

Managing International Mining

by

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Abstract

The purpose of this paper is to describe work undertaken, within the System Dynamics Research Group at Bradford Management Centre, into the development and application of a System Dynamics model of an international mineral industry; aimed at providing a basis for analysis of the inter-relationship of supply, consumption and price over time, under different production and stocking policies. A review is presented of some of the major characteristics and problems associated with such industries. This is followed by an outline description of the model and the way it has been applied to examine various supply responses, in the light of changing consumption patterns. Demonstration results deal with model validation and with analysis of international buffer stocks and conflicting supply policies on the historic situation in the copper industry.

MAJOR CHARACTERISTICS AND PROBLEMS OF  
INTERNATIONAL MINERALS INDUSTRIES

An international mineral industry is defined here as the total industrial process of mining, treating and fabricating the mineral and marketing of the fabricated product to consumers. The significant characteristics of such industries are that supply originates in a number of countries (often at very different stages of economic development), fabrication and consumption take place largely in the industrially developed countries and that international transactions are chiefly based on a world exchange price (L.M.E., Comex). The existence of such an exchange price provides facilities for hedging, a source of supply for merchants and a basis for speculators to join the market. The combined effect of these characteristics results in a high degree of price instability.

These characteristics also indicate the truly transnational nature of mineral trade and form the basis of the many economic, social and political problems surrounding mineral industries. From an economic point of view capacity investment on most minerals has been seriously affected in recent years by:

- 1) the enormous cost rises in resource development projects which during the last decade, have increased at a rate considerably in excess of the general rate of inflation<sup>1,2,3</sup>, as a result of declining ore grades and more stringent measures in antipollution legislation;
- 2) the depressed state of most mineral markets (copper prices for example in real terms are presently as low as at any time since 1930's whilst stocks are at historic heights<sup>3</sup>; and
- 3) the cost and problems in generating the necessary funds to establish new projects.<sup>3</sup>

From a political point of view the problems stem broadly from the increasing numbers of new countries coming into existence and the fact that a large proportion of presently known mineral wealth lies in such developing countries. The moves made by many such countries to establish economic as well as political independence has resulted in a considerable shift in bargaining power between host governments and the international mining groups on whose capital and expertise mineral developments have been traditionally based. The prime result has been a slowing down in private investment in new mineral projects and a shift in location of investment towards these countries where political risk is considered least.

Lengthy discussions between mineral producers and consumers have taken place through the United Nations (UNCTAD) on the problems of risk sharing in a search for internationally acceptable measures to increase stability and encourage investment. These discussions have centred mainly on the questions of commodity funds, buffer stocks and the use of an International Resources Bank. However, apart from the now well established tin buffer stock the size and usefulness of these facilities remain an open question.

In view of the foregoing supply problems and the no less important consumption fluctuation exhibited by most minerals, the balance between consumption and production is a very delicate one. In the medium and long term there is however considerable scope to achieve supply adjustments in response to consumption changes and, although price stability has only been achieved over short periods, most natural resource industries have demonstrated over the past 25 years, an ability to keep supply sufficiently ahead of consumption to prevent serious shortages.<sup>4</sup>

In general, however, price in these industries is not a simple function of the consumption/production balance. When these two factors move out of phase there will obviously be price changes but these changes will depend additionally on the overall stock situation in the industry. Stocks have considerable importance for a number of reasons. Firstly, they act as indicators of the market situation and play a disproportionate part in determining price movements. It is their function in this respect which precludes any straightforward analysis of price by simple economic theory. Secondly, they are inherent in policies applied at all levels of the industry. This point is of particular importance in respect of consumers and fabricators, who generally tend to reduce stocks when the market is oversupplied (since costs are reduced and reliance is placed on being able to buy at short notice) and increase stocks when the market is rising. This type of policy can also be identified on the part of merchants and speculators where the desire for stocks is generally increased with consumption or price increases in anticipation of further increases and vice versa. The consequence of such stockholding policies is to amplify consumption changes vertically through the industry. Supply responses are therefore made in relation to demand (or amplified consumption) which for an almost continuously rising market will be generally in excess of true consumption. Prices are then a reflection of this demand/production balance and the absolute stock levels. Stockholding policies as described above, are of course, contrary to the true purpose of stocks which is to buffer production against consumption fluctuations and this highlights the third reason why stocks are important. That is, they provide a means of increasing market stability.

#### OVERVIEW OF THE MODEL

The purpose in applying System Dynamics to the minerals industry has been basically twofold:



- 1) to investigate the mechanisms by which supply and price are generated in response to consumption changes; and
- 2) to investigate the way in which policies in various sectors of the industry relate to these mechanisms.

The policies of prime concern to the future of the mineral industries are those associated with stocking, production and investment within individual sectors of the industry and those associated with stability measures (e.g. buffer stocks) on an international basis. It is particularly evident from the outline of industry problems presented in the previous section that one of the important determinants of future mineral supply, centres on measures to over-come the conflicting objectives (and hence policies) between different sectors of supply (e.g. the privately and publicly controlled sectors). The model has been designed with this orientation in mind by the incorporation of two supply sectors whose market shares are generated within the model, over time. By suitable adjustment these sectors are capable of representing, for example, individual/groups of companies, or individual/groups of countries. In total the model is capable, by suitable paramaterisation, of being adjusted to represent any particular mineral industry.

The model incorporates four basic 'types' of sector representing fabricators, merchants, suppliers and buffer stock agency. The outline inter-relationships (or influences) between the fabricators and the two production sectors are shown in Figure 1. This 'influence' diagram depicts the overall postulates on which the model, for these sectors, is based. It is assumed throughout the study that, in general, supply is a function of exogeneously generated consumption. This follows current thinking in a number of the major mineral industries, that consumption is determined largely by the level of economic activity in the industrialised mineral consuming countries and assumes substitution effects to be small within current prices ranges.<sup>6</sup> Consumption is, therefore, taken as the exogeneous 'driving'

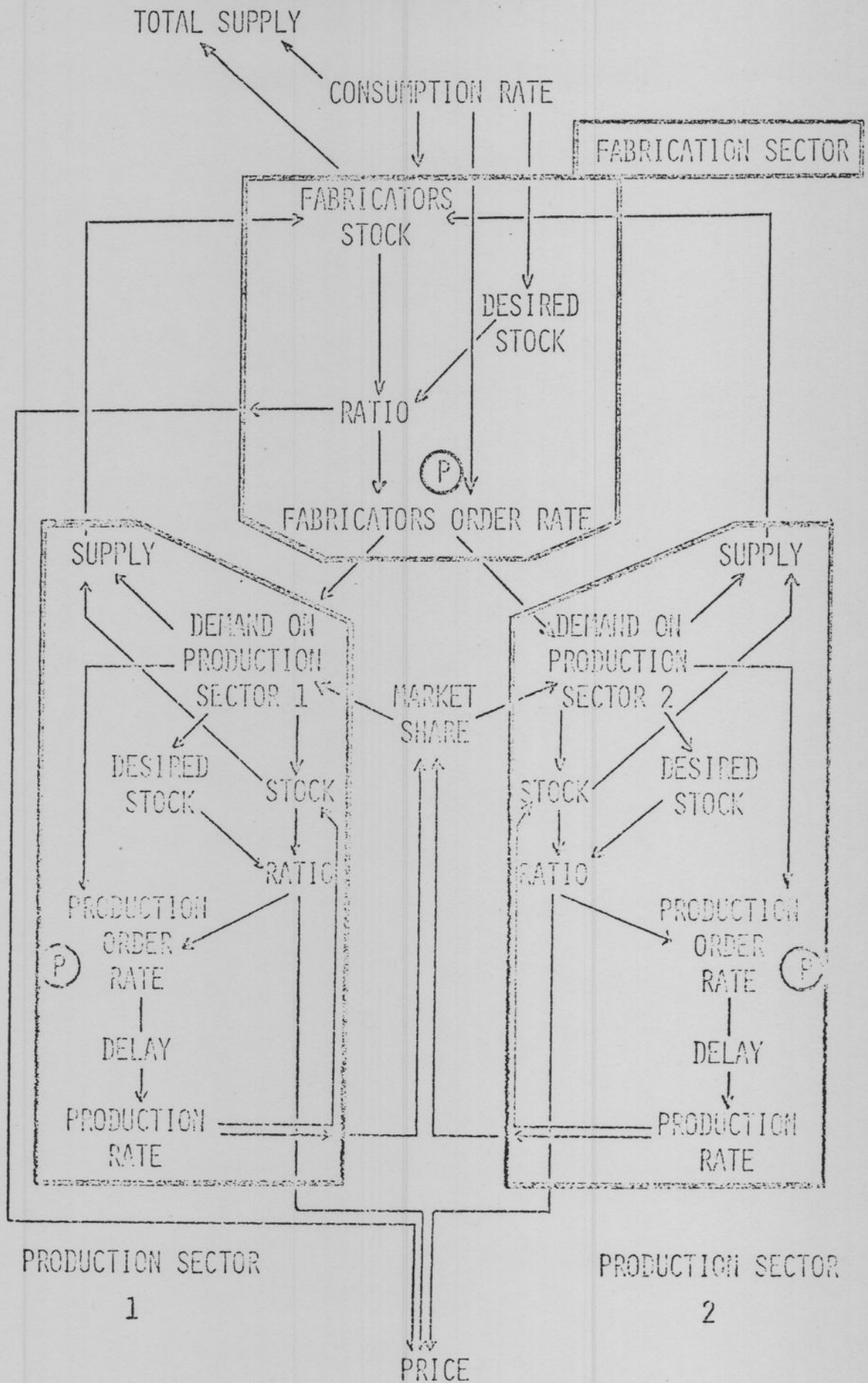


Figure 1 Influence Diagram of Major Sectors of the Model

variable of the model and this transmits a demand, based on both transactional and stocking motives, through fabricators (and merchants) to suppliers. The merchant's sector (not included in Figure 1) is incorporated to isolate an additional stocking element of the industry which is of prime significance during periods of tight supply.

The model is based throughout on flows of refined metal, information and finance and the main policy variables (denoted by P in Figure 1) are the fabricators' and producers' order rate. These variables are based on demand and stock information and regulated by functions, which will be described in later sections. The production order rates, in each production sector, represent production to be instigated which, after a delay result in stock increases and supply rates to satisfy the total consumption. Additionally, the production rates govern the share of the fabricators demand allocated to each production sector. The production sectors are, therefore, directly linked by market share. The industry price is seen from Figure 1 to be generated on the aggregate difference between the desired and actual stock levels within each sector. The overall price is not directly fed back to govern the policy of each sector; rather these policies are generated by the individual stock ratios of each sector, which effectively represent the interpretation of price within the sectors. Overall price, is however, taken to be the major variable which monitors the behaviour of the industry, and it is used as the main input to the buffer stock section of the model.

A simplified version of the inter-relation of the buffer stock sector with the other model sectors is shown in Figure 2. Buffer stock transactions will be seen to transfer stock between the buffer stock and the individual sector stocks, depending on the current generated price, the designated floor and ceiling prices and the current levels of stock and cash available to the buffer sector. Provision is made for the proportion of stock, to be transferred to each individual sector, and for the buffer stock intervention prices, to be modified.



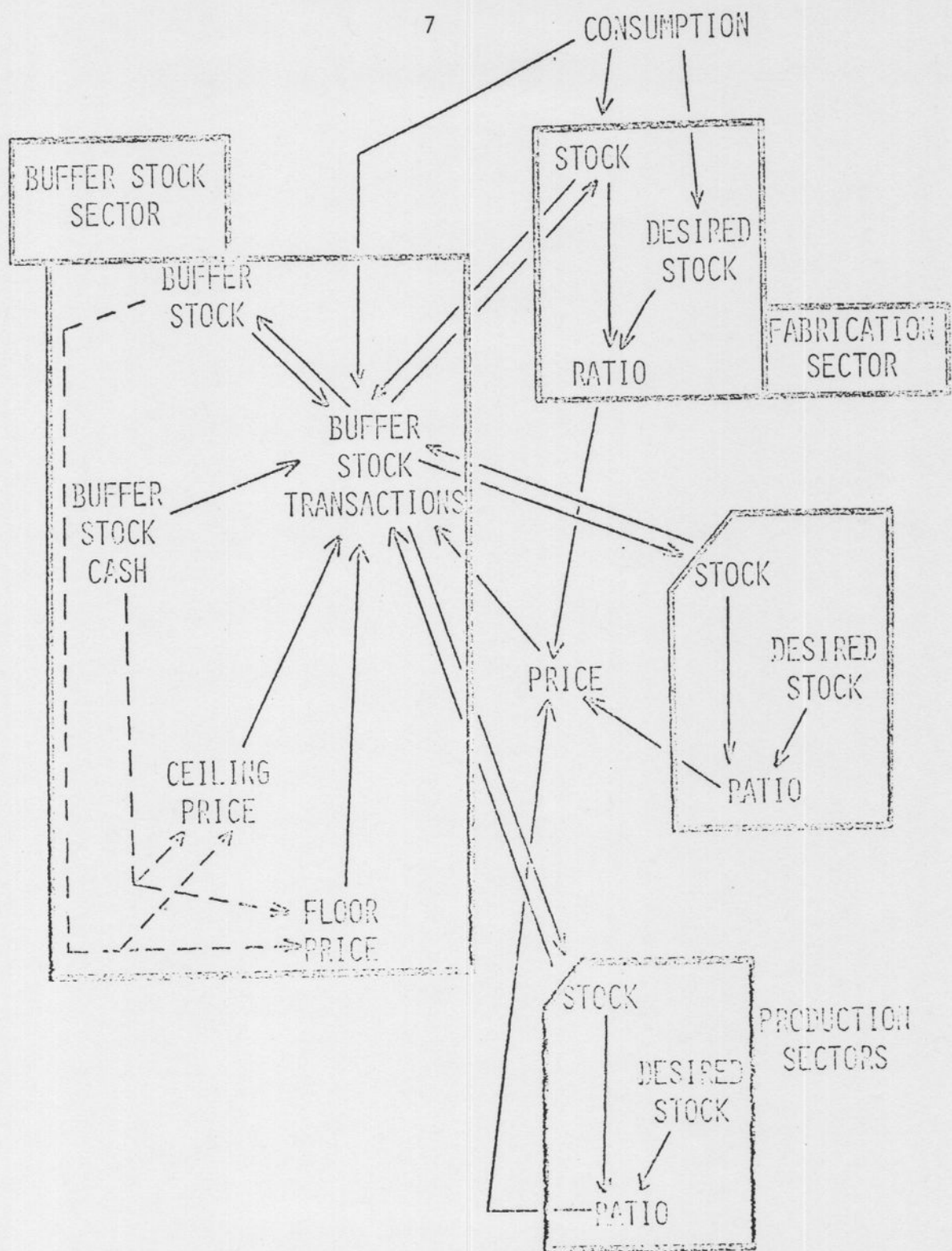


Figure 2 Relationships Between Buffer Stock and Other Model Sectors



The intervention prices can themselves be made variables, depending on the current levels of stock and cash available to the buffer sector, as indicated by the dotted influence lines in Figure 2. The rate at which the buffer buys and sells is determined as a percentage of the average consumption rate.

#### INVESTIGATIONS USING THE MODEL

In general, it is possible to use the model for a wide range of investigations, ranging from assessments of the effects of simple production cutbacks (voluntary or enforced) and consumption changes, to the effect of more complex policy change at different levels within the industry. The mode of experimentation used has been to develop the diagrams of Figures 1 and 2 into a continuous simulation model in terms of explicit time-based relationships representing the influences shown; and to simulate these relationships over many time periods to analyse the behaviour of all system variables under varying assumptions.<sup>7</sup>

A selection of experimental results, based on the application of the model to the historic price levels translated into £1978 using the GNP inflation index. A constant policy for fabricator order rate has also been used throughout, whereby it is assumed that fabricators wish to maintain a desired stock level, based on a number of weeks of average consumption. The fabricators order rate (demand on producers) is, therefore, that required to meet current industrial consumption plus an amount to correct any discrepancy between their actual and desired (target) stocks, over a given time period. Hence, the fabricators' order rate is an amplified version of the industrial consumption rate.

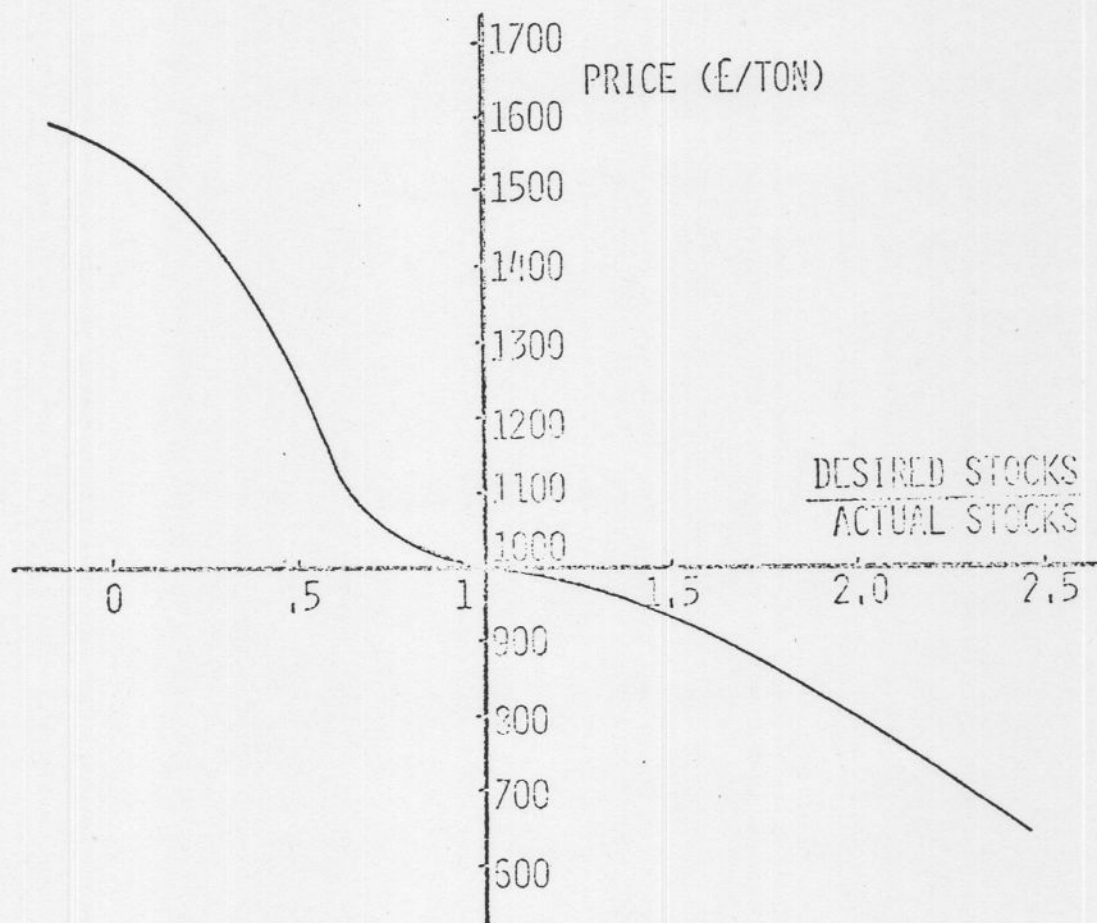


Figure 3 Price Generation Curve

## PRODUCTION POLICY INVESTIGATIONS

The model has been extensively used to investigate the effects on price and supply of production policies. It is assumed that, within limits, producers are capable, in aggregate, of adjusting production in the medium term to match demand on them; either by adjusting output from current mines or adjusting the rate at which new mines are bought on stream. Production is therefore instigated at a rate to meet current demand and additionally multiplied up or down depending on the ratio of producers desired to actual stock. Like fabricators, the desired (target) producer stock increases with the average production demanded. Two policies for the production multiplier are shown in Figure 4. Policy type I indicates that the production rate will be moderately increased as desired stock exceeds actual stock and vice versa. This is described as a 'medium' response policy. Policy type II represents a greater response to stock discrepancy and is referred to as an 'aggressive' response policy. It should be realised that it is possible to represent any type of production policy, by adjustment of the function used in Figure 4.

A policy of type I, as described above, has been found to most closely represent the situation in the copper industry over the last 26 years. Figure 5 shows the total production rate, the total stock situation and the generated price produced by running the model using the actual copper consumption over this period as input. Output graphs of this type are produced directly from the DYSMAP simulation programme. These results are based on 65/35 percent split in market share between production sectors 1 and 2, which, since both sectors were modelled using the same production policies, remains constant over the period. It will be seen that the generated price closely follows the actual

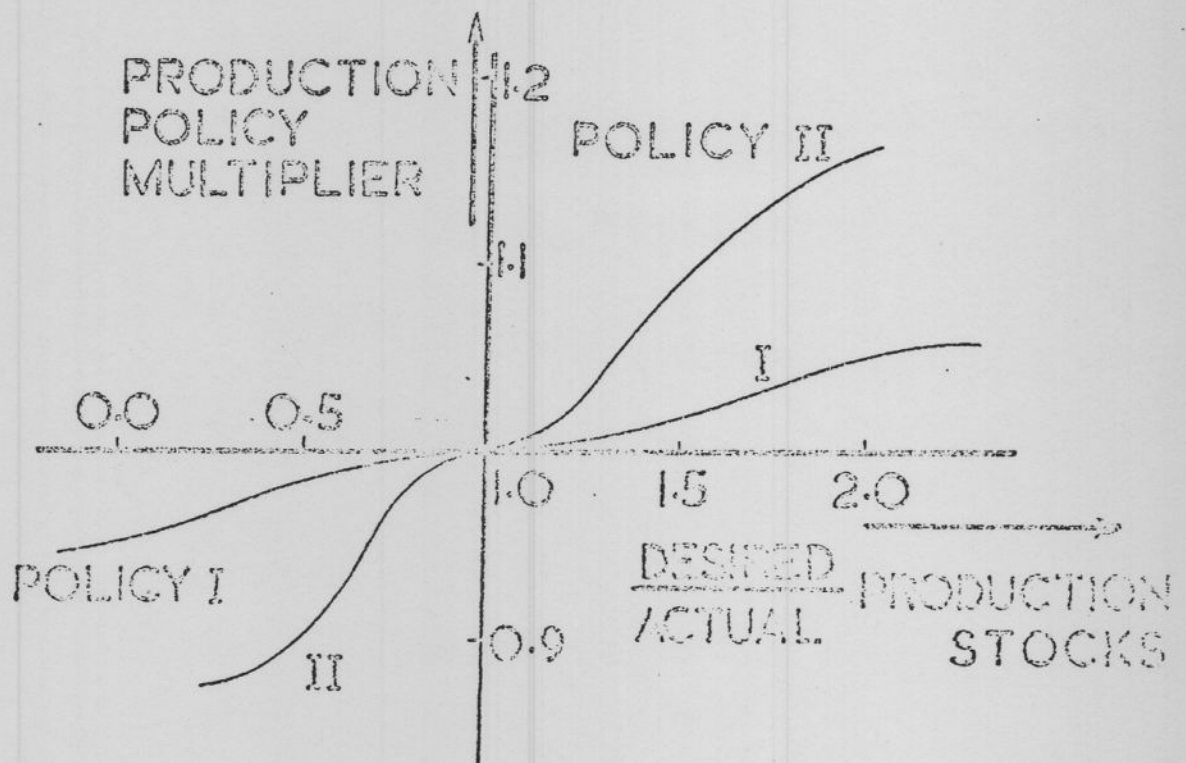


Figure 4 Production Policies



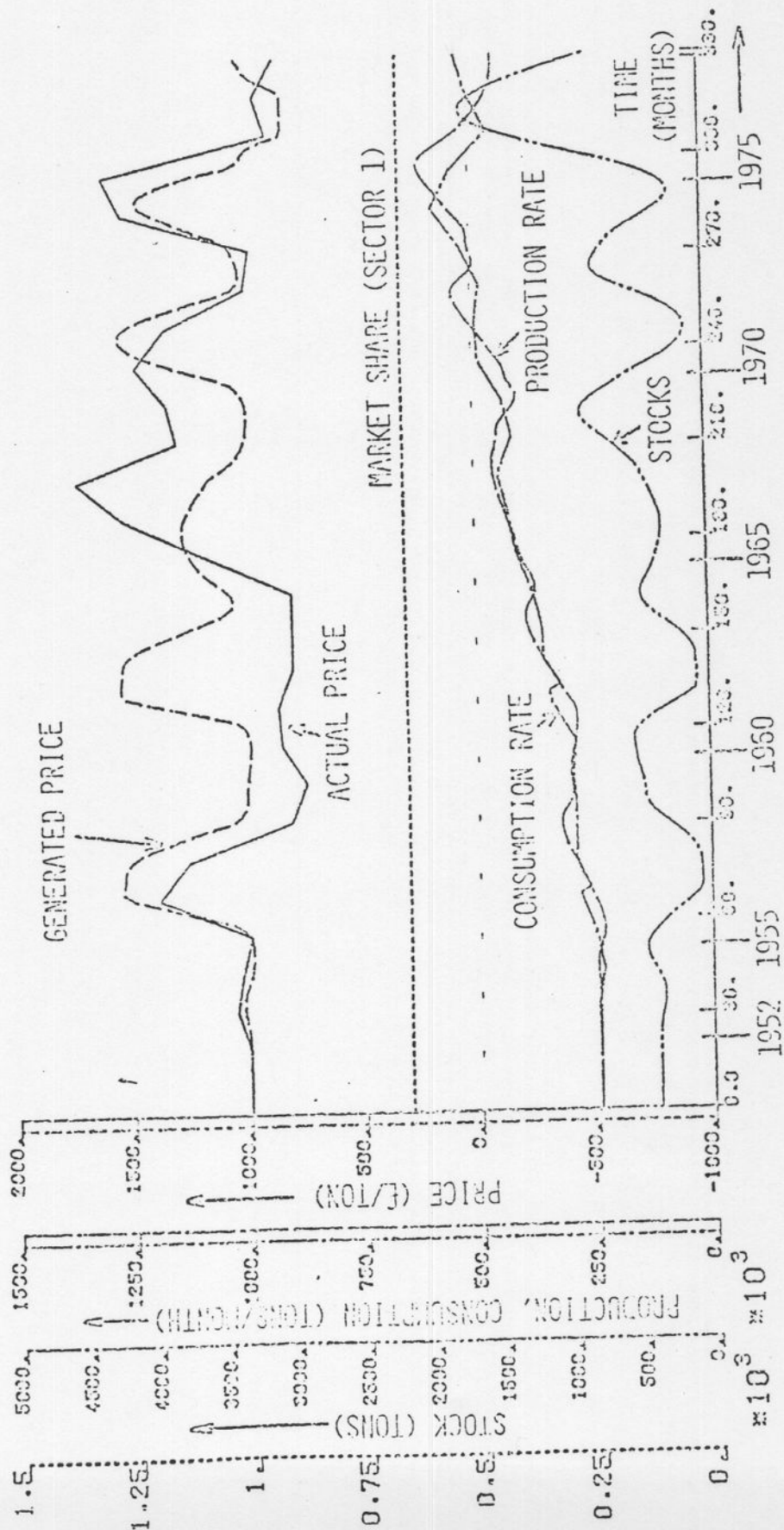


Figure 5 Model Output of Major Variables Using Production Policy Type I

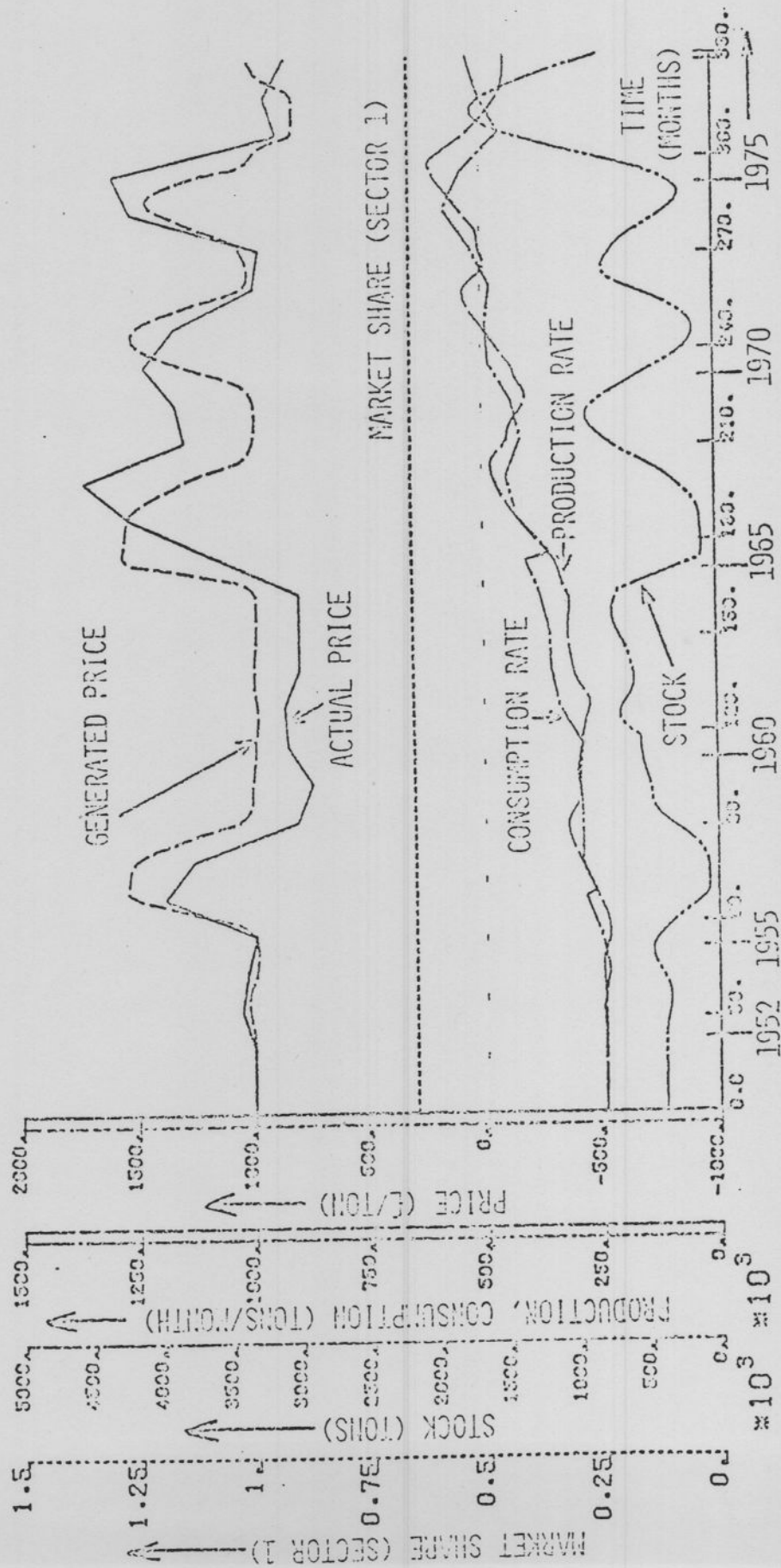


Figure 6 Model Output Incorporating Stock Pile Sales

price achieved in the industry over this time period. The major discrepancy occurs during the early 1960's, when the actual price was in fact artificially low due to the unloading onto the market of the United States' strategic stock pile of copper. Taking this into account in the model produces the output shown in Figure 6, which gives very close correlation between the actual and generated price.

This result brings out a number of points concerning model validation. In general the model can be regarded as valid in the sense that it is defensible and well grounded and produces results consistent with actual observations. An industry such as copper has, of course, been subjected to a multitude of policies, speculations and environmental changes at all levels but, as previously indicated, has been consistent in its ability to adjust overall supply to consumption, and it is this underlying response pattern which is modelled here. The functional mechanisms of the model are well brought out by the results of Figure 6. It can be seen that the sale of the stockpile increases working stocks, lowers price and significantly reduces production.

Figures 7 and 8 are presented as a demonstration of how the model can be used to generate alternative configurations for the copper industry under different assumptions concerning supply policies. In Figure 7 the effect of both production sectors using policies of type II in Figure 4 is shown. It will be noted that this more aggressive supply response to consumption changes results in considerable fluctuations in the production rate, but significantly reduces the amplitude of price fluctuations.

Figure 8 shows the overall effects of assuming different policies for each of the two supply sectors. It was assumed for this demonstration that sector 1 started with a 65% market share and followed a moderate production policy of type I (Figure 4). Sector 2 was assumed to follow a fixed annual growth of 6%, which is slightly higher than the



average annual consumption growth over the period considered. It can be seen from a comparison of Figures 6 and 8 that, with the consumption pattern used, this has a dramatic effect on stabilising overall production. Production no longer declines as sharply in response to consumption troughs and does not surge as strongly in response to consumption rises. As a result stocks are higher and price much more stable. The price peak of the late 1960's, following the end of the U.S. strategic stock pile sales, is largely unaffected; but the effect is otherwise very pronounced. This is particularly true of the 1970's, where the amplitude of the consumption cycle has been much greater and where the effect is escalated by the increasing proportion of market share for sector 2 over time, which arises from its policy. The market share between the two production sectors used for this experiment, was chosen as being representative of the split between the two major blocks of copper suppliers to the world market, where it might be envisaged that production policies would significantly differ. That is the CIPEC block (Zambia, Zaire, Peru and Chile) represented by sector 2 and the rest of the world, represented by sector 1. It is of interest to consider these results in this light.

#### BUFFER STOCK INVESTIGATIONS

The second set of experiments to be described deal with the effects on the copper market of creating a buffer stock. The overall purpose of an international buffer stock would be to stabilise price. One of the major problems in such a creation would, of course, be the size and source of funding of the provision but no less a problem would centre on the effectiveness and control of its operation. That is, what size would it need to be, what would be appropriate intervention prices and policies for changing them, and what effect would producer policies have on its operation? The model described in this paper presents



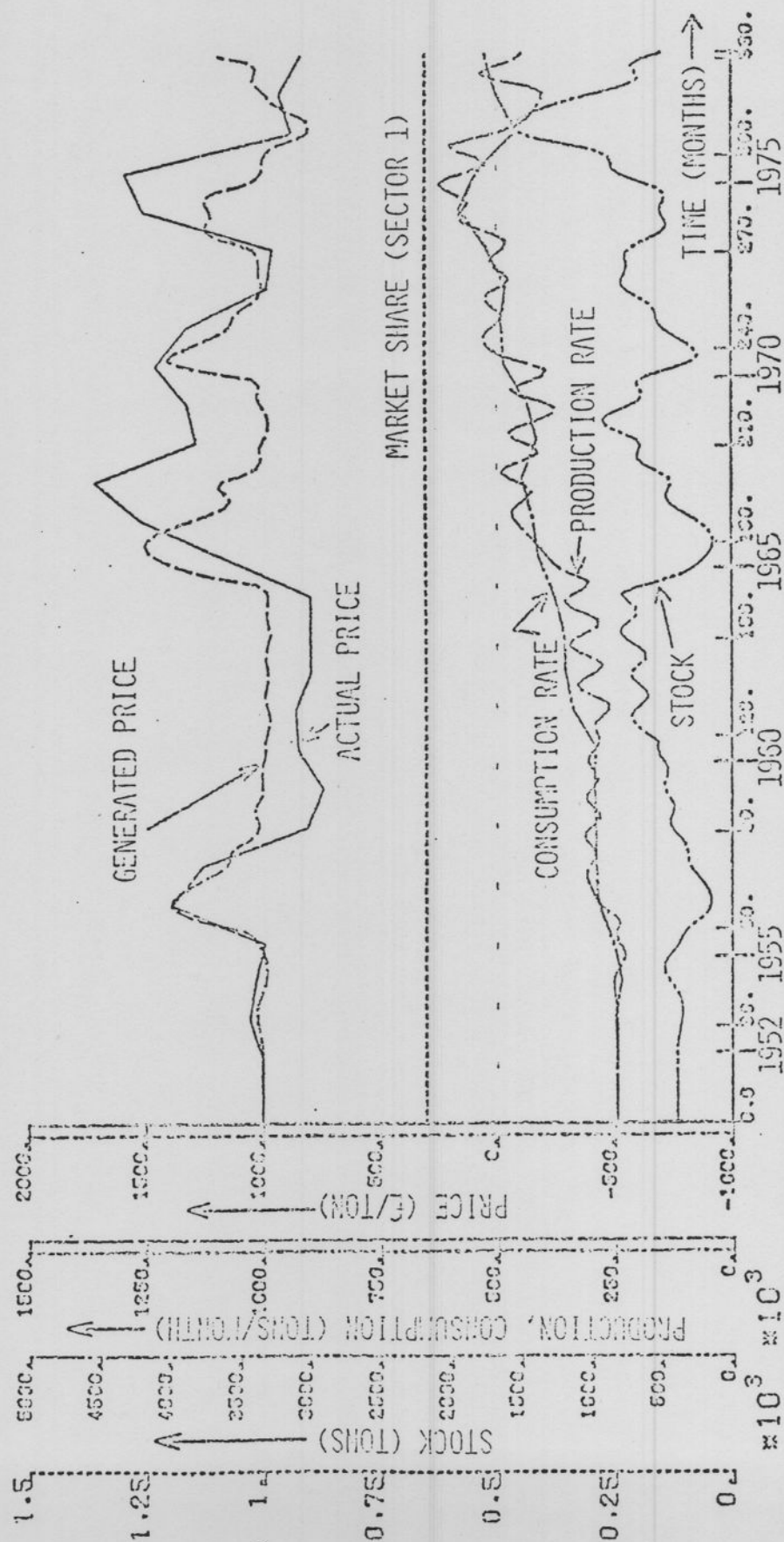


Figure 7 Model Output Using Production Policy Type II

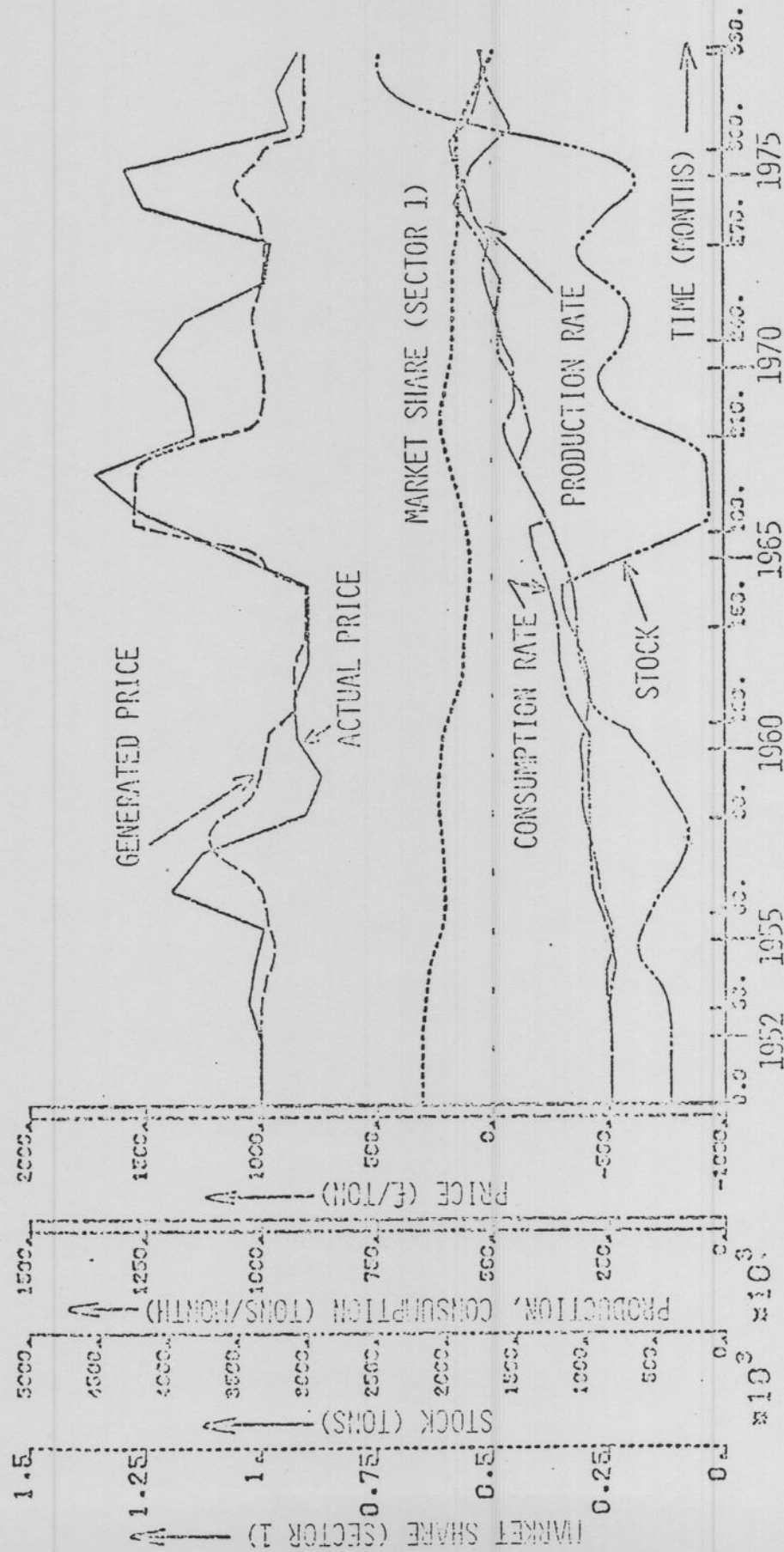


Figure 8 Model Output with Production Sector 2 Using Constant Annual Growth Policy

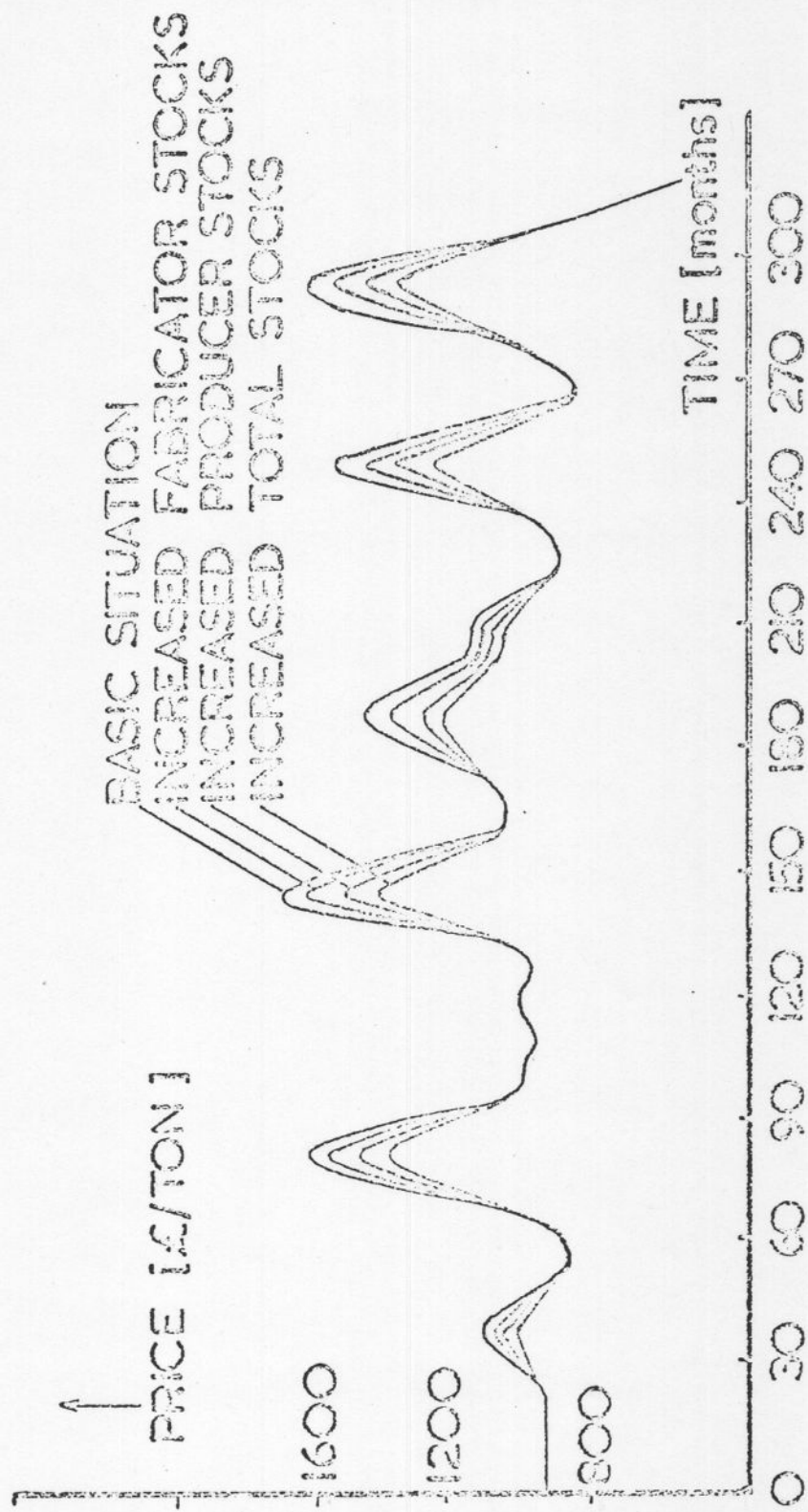


Figure 9 Effect on Price of Increased Stock Holding

an ideal method of investigating these problems.

Before considering an actual buffer stock as such it is worth noting what effect additional stock holding in general has on the overall market price. Figure 9 shows results from the model based on doubling fabricator's desired stocks, doubling producer's desired stocks and doubling both. This interesting result demonstrates dramatically that increasing stocks has no effect on the price troughs but reduces the price peaks. This is because additional stock will effectively act to reduce the effect on price of excess demand but will have no effect on price when there is excess supply. This situation clearly contrasts the cases of stock effectiveness when carried out within the industry, and when carried out by an external buffer sector. In the demand situations, but also price troughs are raised by buffer purchases during excess supply situations.

The buffer stock investigations to be described centre on the superimposition on the model of the buffer stock sector outlined in the section of the paper on model description. Initially buffer stock sales are instigated at a rate of 30% of the average monthly consumption rate, when the price exceeds a given floor price. Figure 10 shows the effect on price transactions. These results are based on type I production policies (see Figure 4), a 65/35 split in market share between the sectors and a 50% split in buffer transactions between fabricator and producer stocks. The size of the buffer tested in Figure 10 was that represented by 3 months cover of the 1952 consumption rate (730,000 tons) and this was assumed to be made up of 90% metal and 10% cash. The ceiling price was set at £1200/ton and the floor price at £990/ton. It should be noted that the buffer buying and selling rates increase over time with consumption and that 730,000 tons of initial stock represents only 1.25 months cover of the 1978 consumption rate.



It can be seen from Figure 10 that this size of buffer stock is insufficient to maintain the price between these very tight bounds for the whole of the historic period considered. Stock depletions cause the price to exceed the ceiling price on occasions and cash depletions cause the price to fall below the floor price at the end of the period. This particular result was chosen to demonstrate how much graphical outputs can illustrate very clearly the extent to which a given size of stock is effective at each point in time. The table in Figure II summarises the results of a number of such experiments and indicates the size of buffer stock which would have been required for a range of different floor and ceiling prices. It will be seen that in fact a buffer stock of 1.14m tons is necessary to fully maintain the price within the bounds of 990 and 1200 £/ton. This requirement is dramatically reduced as the ceiling price is raised and dramatically increased as the floor price is lowered. This latter result occurs since at a floor price of £900/ton the buffer agency has to sell but never buys.

It should be remembered that these results incorporate the very important effect of production policies. In particular they take into account the fact that producers will reduce production when demand is declining, i.e. when stocks are high and price low. This effect obviously reduces the magnitude of buffer purchases necessary to maintain the floor price during a market slump. It is often postulated, however, that an integrated buffer stock scheme should only be instigated, on the understanding that producers will cooperate, by making additional discrete cutbacks in production, during such circumstances to further reduce the pressure on the buffer stock. In order to test how such cooperation would affect the size of the required buffer stock, experiments have been made which incorporate additional production cutbacks of 10% whenever the actual price falls reduces the floor price. This policy produced the very interesting results that, in the circumstances investigated, the total size of the required buffer stock over the whole period was in fact increased by about 10%. This is due to the fact that although buffer purchases

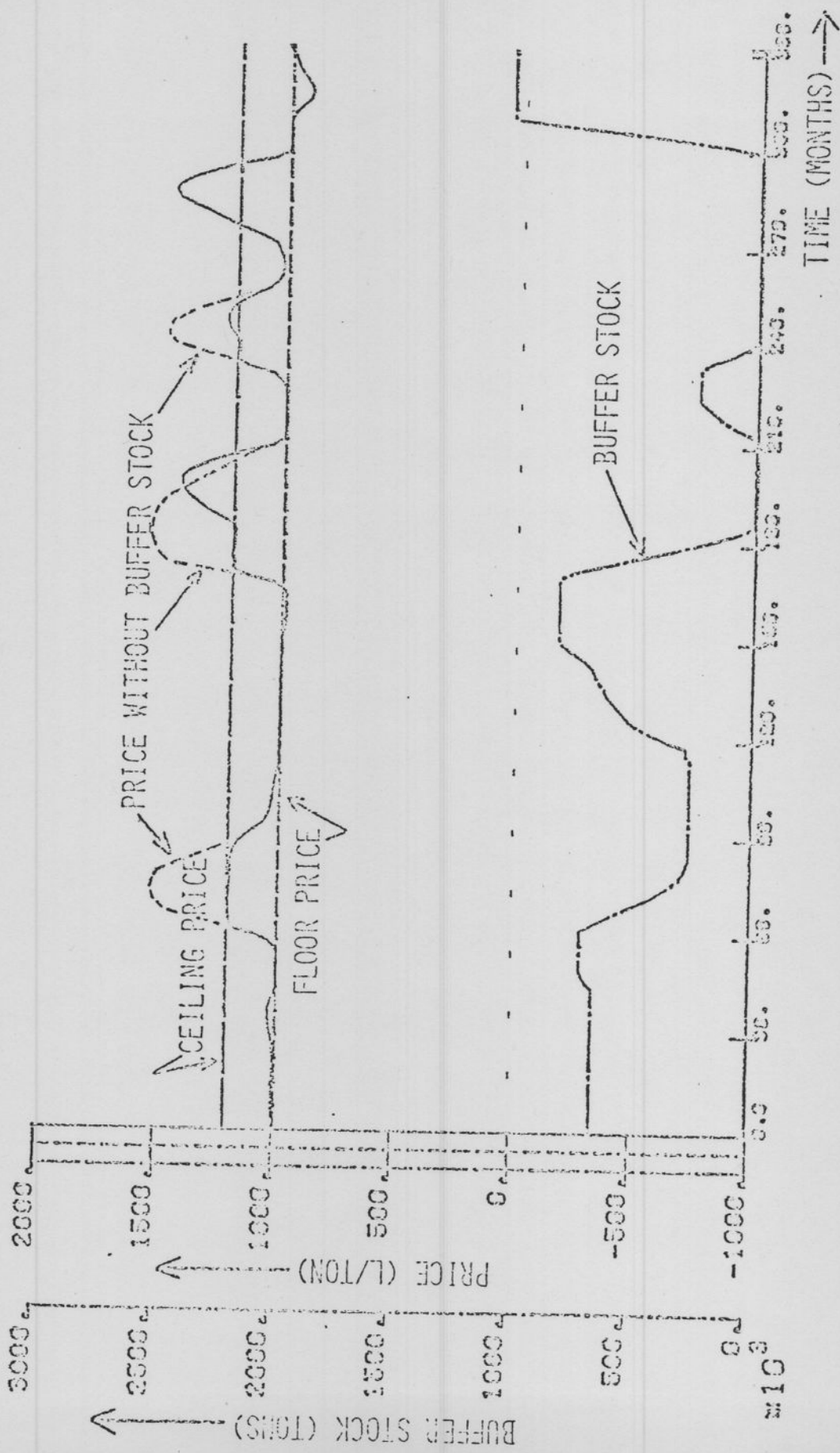


Figure 10 Effect of Buffer Stock on Price Using Fixed Intervention Prices and Type I Production Policy

		CEILING PRICE £/TON		
		1200	1300	1375
FLOOR PRICE £/TON	900	2.44	1.53	1.10
	990	1.14	0.22	0.15

Figure 11 Buffer Stock Requirements (millions of tons) for Different Floor and Ceiling Prices

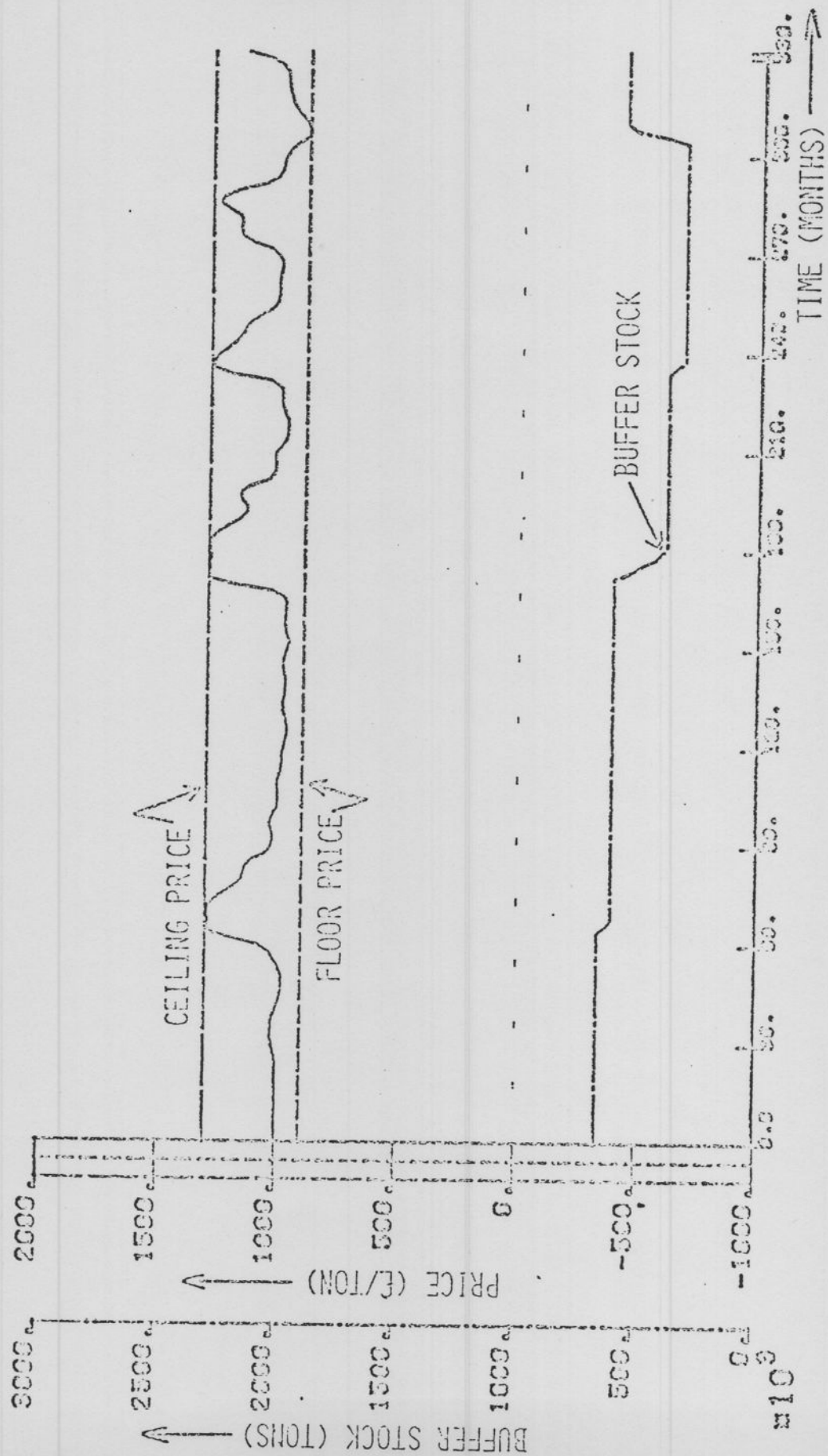


Figure 12 Effect of Buffer on Price Using Type II Production Policy



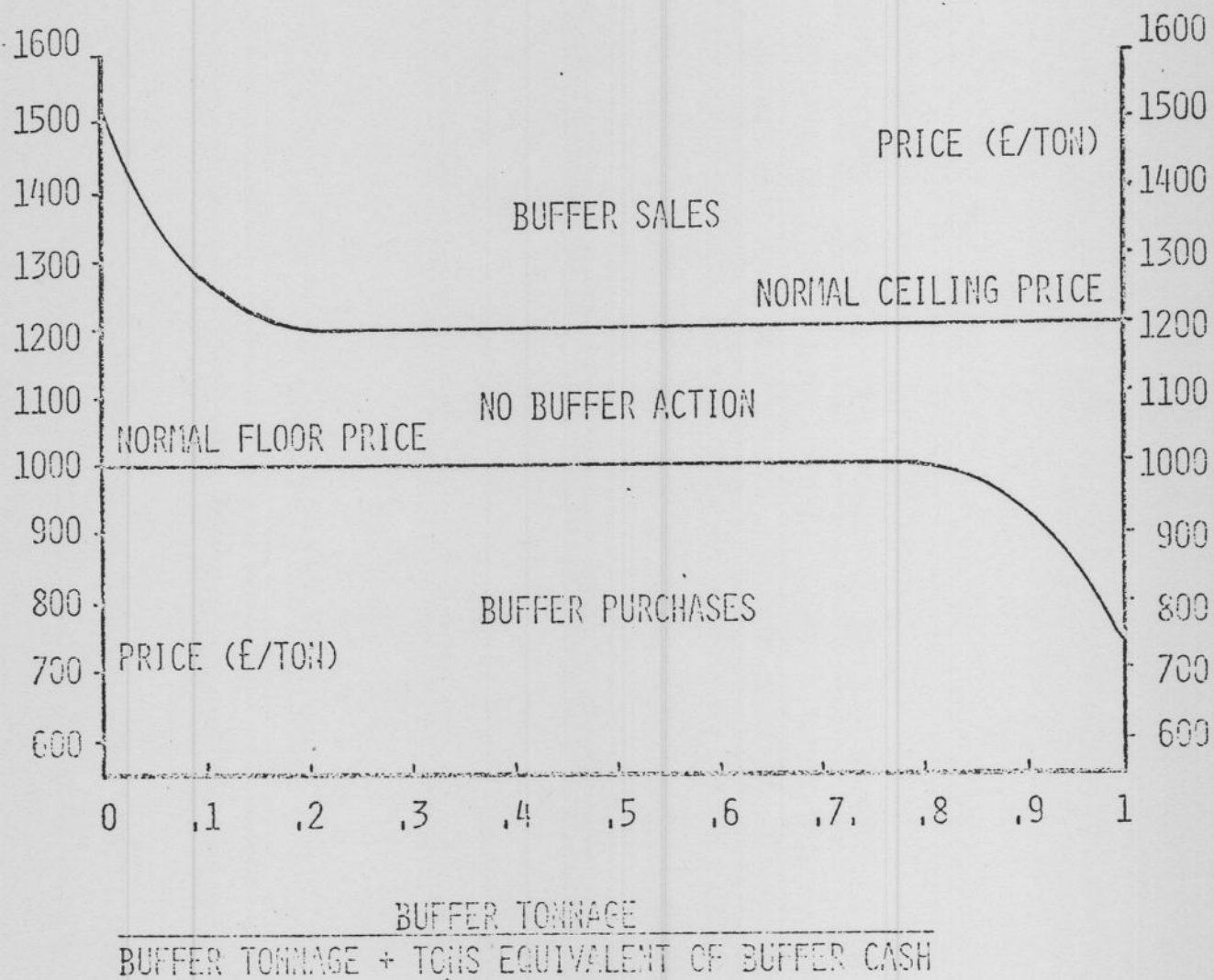


Figure 13 Control Policy for Varying Buffer Stock Intervention Prices

are reduced as expected during periods of low price (with financial savings to the buffer fund), less metal is bought into the buffer for subsequent use during periods of high demand, necessitating a higher initial requirement to cover such periods.

All the above results were, as previously stated based on type I production policies. Figure 12 is included to demonstrate that, using production policies of type II, with their consequent smoothing effect on price, the buffer stock requirement is greatly reduced. For the intervention prices shown (900 and 1300 £/ton) a stock of 450,000 tons is required compared with 1.53 million tons as given in Figure 11.

The foregoing analysis has, of course, assumed fixed buffer stock intervention prices and one of the main problems in practice centres on the control policies to use for effective redesignation of these factors, acceptable both to producers and consumers. It is possible to use the model developed to test the effects of variable intervention prices. Figure 13 shows a simple case of such control which has been incorporated into the model, based on the dotted influences in Figure 2. As the buffer stock nears depletion the ceiling price is raised to restrict sales and when the buffer stock nears the top of its purchasing power the floor price is reduced to restrict purchases. Figure 14 shows the effect of this on a ceiling price of £1200/ton and a floor price of £990/ton using type I production policies. A buffer requirement of only 700,000 tons is now required (compared with 1.14 million tons for these intervention prices in Figure 11), but of course price is less well controlled.

### CONCLUSIONS

This paper has described the development and application of a continuous simulation feedback model to an investigation of the dynamic relationships governing consumption, supply and price in mineral industries. The aggregate problems facing such industries are immense

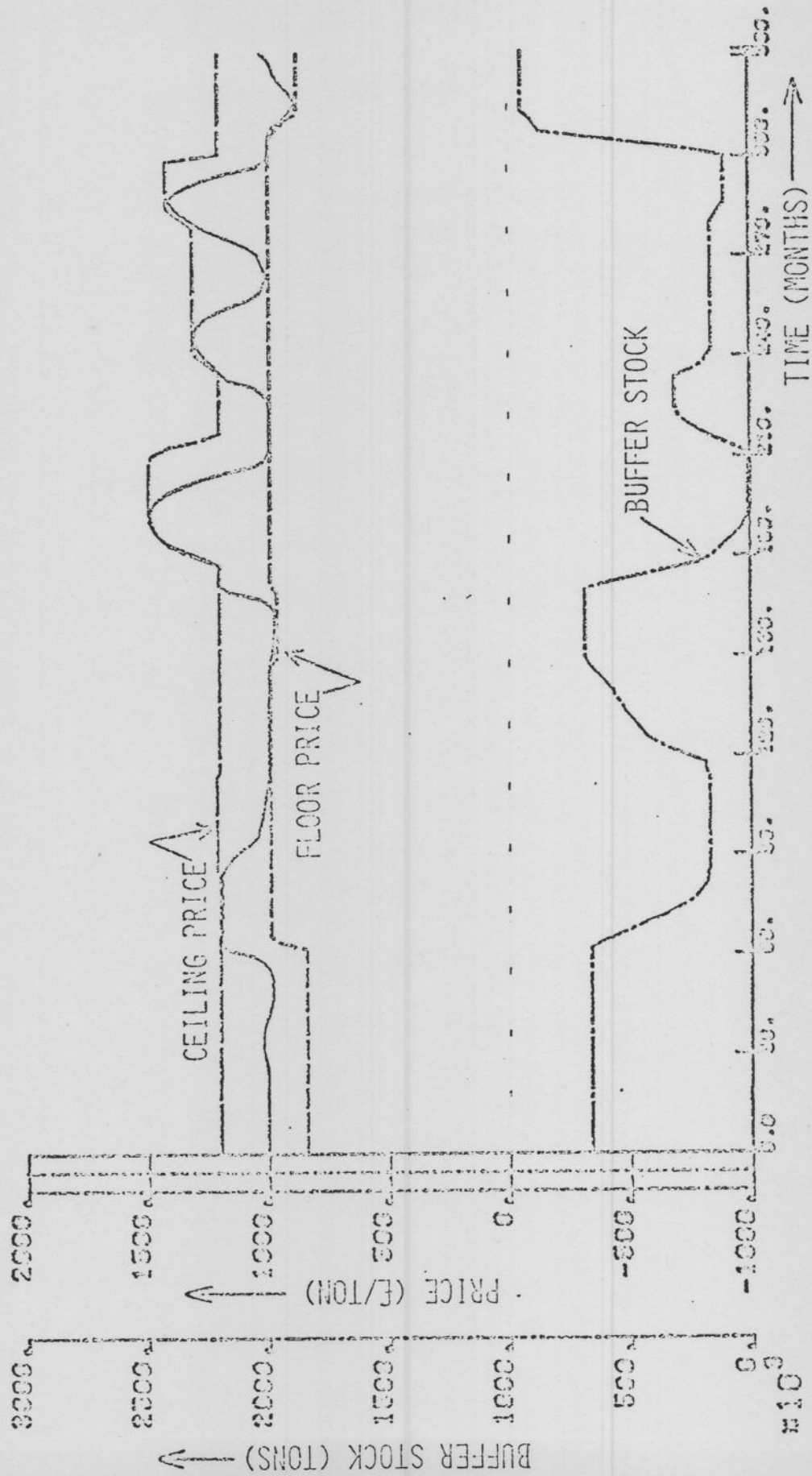


Figure 14 Effect of Buffer Stock on Price Using Variable Intervention Prices

and there is considerable need for analytical approaches to aid understanding of the many complex issues involved. It has been demonstrated how the model described is capable of aiding such understanding. By its ability to link together physical, information and cash flows it has considerable potential for policy design at all levels of such industries and it is capable of reducing difficult concepts to easily understandable graphical results of trends through time. These dynamic facilities give the method a significant advantage over other methods of aggregate economic analysis. No where is this more evident than in the analysis presented of the currently controversial issues surrounding buffer stocks; where it has been shown possible to assess the effects of such stocks taking into account the effect of producers' and fabricators' policies. The results demonstrated represent only a small number of potential applications of the model and the model itself represents only one of a number under development in the current mining research.



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