by modernisation.

Suppose a new integrated steel plant can be constructed at the following levels of capacity of crude steel : $z_1, z_2, \ldots, z_p$.

The investment-options for setting up a new plant involve primarily two kinds of choice:

(i) choice of technology and
(ii) choice of scale for a given technology.

The crude steel capacity levels of $z_1, z_2, \ldots, z_p$ include all possible options of technology and scale.

Regarding investment-options (b) and (c), let the number of ways in which the existing plants in the economy can be expanded be m and the associated incremental capacity-levels be $y_1, y_2, \ldots, y_m$. While p depends only on technology, m and n are crucially dependent on the initial number and type of plants in the economy. It may be noted that the capacity-levels are 'incremental' in the sense that they represent the additions that are possible to existing capacity-levels. Similarly, let the number of ways by which the existing capacity-levels of the existing plants can be augmented through modernisation be n. Let the associated `incremental' capacity-levels be $x_1, x_2, \ldots, x_n$.

Considering the greenfield plants and all the existing plants in the economy, the economy can achieve a certain number of (incremental)capacity-levels after investment. [The incremental capacity-levels will hereinafter be referred to as capacity-levels.]

Considering all the investment-options, k, under (a), (b) and (c), we have k=p+m+n

Then the number of possible levels of capacity obtained by combinations of these k options will be 2^k. This is because, for each investment-option, there are two possibilities:

(i) Its existence
(ii) Its absence

Combining all the options the number of possible combinations will be

$$= (1+1)(1+1)\ldots\ldots k \text{ times}$$
$$= 2^k = N, \text{ say}$$

The above includes the possibility of absence of all options, ie. zero investment.

Let these capacity-levels arranged in an ascending order of magnitude be

$$Q_1, Q_2, \ldots\ldots, Q_N.$$

It may be reiterated that each Q_i (i=1,2,....,N) actually represents a combination of the investment-options available to the economy. As already mentioned, there are 1,2,...,k options available . Let the corresponding capacity-levels be $\bar{Q}_1, \bar{Q}_2, \ldots, \bar{Q}_k$. The capacity-grid is then formed by combining the above $\bar{Q}_i$'s. Thus Q_2 may be a combination of $\bar{Q}_1$ and $\bar{Q}_2$ ($Q_2 = \bar{Q}_1 + \bar{Q}_2$) or Q_5 may be a combination of $\bar{Q}_1, \bar{Q}_2, \bar{Q}_3$ ($Q_5 = \bar{Q}_1 + \bar{Q}_2 + \bar{Q}_3$) and so on.

Adding a time-subscript to each Q_i, i=1,2,...,N, let Q_{it} refer to the ith capacity in the tth period. Before the optimal investment-path is arrived at, the same set of capacity-levels is available to the investment-planner in each period t, i.e. the economy can be at any of the capacity-levels

$$Q_{1t}, Q_{2t}, \ldots\ldots, Q_{Nt}, \text{ for all } t=1,2,\ldots,T.$$

As mentioned before, the additional demand (over Base Availability in each period) faced by the economy in each period t is D_t, t=1,2,...,T.

The following matrix shows the set of Q_{it}'s along with the additional demand for each period:

$$
\begin{array}{llll}
D_1 & D_2 & & D_{T-1} & D_T \\
Q_{11} & Q_{12} & \cdots\cdots\cdots & Q_{1,T-1} & Q_{1T} \\
Q_{21} & Q_{22} & \cdots\cdots\cdots & Q_{2,T-1} & Q_{2T} \\
\cdot & \cdot & & \cdot & \cdot \\
\cdot & \cdot & & \cdot & \cdot \\
Q_{N1} & Q_{N2} & \cdots\cdots\cdots & Q_{N,T-1} & Q_{NT}
\end{array}
$$

In period t=1, the additional demand is D_1 and the possible capacity-levels are $Q_{11}, Q_{12}, \ldots, Q_{N1}$. Similarly the capacity-levels for the periods 2,3,...,T are also given in the matrix.

Since investment is nothing but addition to existing capacity, in the above framework it may be given by the difference in the levels of capacity at two different points on the capacity-grid at two different periods. Considering a transition from Q_i in period t to Q_j in period t+1, the investment in period t is given by

$$I_t = (Q_{j,t+1} - Q_{i,t})$$

It may be useful here to elaborate on the exact nature of the variable I_t. This variable represents a set of options for investment leading to different increments in capacity, i.e. each option transforms the state variable Q_t in a different way. For instance, suppose two investment-options are available:

a) Build a new plant of capacity 2.0 mtpa(million tonnes per annum);

b) Expand an existing plant by 1.0 mtpa.

The total number of possible investment-decisions are then the following:

(i) No investment takes place,
(ii) Option (a) is chosen,
(iii) Option (b) is chosen,
(iv) Both options (a) and (b) are chosen.

Then the feasible values for Q_t are

0, 1.0, 2.0 and 3.0 mtpa.

This set of incremental capacity-levels, or this capacity-grid, as it will be referred to from now on, will be the same for each period t, as already mentioned. But given any capacity-level at any time-period t, it may not be possible to move to all the capacity-levels in period t+1. This is because, while it may be possible to build several new plants (if there is no fund-constraint) over consecutive time-periods, it may not be possible to expand the capacity of an existing plant more than once. In the light of the example given above, suppose that the optimal investment-path chosen is option (b) in one particular period. Then the options 1.0 mtpa and 3.0 mtpa i.e. options (iii) and (iv) will not be available for selection in the subsequent periods. This is because once an existing plant has been expanded, it cannot be expanded again. So movements along the capacity-grid will be restricted by such considerations.

The other restriction on investment, i.e.

$$I_t = (Q_{j,t+1} - Q_{i,t}) \geqslant 0$$

has already been mentioned. It may be noted that I_t, although measured in the same units as capacity, also represents a set of combination of investment-options. Referring back to the illustration given above for the capacity-grid, if $Q_{j,t+1}$ refers to Q_5 and $Q_{i,t}$ refers to Q_2, then

$$I_t = \bar{Q}_1 + \bar{Q}_2 + \bar{Q}_3 - (\bar{Q}_1 + \bar{Q}_2)$$

$$= \bar{Q}_3$$

So investment here refers to undertaking the third investment-option out of the k options available to the economy.

Since demand is assumed to be non-decreasing over time, no disinvestment is allowed,

$$I_t \geqslant 0$$

This implies that for each pair $(Q_{j,t+1}, Q_{i,t})$, where transition takes place,

$$j \geqq i.$$

3.3.4 COSTS

Any investment-project has two kinds of cost associated with it:

(i) Capital cost and
(ii) Operating cost or manufacturing expenses.

The first type of cost is the cost of clearing site, setting up plant and equipment, etc. and involves the cost of getting the productive unit (i.e. a steel plant) ready to yield the additional output resulting from this investment. The additional output is usually obtained a few years after initiating investment and this interim period is referred to as the `gestation lag' of the project. Capital cost is incurred during this gestation period. After it is over, additional output (as a result of this investment) comes forth annually for a long period which is termed the `lifetime' of the project. The more durable a project, the longer its lifetime.

Given the fixed plants and equipments, certain costs must be incurred annually which include costs of raw materials, labour, fuel, etc. Such costs are called manufacturing expenses or operating costs. So, for each investment-option there is a time-profile for capital costs and a time-profile for manufacturing expenses.

In the framework of the present model, the capital costs are related to the level of investment, I_t, and the manufacturing expenses are related to the level of production, say, q_t, for the tth period. It is clear that the capacity-level Q_t (dropping the sub-script i for the ith combination) need not be equal to the production-level q_t, because capacity may not be fully utilised.

A third type of cost considered in M1 is import cost, related to the level of imports taking place in each time-period. All the above costs will be discussed in detail in the following sections.

3.3.4.1 UNIT CAPITAL COSTS AND UNIT MANUFACTURING EXPENSES

As mentioned in Section 3.3.4, each investment-option has capital costs and manufacturing expenses associated with it. All such costs are evaluated at constant prices. Suppose the present value of capital costs and manufacturing expenses of all the domestic investment-options are

$c^*_1, c^*_2, \ldots, c^*_k$

and $o^*_1, o^*_2, \ldots, o^*_k$ respectively.

Each investment-option has its lifetime over which output is obtained annually. Suppose the jth option has the following stream of output operating at maximum capacity for successive years, after it starts producing at the lth year and continues to produce till year L :

$q_{jl}, q_{j,l+1}, \ldots, q_{jL}$

Applying the annual rate of discount[4], say, i, to the stream of quantities of output over the years, the present value of the output over the lifetime of the jth investment-project is obtained:

$$\frac{q_{j1}}{(1+i)^{1}} + \frac{q_{j,1+1}}{(1+i)^{1+1}} + \dots\dots\dots + \frac{q_{jL}}{(1+i)^{L}} = \bar{q}_j \text{ , say.}$$

Let $\dfrac{c_j^*}{\bar{q}_j} = c_j$ and $\dfrac{o_j^*}{\bar{q}_j} = o_j$ be the unit costs of the jth project. Similar unit costs are obtained for all the domestic investment-choices. Then the relevant unit costs are $c_1, c_2, \dots, c_k$ and $o_1, o_2, \dots, o_k$ of the k investment-options.

3.3.5 PROCEDURE FOR OPTIMISATION OF M1 IN DISCRETE FORM

The investment-planning problem discussed in sections 3.3.1-3.3.4 is solved by using the Principle of Optimality that underlies the solution procedure for all dynamic programming problems. The Principle of Optimality and its applications have been discussed in Section 2.4 of Chapter 2. As for the continuous problem, here also the dynamic optimisation exercise is carried out for a total number of M^{T-1} times, each exercise associated with a particular combination of imports at different demand stages. The solution procedure for each such exercise will be outlined below in Section 3.3.5.1.

3.3.5.1

The Principle of Optimality states that given an optimal solution for a multi-stage decision-making problem, the solution for each stage must constitute an optimal solution for the corresponding sub-problem, provided the boundary values of the state variables at that stage are consistent with the over-all optimal plan.

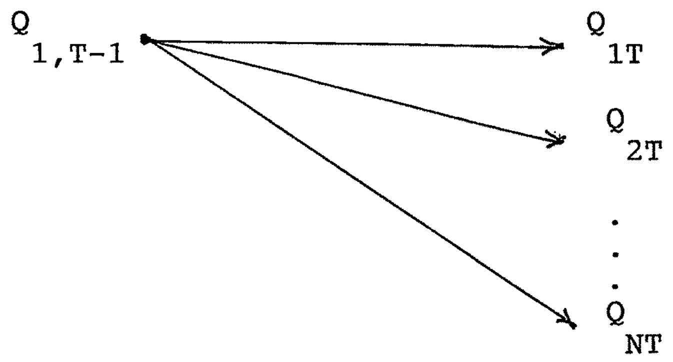
The matrix for the demand-vector and the capacity-grid as given in Section 3.3.3 may be recalled.

$$
\begin{array}{lllll}
D_1 & D_2 & \ldots\ldots\ldots\ldots\ldots & D_{T-1} & D_T \\
Q_{11} & Q_{12} & \ldots\ldots\ldots\ldots\ldots & Q_{1,T-1} & Q_{1T} \\
Q_{21} & Q_{22} & \ldots\ldots\ldots\ldots\ldots & Q_{2,T-1} & Q_{2T} \\
\cdot & \cdot & & \cdot & \cdot \\
\cdot & \cdot & & \cdot & \cdot \\
Q_{N1} & Q_{N2} & \ldots\ldots\ldots\ldots\ldots & Q_{N,T-1} & Q_{NT}
\end{array}
$$

Since no investment takes place in the terminal period (stage T), following the method of backward recursion (discussed in Section 2.4 of Chapter 2) the transitions from stage T-1 to stage T are considered. The economy moves fromgiven capacity-levels in period T-1 to other capacity-levels in period T by domestic investment and the aim is to fulfil D_T by domestic production and/or imports.

Consider the starting capacity-level $Q_{1,T-1}$ in the capacity-grid for the T-1st period.

The possible transitions are to $Q_{1T}, Q_{2T}, \ldots . Q_{NT}$.



It may be reiterated that only those transitions are feasible where D_T is met through domestic production and/or imports and where investment is non-negative, i.e.

$$I_{T-1} = (Q_{j,T} - Q_{i,T-1}) \text{ for } i,j=1,2,\ldots,N$$

$$\geq 0.$$

Since the import-level is given for each optimisation exercise, it may be netted out from the target demand.

Let $DD_T = D_T - m_T$

Now the following must be checked :

Is $DD_T < Q_{1,T-1}$?

If so, then the existing capacity is enough for meeting the future demand, implying that the optimal investment-level is zero. Thus only operating costs will be incurred to the extent of meeting DD_T^5. However, if $Q_{1,T-1} = Q_{1,T} < DD_T$, then investment is required. Then the next feasible transition to Q_{2T} is considered. (It may be noted that here also Q_{2T} is compared with DD_T and if found to be smaller, then transition to Q_{3T} is considered and so on till Q_{NT}.)

In case $DD_T < Q_{2T}$, then

investment is equal to $(Q_{2T} - Q_{1,T-1})$.

This investment actually represents a combination of investment-options, each of which has a unit capital cost as well as a unit manufacturing expense (in terms of present value). For the purpose of illustration, suppose the combination is AB (i.e. comprising investment in option A with capacity A and investment in option B with capacity B respectively) where the unit capital costs are c_A, c_B and unit manufacturing expenses are o_A, o_B.

Then for investment AB, the fixed cost is

$$=Ac_A + Bc_B$$

For the purpose of calculating manufacturing expenses, o_A and o_B are compared. The capacity of the investment-option with the lower unit manufacturing expenses is exhausted first. eg.

if $o_A < o_B$, then

compare DD_T and A.

If $A \geq DD_T$, then

manufacturing expenses of the transition is[6]

$=DD_T.o_A$

The discussion in Section 2.4 of Chapter 2 regarding the treatment of imports may be recalled here. Let m_T be the given level of import at stage T. If p_m is the unit import cost (at constant prices) and s the number of years between two successive demand stages, then total cost of transition is

$$= (Ac_A+Bc_B) + \frac{(p_m m_T)}{(1+i)^s} + \frac{o_A DD_T}{(1+i)^s}$$

The cost of transition from $Q_{1,T-1}$ to each capacity-level $Q_{3T}, Q_{4T}, \ldots, Q_{NT}$ in period T is thus calculated and the minimum cost among all these is noted, along with the associated capacity-levels.

The above exercise is repeated for each starting-capacity in period T-1,namely, $Q_{2,T-1}, Q_{3,T-1}, \ldots, Q_{N,T-1}$. Thus for each capacity-level $Q_{j,T-1}$, j=1,2,...,N in period T-1 an associated minimum cost of transition to period T is obtained along with the associated least-cost capacity-level in period T. Let this minimum cost be X_j ,j=1,2,...,N.

Going back one step to stage T-2, consider the starting capacity-levels $Q_{i,T-2}$ (i=1,2,...,N) in the capcity-grid, one by one. Suppose the cost of transition from $Q_{i,T-2}$ to $Q_{j,T-1}$ is c_{ij}. Now, associated with $Q_{j,T-1}$, there is also a least-cost available for transition from period T-1 to period T, namely X_j. Then the cost associated with transition from $Q_{i,T-2}$ to period T via $Q_{j,T-1}$ is

$$Y_{ij} = c_{ij} + \frac{X_j}{(1+i)^s}$$

For the ith starting capacity-level $Q_{i,T-2}$, all such costs are noted for all possible j (i.e. j=1,2,...,N) and the minimum is noted. Let this cost be Y_i.

Then Y_i is obtained for all i=1,2,...,N, i.e. for all possible starting capacity-levels in period T-2, least-cost transitions to period T are known.

Moving back now to period T-3, the above process is repeated, only now Y_j takes the place of X_j. So again a series of minimum costs, say, Z_i, i=1,2,...,N are obtained along with associated transitions for each starting capacity-level in the capacity-grid in period T-3 for transition to period T.

Moving back in time from period to period in the way described above, the initial stage is reached. Then for all possible initial capacity-levels the associated optimal investment-paths to stage T along with the optimal costs are known. Since the initial capacity is known, the particular optimal path associated with it is also known, along with the optimal cost. Thus the backward recursion method of solving a dynamic programming problem is applied in this particular investment-planning problem where the initial value of the state variable (here capacity) is given.

3.3.5.2

Proceeding in the above manner, M^{T-1} optimal investment paths and associated least-costs are obtained for different import-combinations.

3.3.5.3

The optimal investment-path mentioned above is optimal for a sequential decision-making problem where two successive decision-making stages are separated by s years. However, the increase in demand is reflected in annual increases in the demand-projections while the capacity, in the present problem, increases with a gap of s years. To the extent the existing capacity falls short of demand in the interim years, the shortfall must be met through import. So for each optimal investment path (corresponding to a particular combination of imports), the annual gap between demand and supply is ascertained for each year, in the interim years falling between two successive demand stages. Imports, taken to be at a maximum permissible limit (in case the annual gap is more than the maximum limit) and as equal to the gap otherwise, are then evaluated at the given unit import cost p_m and suitably discounted. This import cost is then added to the optimal investment-cost (including import cost for T-1 demand stages) already obtained. These costs (M^{T-1} in number) are then compared and the minimum noted. The corresponding investment-path then gives the optimal investment-path and the associated import-combination the optimal import-levels.

3.3.6 A SUMMARY

The chapter started with the background of thedevelopment of the investment-planning model M1. This was followed by a detailed discussion of the various features of M1 and the procedure followed for the optimisation exercise. This model provides the basis for the empirical exercise that is presented in the following chapter.

NOTES FOR CHAPTER 3

1. See Section 1.5 of Chapter 1.
2. See Section 1.4.2 of Chapter 1.
3. See Annexure.
4. The rate of discount used is the social rate of discount, discussed earlier in Chapter 2. In the Indian context, this rate of discount is fixed by the Planning Commission.
5. It may be recalled from Section 3.3.2 that the possibility of exporting the surplus output over and above the additional demand, has been ruled out. If exporting, even `dumping', is allowed, then there could be full capacity utilisation by using the advantages of the export market. Then a separate export revenue function may be set up or exports can have an impact on the objective function via the cost function, as a negative cost item.
6. If, on the other hand, $A < DD_T$, then manufacturing expenses is equal to $AO_A + (DD_T - A)\,O_B$.

A N N E X U R E TO CHAPTER 3

TABLE 1
CAPACITY UTILISATION FOR INGOT STEEL PRODUCTION

PLANT	RATED (INGOT) CAPACITY (THOUSAND TONNES)	CAPACITY UTILISATION (%)		
		1990-91	1991-92	1992-93
BHILAI	4000	87.8	93.6	98.6
DURGAPUR	1600	54.7	54.4	42.3
ROURKELA	1800	69.2	68.6	69.8
BOKARO	4000	70.2	85.4	89.7
IISCO	1000	32.4	36.4	36.3

Source : Steel Authority of India Ltd. (1994)

TABLE 2
PRODUCTIVITY INDICES- BHILAI STEEL PLANT (Unit : %)

MILL UTILISATION	1986 -87	1987 -88	1988 -89	1989 -90	1990 -91	1991 -92	1992 -93
BLOOMING MILL	58.7	62.8	69.0	71.4	72.7	75.6	76.2
RAIL & STRUC -TURAL MILL	59.1	58.6	61.1	62.4	60.8	61.6	61.1
MERCHANT MILL	53.4	59.5	60.6	64.1	68.5	69.1	71.6
WIRE ROD MILL	60.2	58.0	63.8	68.9	65.0	64.8	67.8
PLATE MILL	64.7	64.6	80.7	77.5	83.7	86.6	87.0

TABLE 3

PRODUCTIVITY INDICES- DURGAPUR STEEL PLANT (Unit : %)

MILL UTILISATION*	1986 -87	1987 -88	1988 -89	1989 -90	1990 -91	1991 -92	1992 -93
BLOOMING MILL	44.7	49.5	47.9	45.2	47.4	45.7	43.0
SECTION MILL	34.2	38.8	40.7	39.1	37.8	39.9	37.7
MERCHANT MILL	36.0	47.3	47.2	52.1	54.0	46.9	30.0
SLEEPER PLANT	29.0	39.0	25.1	34.7	33.4	20.0	28.4
FISHPLATE PLANT	17.9	21.9	20.5	20.8	20.8	20.0	22.7
SKELP MILL	24.3	29.3	32.9	30.2	31.9	31.4	33.7
WHEEL PLANT	23.4	23.3	26.1	32.8	22.9	19.7	-
AXLE PLANT	33.3	27.0	29.5	31.2	24.9	21.2	12.1

* Based on Installed Calendar Time.

TABLE 4

PRODUCTIVITY INDICES-ROURKELA STEEL PLANT (Unit : %)

MILL UTILISATION*	1986 -87	1987 -88	1988 -89	1989 -90	1990 -91	1991 -92	1992 -93
SLABBING MILL	46.6	49.1	51.2	49.0	52.8	50.9	54.1
PLATE MILL	58.4	53.3	57.2	56.7	56.8	60.7	55.6
HOT STRIP MILL	48.2	54.5	58.1	59.3	58.8	60.1	65.7
COLD ROLLING MILL							
- 1700 MM	47.1	52.1	56.6	58.9	62.2	67.9	66.5
- 1200 MM	52.6	57.7	63.4	68.6	65.8	71.3	72.3
TANDEM MILL	28.1	37.7	38.8	43.8	42.7	47.5	49.6
GALVANISING LINES	45.9	77.4	77.7	79.0	77.7	75.8	75.8
ELECTROLYTIC TINNING LINE	52.0	44.2	49.1	23.5	11.9	18.4	28.6

* Based on Available Time.

TABLE 5

PRODUCTIVITY INDICES - BOKARO STEEL PLANT (Unit : %)

MILL UTILISATION*	1986 -87	1987 -88	1988 -89	1989 -90	1990 -91	1991 -92	1992 -93
SLABBING MILL	56.2	65.4	70.3	68.2	68.5	71.1	69.5
HOT STRIP MILL	48.9	53.4	60.0	61.0	63.0	68.1	63.9
H.R. COIL FINI -SHING(SHEARING LINES)	52.2	50.2	58.0	62.6	62.1	67.5	62.9
COLD ROLLING MILL							
PICKLING LINE	29.0	40.3	44.0	49.1	49.3	41.7	48.0
TANDEM LINE	23.6	28.1	35.5	41.2	44.7	43.5	47.8
SKIN PASS MILL	28.2	36.5	50.7	52.9	49.1	37.7	36.5
COLD ROLLED COIL FINISHING	24.2	27.2	34.6	40.0	33.2	32.1	31.0

* Based on Calendar Time.

TABLE 6

PRODUCTIVITY INDICES - IISCO LTD. (Unit : %)

MILL UTILISATION*	1986 -87	1987 -88	1988 -89	1989 -90	1990 -91	1991 -92	1992 -93
BLOOMING MILL	51.5	49.4	44.0	34.1	34.3	39.4	39.4
BILLET MILL	31.3	32.9	27.6	20.1	20.1	24.1	23.8
HVY STRUCTURAL MILL	35.0	31.2	29.8	31.6	31.8	35.0	34.6
LIGHT STRUCTU-RAL MILL	57.8	60.7	59.6	52.5	NA	57.1	53.9
MERCHANT AND ROD MILL	60.3	59.2	52.6	57.0	57.6	51.3	53.9
SHEET MILL :							
ROUGHING MILL	57.8	61.9	63.0	35.4	NA	NA	NA
FINISHING MILL	52.8	56.3	56.6	33.2	NA	NA	NA

Note: The source of data for the productivity indices of all the plants are SAIL (1992) and SAIL (1994).

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