

Modelling the Future of Mining Groups

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ABSTRACT

The typical International Mining Company (IMC) is a cross between a merchant bank and a consulting firm and usually has only a minority equity stake in its operating companies, which are often large corporations themselves.

It is often argued that what is good for the subsidiaries is good for the IMC but this has been called into increasing question because of the different corporate objectives which may be pursued by the IMC and the operating companies, especially in the face of an extremely unstable economic environment.

The article describes a model of a mining group which shows how conflicts can arise between Head Office and subsidiaries and how what is good for the IMC is not necessarily good for the subsidiaries and vice versa.

Traditionally, the mining industry has not engaged in corporate planning but has tended to react to investment opportunities as they arise. The model looks at some obvious planning approaches and shows that they may be harmful to the corporate entity.

This paper is a shortened and rewritten version of 'A Control Model for an International Mining Company' presented by the author at the XXIII Conference of the Institute of Management Sciences Athens July 1977. Copies of that paper may be obtained from the author.

The System Dynamics Research Group at the University of Bradford's Management Centre is heavily involved in research and teaching in the area of the design of corporate policies. During the past few years the Group has worked on many industries. Two years ago, with funds from the Social Science Research Council, members of the Group, led by the author, embarked on an investigation of policy-making in mining companies with the broad aim of seeing whether the policies traditionally followed by UK mining finance houses were likely to continue to be viable in the last quarter of the twentieth century. To date, a number of sub projects have been completed dealing with operating policies for underground and open-pit mines, the overall structure of the metals industry, and with a model for the corporate future of an International Mining Company. See Coyle and Montaldo (1977), Wolstenholme (1977), and Montaldo (1977A and 1977B).

The research project will continue until 1978 but the purpose of this paper is to describe the initial work on the corporate model. Further developments will be published in due course, but the comments and criticisms of the mining industry will be appreciated by the author.

International Mining Companies

The neatest definition of an IMC is, perhaps, the following paraphrase from Rio Tinto Zinc's Annual Report for 1975.

'RTZ is a British-based group of mining and industrial companies with interests in almost every major metal and fuel, including aluminium, coal, copper, gold, iron ore, lead, silver, tin, uranium and zinc.

It has geological teams in countries where no operations yet exist, in addition to being a shareholder in major operations with their own national managements and local participation.

RTZ's London headquarters provide consultancy services and the parent organisation in London plays a major part in the raising of the large-scale finance required for operations throughout the world.'

The central paragraph, both literally and figuratively, has been emphasized to demonstrate the salient research and policy issue -

'Can this continue for the remainder of the Century in the face of :-

- i) increasing geological difficulties, possibly ameliorated by major technological developments (e.g. manganese nodule mining).
- ii) the tendency of 'local' companies to take on life objectives of their own.
- iii) greater socio-economic problems of mineral prices and the willingness of other countries to allow 'foreigners' free rein in their operations and remission of earnings to some other geographical area?

The companies which most noticeably satisfy this definition, apart from Rio Tinto Zinc, are Consolidated Gold Fields, Charter Consolidated and Selection Trust, though there are other, generally smaller, companies. There are similar companies based in U.S.A., Canada, South Africa, Belgium etc.

The IMC's have long seen themselves as mining companies in the sense that many of their London staff have been trained in mining or geology. It will however, be the viewpoint of this paper that an IMC is really a cross between a merchant bank and a firm of consulting engineers. It is indeed, argued in some mining circles that the IMC's should in future operate as fee-earning management and engineering consultants rather than as equity-investing entrepreneurs.

Whether or not this comes to pass, there is no doubt that the London staffs represent massive expertise, not only in mining and geology, but also in finance and the ability to put together extremely complicated, and often very profitable, financial packages to support new mining investment, and that the activities of the IMC's have important effects on the whole U.K. economy.

Having raised the possibility that IMC's may be facing large changes in their pattern of operations, we examine some information about the industry, using two major companies purely for illustrative purposes. It must be

stressed that, although a number of leading mining figures have given generously of their time and help in discussing the work, the interpretations placed on public data are entirely those of the research team and in no way represent the view of any company or individual in the industry.

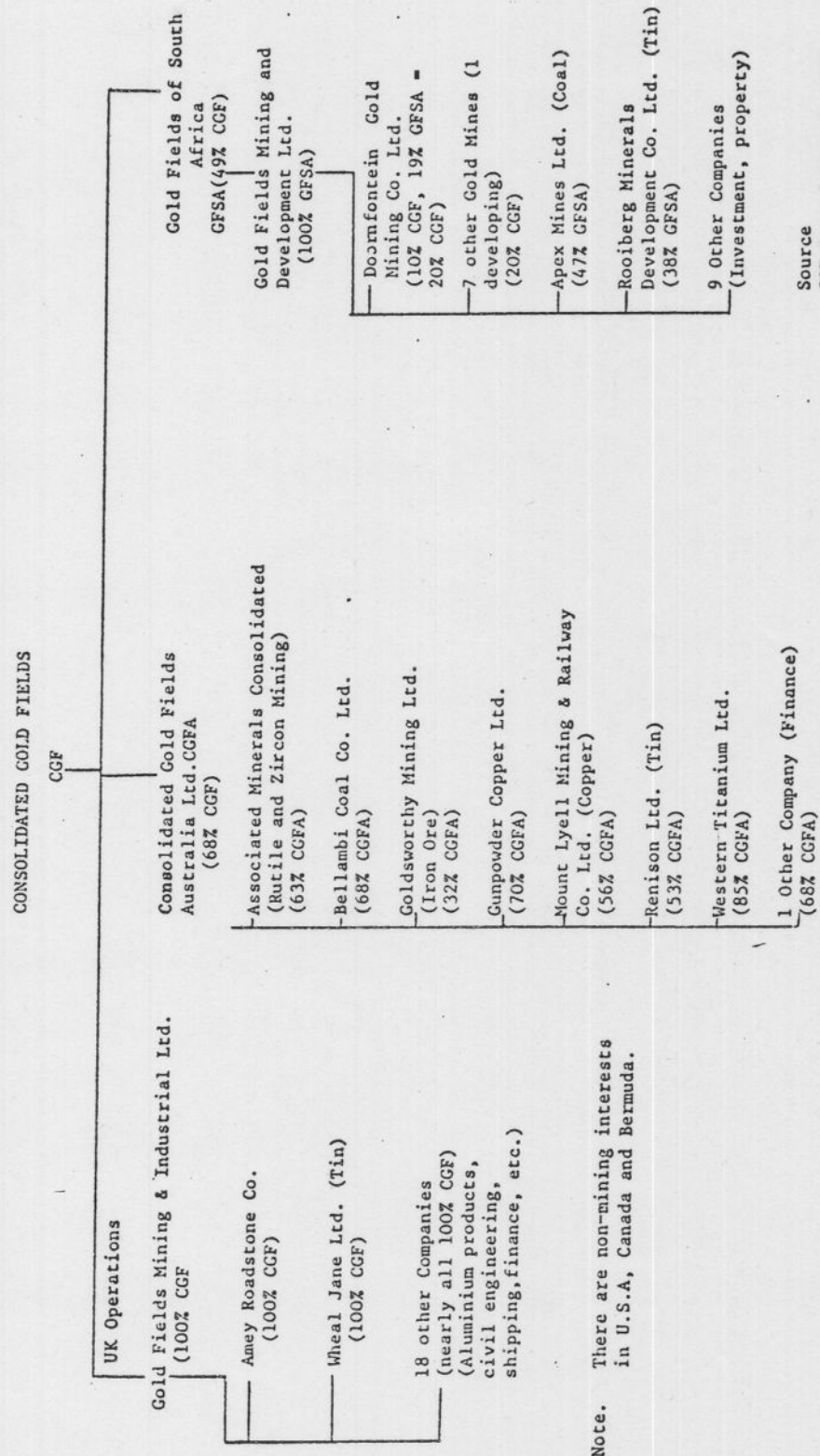
PATTERNS OF OWNERSHIP AND OPERATIONS

The IMC's have a long and complex history. For example, Consolidated Gold Fields 1976 Annual Report was the 89th. Their pattern of ownership is usually very complicated, partly for historical reasons e.g. acquisition of an operating company, partly to conform to local mining laws, and partly to take advantage of local taxation offsets.

A summary of corporate structure for Consolidated Gold Fields appears in Figure 1 - the pattern being a major company in South Africa and Australia (the main operating areas for CGF) - with a substructure of local companies partly owned or managed by CGF's major local subsidiary. CGF effectively controls a substantial slice of the South African Gold Mining Industry though usually with only about a 16% equity stake. In Australia the average equity holding in mining companies is 41%. The average equity stake of CGF in all its operating mines is 27%.

The last figure is a straight average of CGF's beneficial interests and clearly should be weighted in some way to reflect relative importance, perhaps by equity value or by turnover, both of which have difficulties of which valuation to use. From the viewpoint of corporate policy making, the expected future life for the operation, profit and equity expectations, and the Board's preferences for being in or out of a particular metal at any one time, not to mention their view of political considerations, would be at least as important as weighting factors. There are no ways of knowing in general what these factors are nor how they change, which illustrates some of the problems of data analysis for this industry.

FIG. 1 Consolidated Gold Fields Ownership Structure



RTZ has a different emphasis from CGF and a far higher equity stake - about 48%

A comparison of turnover for RTZ and CGF is represented in Table 1.

TABLE 1

£M	CGF (1975)	RTZ (1975)
Turnover of Group	565	1262
Derived from:-		
Borax and Chemicals		154
Copper		194
Gold	180.8	
Lead/Zinc and Silver	28.2	192.8
Ilmenite, Rutile, Zircon	50.8	
Platinum	11.3	
Iron		178.5
Uranium		46.2
Tin	28.25	45.2
Exploration and Research	3.6	24.6
Profit before Tax	67	171.3
Exploration as % of pre-tax profit	5.4	16%

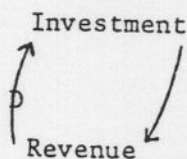
CORPORATE MACRO-DYNAMICS

The RTZ accounts include a 10 year history of the Group turnover, profit and metal prices in both current and real terms. This is reproduced in Figs 3 and 4 which shows, of course, total Group turnover and not simply the mining turnover. Mining accounted for 64% of Group turnover in 1975, a proportion which had declined over the years as RTZ has diversified. Since we are concerned with the overall dynamics and its connection to corporate strategy we use aggregate real turnover for RTZ.

We need to distinguish between RTZ as a Group, and RTZ as a Company whose revenue largely comprises Group Profits, dividends and fees for services. The Company most nearly fits our definition of an IMC but it is inextricably bound with the Group resulting from its activities, not least by interlocking directorships.

For RTZ in Fig. 3 the dynamics present some puzzling features. We know that the Group set out to achieve growth, which they clearly did. Furthermore, it is hardly surprising to see that the profit and turnover 'surge' in 1973-75 is almost exactly matched by the copper price boom of those years. However, the price movements in 1966, 68 and 70 are scarcely detectable in the curves of turnover and profit. This suggests that corporate policy is at least as strong an explanatory factor for performance as are price variations, even allowing for the part played by lead and zinc prices in producing turnover and profit. An important aspect is undoubtedly the 'metal mix', itself a policy, which is shown in Table 1. This issue is to be the subject of future research.

We do not know what policies, if any, RTZ has followed over the last 10-15 years, but we do know that their aim was growth and the evidence of Fig. 3 is that up to about 1970 they were extremely successful in achieving it. In the 10 years prior to 1970 the growth of real profit and turnover is so smooth that it cannot easily be distinguished from the behaviour of the classical positive feedback growth system represented by



where the delay, D, seems to be in the order of 5-6 years. During this period RTZ seems to have coped perfectly well with the dynamics of metal prices.

TABLE 2. CGF COMPANY EXPLORATION SPENDING

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Exploration Spending	329	701	236	817	720	973	1216	2273	3568	4260
Mining Revenue	2621	4052	6682	8897	2338	6245	6307	14822	13257	4784
Company Pre-tax Profit	10609	15060	17047	19210	14106	19214	34836	66239	67292	44612
Two year Average Pre-tax Profit		12834	16053	18128	16658	16660	27050	50562	66765	55952
Exploration as % of Mining Revenue	12.5	17.3	3.5	9.2	3.1	15.6	19.3	15.4	26.9	89.0
Exploration as % of previous Mining Revenue		2.7	5.8	12.2	8.1	41.6	19.5	36.1	24.1	32.1
Exploration as % of Current Profit	3.1	4.7	1.4	4.2	5.1	5.1	3.5	3.4	5.3	9.5
Exploration as % of last year's pre-tax profit		6.6	1.6	4.8	3.7	6.9	6.3	6.5	5.4	6.3
Exploration as % of 2 year Average Profit		5.5	1.5	4.5	4.3	5.8	4.5	4.5	5.3	7.6
Exploration as % of past 2 year average pre-tax profit			1.8	5.1	4.0	5.8	7.3	8.4	7.0	6.4

MONEY VALUES IN £ THOUSAND. SOURCE COMPANY DOCUMENTS

Fig.3, THE MACRO-DYNAMICS OF RTZ (Group)

1975 prices

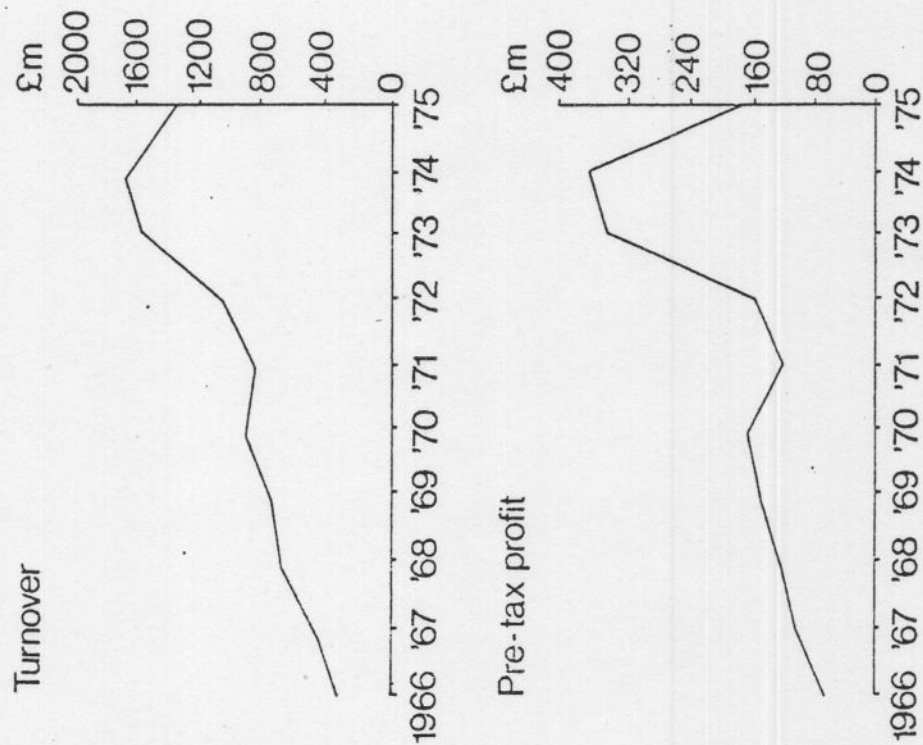
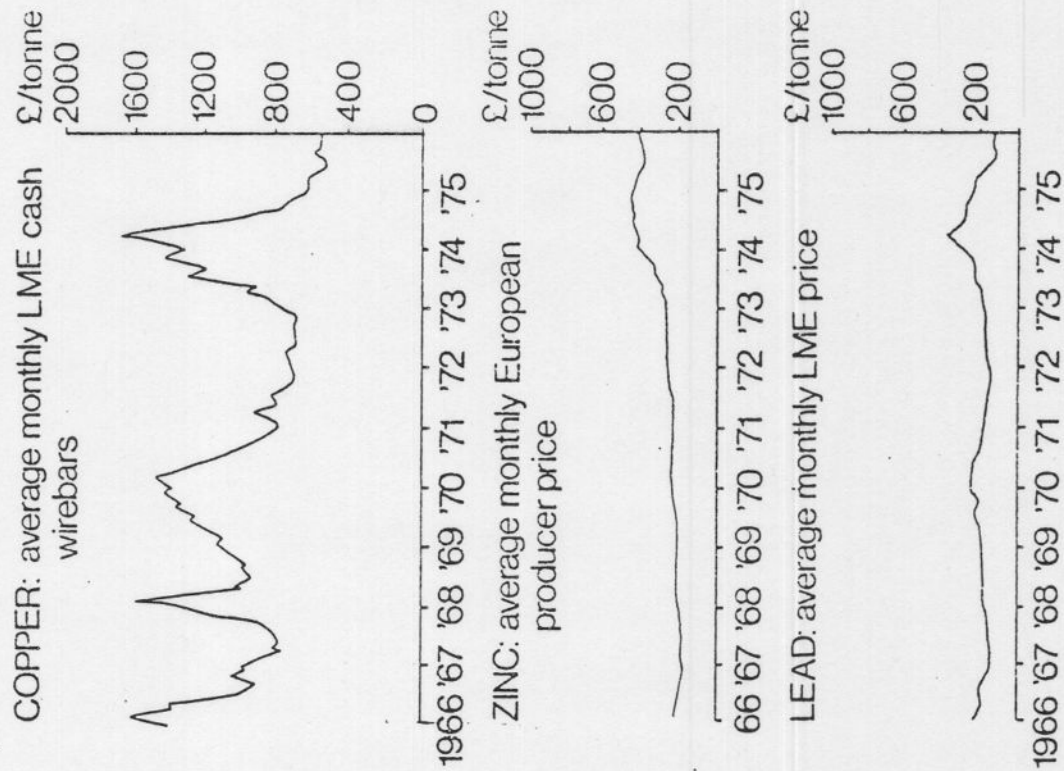


Fig 4, BASE METAL PRICES (1975 basis)



After 1970 the dynamics of metal prices were, if anything, less severe, yet we observe an alteration in the behaviour mode from smooth growth to either oscillation or transition to a stable level, though this last seems extremely improbable and would be counter to the whole history of mining.

To the extent, therefore, that policy affects dynamics we are led to the following possible explanations of the change in the dynamics -

- a) RTZ's policies which were successful in producing growth up to the 1970-72 turnover level of some £900M (1975 prices) do not work as well above that level. This would mean that there was some non-linear connection between investment and profit which produced unstable behaviour above a profit level of about £160m in 1975 terms.
- b) The relationship between policy and performance is time-dependent in the sense that the economic world changed in about 1970 in such a way that RTZ's policies operated less stably than they had in the past. This seems unlikely, in that time delays in the system would suggest an environmental change in the late 1960's, which considerably predates the obvious environmental change of the energy crisis and inflation of the early 1970's.
- c) RTZ's policies changed in 1970-72, but again this seems implausible as the Company would have seen little need for change in their performance up to that time.
- d) The policy decisions taken in the early 1960's carried within them the seeds of change in that the growth of major subsidiaries, such as Conzinc Rio of Australia, CRA, would inevitably change the pattern of the Company. This means in effect, and this is only speculation based on conversation and the non-financial parts of company accounts, that CRA, for example, would acquire objectives of its own so that, although its turnover would still appear in RTZ's total, its own policy decisions would start to impinge on RTZ performance in a way which might not be most conducive to RTZ's overall growth objectives.

It should be understood that we have used RTZ and CGF purely for illustrative purposes and that neither company is in any way being quoted nor are they being held up as examples of good or bad management.

DEFINITION OF TERMS

All the mining companies engage in 'exploration' to locate new deposits and, in due course, to bring them on stream as producing mines. They also attempt to discover new reserves, or to prove suspected ones, adjacent to operating mines and to open up new working areas in order to maintain or extend the life span of the mine. In mining practice the terms 'exploration' and 'development' are often used to denote these processes, though there is clearly no hard-and-fast division. To avoid confusion, we shall use the following definitions.

Exploration - the discovery of new ore bodies which do not lie within areas already laid out for a mine. Exploration may take place in a totally new area or on a geological extension of an existing mining district. It includes just enough exploratory drilling to establish the approximate value and extent of the deposit.

Our definition includes the rough survey of an area to see if it holds any promise and also includes the buying of rights in an area which has been explored by others.

The managerial significance of exploration expenditure is that it is the cost of trying to ensure the long-term survival of the Company or the Group as opposed to any particular entity within it. The unit cost, EXCOST, is expressed as £/unit of metal discovered.

Construction - is the process of creating a new mine. It includes detailed drilling, shaft sinking or overburden removal and the construction of processing plant there, or elsewhere. This expenditure is incurred only once and the cost parameter, CONCST, is expressed as £/metal ton contained in the mine.

Managerially it is the cost of real growth or replacement of some exhausted mine.

When the model provides for 'construction' expenditure we subsume the highly complex engineering and financial analysis of whether to invest in a new mine or continue an old one. In short, we treat the hypothetical company in the model as being technically competent in choosing between the alternatives available at any one time, and use the model to study how the company's overall strategy generates the alternatives from which the choice is made.

Capacity Spending

After a mine has been opened up there is a continual process of creating new working stopes or benches, and equipment replacement. All this spending is depleted by production necessitating further expenditure to keep the mine in being. We refer to this as 'production capacity spending' and the parameter, CAPCST, is expressed in £/t/m. The production capacity will have a lifetime, CAPLT, which will depend on the relative intensity of production operations and will be a broad average of the physical lives of the various items involved.

DYNAMICS OF EXPLORATION SPENDING

The CGF accounts provide data on Company exploration spending which seem to be close to our definition of exploration. (Construction spending is normally capitalised). The data, analysed in various ways, are presented in Table 2 and Fig. 5.

Predictably, there is a far closer relationship between last year's pre-tax profit and this year's exploration spending, than between the two on a current basis, as shown by the comparison between Fig. 5 b) and a). It would, however, be naive to infer from this data that CGF, or any other Company, spends x% of its profits on exploration, and it appears that the spending is modified by:-

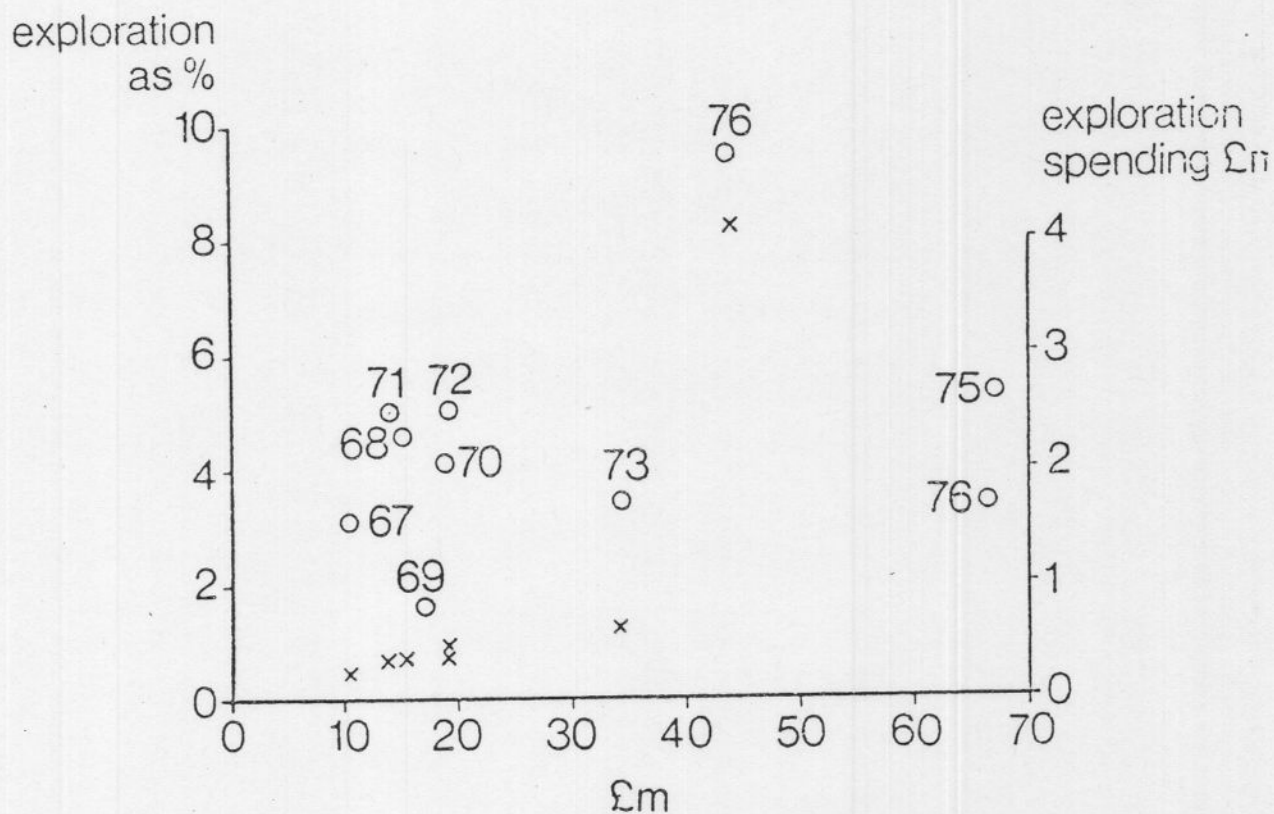
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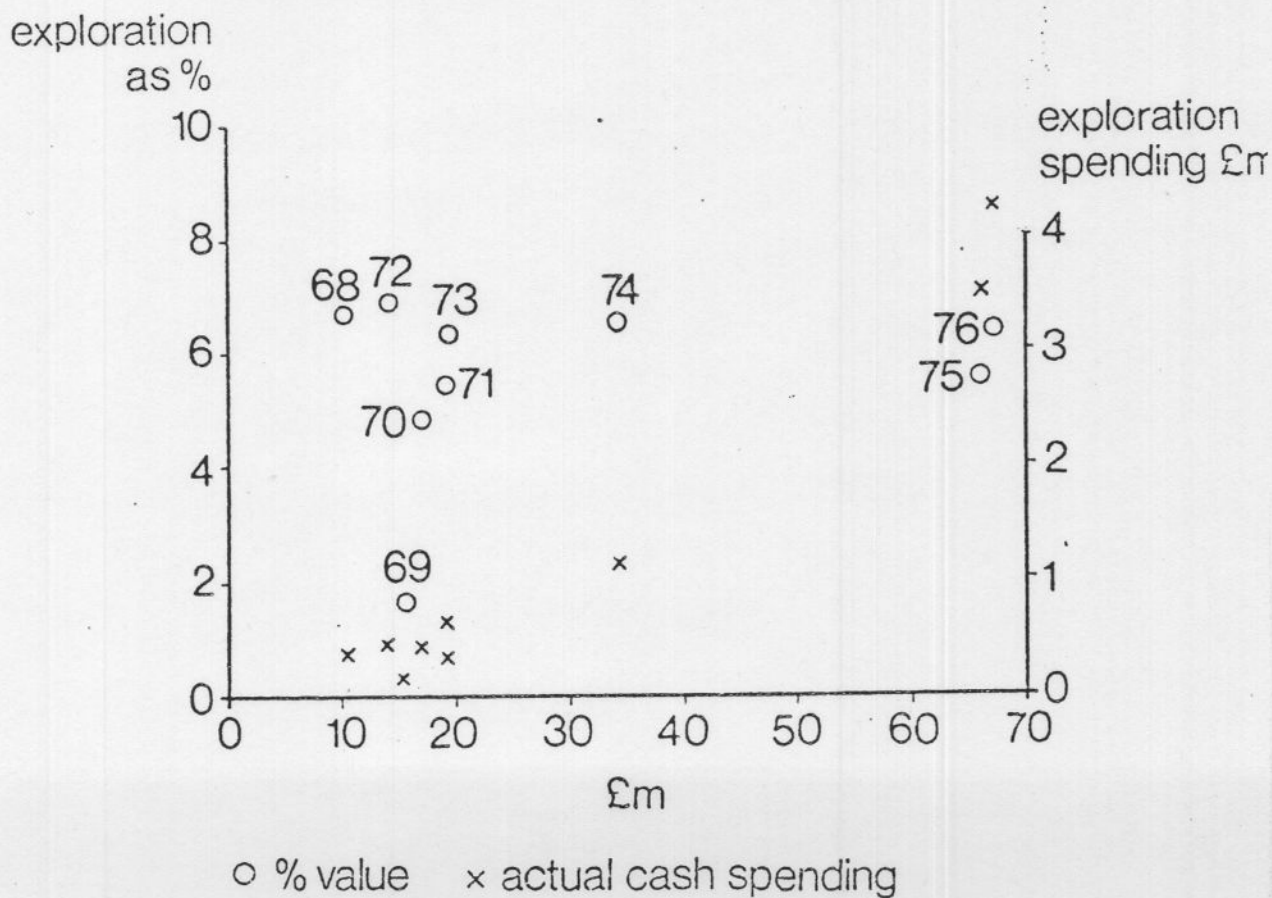
MONEY VALUES IN £ THOUSAND. SOURCE COMPANY DOCUMENTS

Fig 5 CGF's EXPLORATION SPENDING

a, Exploration as % of pre-tax profit



b, Exploration vs previous years pre-tax profit



- a) previous spending, in that an exploration team cannot be expanded, and should not be dispersed, too rapidly.
- b) apparent need to replace mines nearing exhaustion.
- c) availability of reasonable prospects for exploration.
- d) perceived need to get into a metal whose long-term outlook is attractive.

CORPORATE POLICY ISSUES IN MINING

Having so far summarised, albeit briefly, some of the dynamic history of two selected mining companies we now attempt to formulate some of the policy questions which appear to face International Mining Companies, and thus to define the scope which a corporate model should have in order to be potentially useful in the industry.

- a) What growth objective should be pursued, or should the company aim at preservation.
- b) How much equity participation should be sought in a new venture, how much should be provided as loans or debentures, and how much by 'foreign', participation?
- c) How long should be the life-horizon for a company? i.e. at what point should it say 'We have no need for further mining investments, because what we already have will keep us going for x years'.
- d) What is the virtue of long-range planning for the mining industry?
- e) Which factors should be forecast? The obvious ones are price, demand, and supply, all of which are notoriously hard to forecast, if only because the outcome is dependent on decisions taken in response to the forecasts. It may be 'better' for the company to attempt to predict its own lifetime and to base decision-making on that.

We cannot report all these research topics in one paper and, indeed, some of them will have to be reserved for future work. We can, however, summarise them into one 'key' question:-

Is it true that what is good for the subsidiaries is also good for the International Mining Company which is at the centre of the group?

The model presented below is aimed at this question and we shall, in due course, define what is meant by 'good'.

A CORPORATE MINING MODEL

We shall call the "company" 'Anglo-Consolidated Zinc', ACZ, and more details of ACZ will emerge as the model is described. The model does not, for example, appraise alternatives in the sense of whether it is better to expand production at mine A than at mine B. Rather it looks at the overall picture to study whether an expansive policy would be preferable to a defensive one in given circumstances. In essence, it deals with the managerial 'style' and attitudes of the firm - a top-level view which assumes that the detailed analysis will be delegated. Despite the fictional nature of ACZ, the model is applicable to real firms with, perhaps, some modification and the incorporation of their appropriate confidential data.

This distinction between specific decisions and the generation of long-term corporate futures is vital to an understanding of what the model is for, and what it does and does not do. The model does not forecast future profits and losses, let alone forecasting metal prices. Its main purpose is to throw light on the way in which the company's evolution is shaped by, say, its policy on investment versus exploration in the face of the economic shocks which it might receive. For example, would a policy of reducing exploration spending to release more money for mine production investment at times of high price, and vice-versa, have produced better behaviour than Fig. 2 during the metal price history of Fig. 4. Related

questions are how long a company could have pursued such a policy during the relatively high prices of 1966-1971 without encountering the possibility of having too few new deposits available to meet its own lifetime objectives. Hence, where do policies start to conflict and how should they be allowed to over-ride one another? These are very much top level decisions and we are obliged to assume that the lower-level work is performed competently, in order to allow us to concentrate the model at a reasonable level of detail.

THE STRUCTURE OF THE MODEL

The main causal relationships in the model are shown as a simplified influence diagram in Fig. 6. The arrows represent causal relationships and a + sign denotes that an increase in the variable at the tail of the arrow will lead to an increase in that at the head and that a decrease gives a decrease. A - sign indicates the opposite movement. Thus, an increase (decrease) in ACZ's Cash Flow would be expected to lead to an increase (decrease) in Exploration Spending though not necessarily proportionately. Conversely an increase (decrease) in Discovered Reserves would lead to a decrease (increase) in Exploration Spending, though certainly not proportionately. The model therefore contains conservative relationships, such as that Exploration Spending eventually leads to the discovery of reserves, on average and assuming technical competence. It also contains 'policy' relationships such as that the level of Discovered Reserves affects Exploration Spending only because, and to the extent that, management wished it to be so. The main use of the model is thus to design such policies, and there are several, so as to improve system performance by avoiding conflict between them.

The sources for the relationships in the model are general knowledge of the industry, and discussions with mining executives. The opinion of the latter was that the model represented in general what goes on in mining companies but would not be detailed enough to be a model of a company. The model does however, seem to be plausible (valid) enough to satisfy the purpose for which it was derived. For a more detailed treatment of the modelling method see Coyle (1977A) and for the detailed model equations see Coyle (1977B).

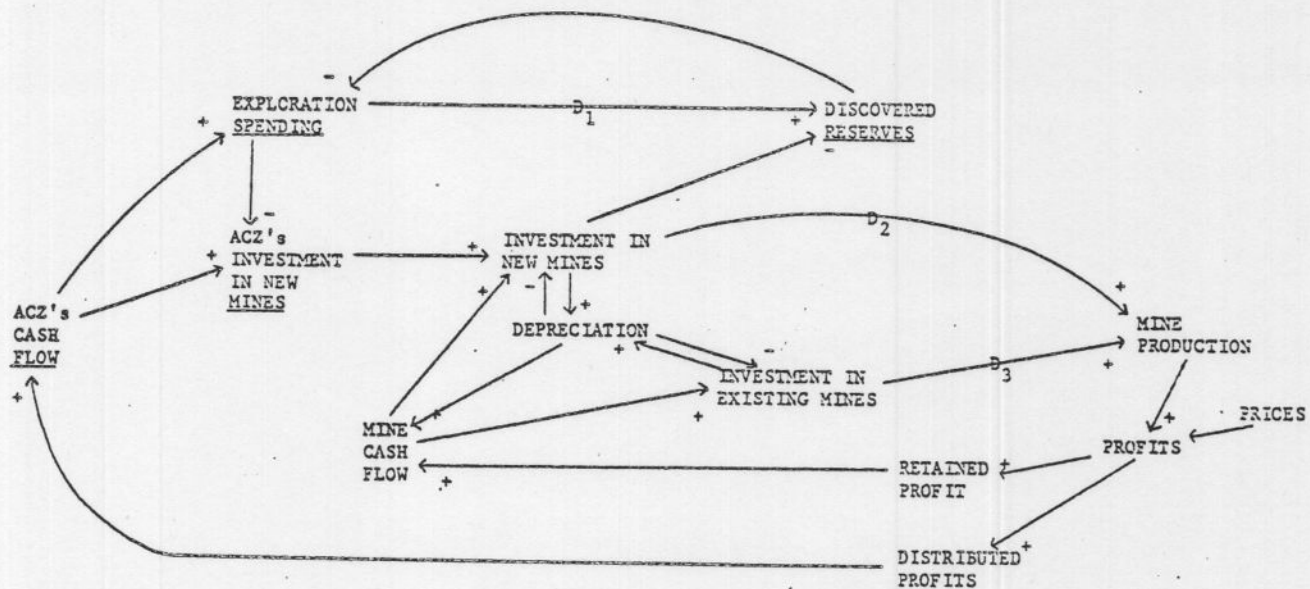
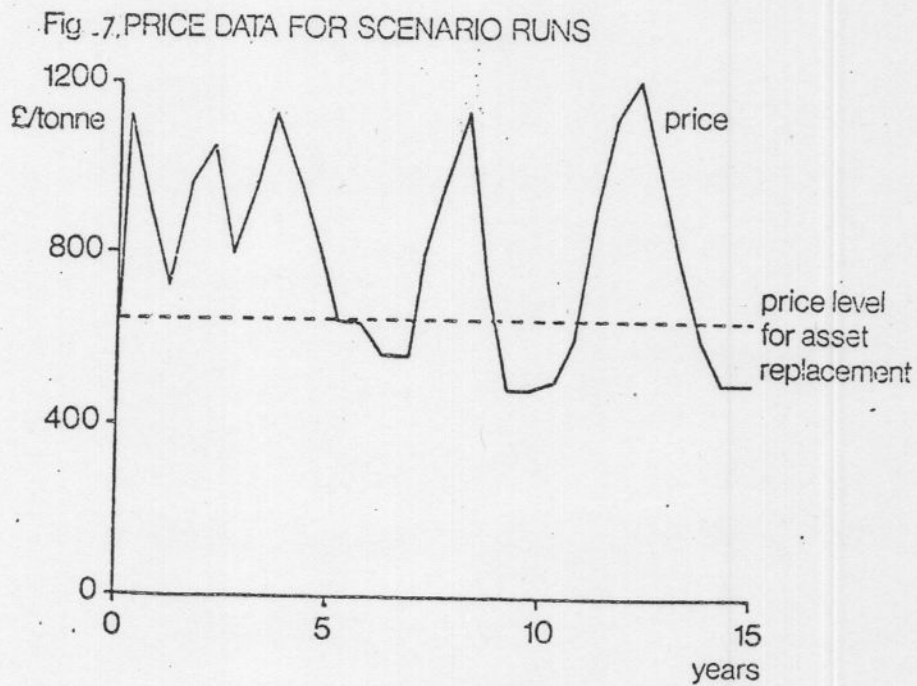


FIG. 6

SALIENT FEATURES OF MODEL



The model contains two parts - ACZ's headquarters decision making, in which the variables of concern to ACZ are underlined; and an amorphous 'operating mines sector'. At this stage the operating mines are not distinguished according to country or metal, or indeed as individual mines, this simplified view being a level of aggregation dictated by the purpose of the model. Technically, it would not be hard to model a particular company for its own planning and operating decision-making.

The only driving force for the model is metal price, something close to historical real price data. Demand is included in the model by implication, in that mines are assumed to decrease production when price, and presumably aggregate demand, is low. Price is generated externally to the modelled corporate behaviour, i.e. ACZ's production does not affect price.

In brief terms, the earnings from operating mines are divided into cash flow retained and cash distributed, some of which goes to ACZ and the rest to the 'Foreign' participants, i.e. anyone other than ACZ. The operating mines re-invest their retained cash flow either in new mines or in keeping existing mines in operation but do no exploration.

In the real world, operating companies do carry out exploration in the sense of the search for new mines as opposed to the detailed investigation of existing orebodies which are already being mined. The latter activity is treated in the model as part of operating costs. In the former case, the implicit assumption in the model is that the operating company is functioning as an agent of ACZ so that the model does no great violence to real life.

ACZ's cash provides for exploration spending which, after a long delay, creates reserves for new mines. The balance of their money goes into new mine investment, though there are delays before the investment can affect production from the mines.

This simple account does not convey all the aspects of a fairly complex model, but it does show that the model contains two interacting sets of control loops - those for ACZ and for the operating mines. Since each set has its own policies (control rules) there is the possibility of conflict between them and the model is intended to study such conflict.

The model also contains 'hard' and 'soft' variables. The hard variables (production capacity, investment, reserves, cash flow, etc.) can easily be recognised in principle and measured in practice. The soft variables, (ACZ's Life Ratio, ACZLR, which is the ratio of ACZ's expected operating lifetime and its required time horizon) would be less obvious in the daily practice of a real company. ACZ can have such a ratio because ACZ is a fictional construct, but there is no evidence that RTZ, CGF, PD or anyone actually has or uses such a concept. What then is the value of such fuzzy variables, apart from serving as an academic exercise?

Common sense indicates that a real firm must have a mental picture of something like this ratio, if it gives any thought at all to the future. The purpose of using it in the model is therefore to render the idea tractable, so that one can study how important it is to the system, how it should be reacted to, and the extent to which it conflicts with other system policies.

The parameter values for the model have been arrived at as follows:-

a) Economic Parameters

These have been abstracted from Company Reports, but would be the subject of more accurate study for a 'real' model of a particular firm.

b) Physical Parameters

ACZ produces initially 20000 tonnes of metal/month. Time delays in construction, etc. are typical for the industry.

c) Managerial Policies

Parameters reflecting managerial policy are of the right magnitude, or the model would not work, but they represent no more than informed guesses. However, one of the objects is to design policies so there is no particular virtue in starting with the 'correct' values, as there would be in the case of a 'real' model.

POLICY IN THE MODEL

a) Exploration

ACZ spend a fraction of their Average Pre-tax Profit on exploration. The fraction is normally 30% but is scaled up if ACZ's apparent lifetime falls below par, and conversely. The comparative severity of this multiplication is purely a matter of corporate policy, and represents the consequences of attaching varying degrees of importance to the future.

b) Earnings Retention by Operating Companies

In the model, operating companies normally retain 40% of their profits, but this is scaled up if they see their life horizon reduced. This models operating companies being, as it were, very unwilling to wind themselves up.

c) Investment by ACZ

ACZ retain 40% of their after-tax profit and invest it all in the construction of new mines, in which there is 60% 'Foreign' participation, thereby more than doubling the investable capital. This corresponds to modern practice.

Of the total stream of investment, a certain amount has to be in new mines, or major extensions of existing mines, to replace exhausted reserves. Some of this money comes from a proportion of the operating companies' investments. This fraction of CFGAM which goes into new mines is denoted by CONPC, the Construction Percent. The ideal value is easily calculated from the basic physical and economic mining parameters.

The model represents the real world in that the operating companies can increase or decrease the ideal value of CONPC if it is in their interest to do so. Thus, if production capacity in the operating mines gets too low, spending on long-term new projects is cut back to leave more money for present production maintenance.

d) Production Policy

In the model, production from the mines depends on production capacity and metal price. Production capacity is modelled as being a kind of nominal level from which actual production can depart.

There are three principal options for the dependence of production on price.

The first, paradoxically, is that there should be no dependence, i.e. production is always at nominal capacity and price is ignored. It has been argued that this is the policy followed at some large low-cost open-pit mines.

The second option is that as price rises, one mines the lower grade of ore, thereby reducing metal output. This happens in the South African gold mines.

The third option is the one mainly used in this paper, and this increases metal production when the price is above 'normal', and conversely. This is used to imply that high prices are linked to high demand and the extent of the production increase can easily be made to reflect either physical production constraints at the mines, or price-elasticity, or both

PARAMETER ESTIMATES FOR INITIAL MODEL

In order to get the initial model going we have to estimate some parameters representative of mining practice.

The parameter estimates are drawn from published information and are closely representative of modern mining. The main input is the metal price and the model is so designed that ACZ and its Operating Companies go through periods of very low profitability alternating with boom times.

The price pattern is shown in Fig. 7. The first 10 years of this are the half-year real price of copper from 1965-1975, scaled down a little and starting, for technical reasons of modelling convenience, at the 'Normal' price of £650/tonne at which, ACZ can just replace itself but earns only 1.5% after tax. The final 5 years represent a possible future of a further period of low prices, followed by another cycle of rise and decline. The model does not predict that this will happen, but merely traces the performance of ACZ in such an eventuality and with different policy sets.

The model is to be run over a period of 15 simulated years, a period chosen as it is about the tenure of office of a senior executive. The peaks in price above the replacement level rather exceed the troughs below it so that it should provide enough financial impetus for ACZ to grow over the period. The questions will be how corporate policy, and the relationship between ACZ and the operating companies, affects the amount of growth and its smoothness and how the system copes with the marked and protracted price fall at the end of the period.

SOME MODEL EXPERIMENTS

We do not expect the model to reproduce the growth of any actual mining company during the last 10 years partly because:-

- i) we do not know what policies they followed
- ii) there may well be inadequacies in the model
- iii) the model deals with a single 'metal'

The model will show, subject to its inadequacies, how ACZ would have performed during the period, when managed in the particular way represented by the policy set. Since it is illuminating to think of the first 10 years of Fig. 7 as the 'past' and the remaining 5 years as the 'future', (though not too literally) the runs of the model will trace policy scenarios for ACZ, and we therefore refer to them as 'Scenario Runs'.

The policies to be examined are those affecting retentions, exploration, and investment and in each case, the production policy will be the 'base metal' case of increasing production when price falls.

The other policies are set to represent:

- A ACZ dominating the operating companies
- B The operating companies dominating ACZ
- C A transfer of dominance from ACZ to the operating companies at month 84, i.e. 3 years'ago'.

Dominance in this sense means that, in Case A, ACZ can effectively stipulate the policies of the Operating Companies in such a way as to be most conducive to its, ACZ's best interests. In Case B, the Operating Companies dictate their own policies so as, say, to maximise their own future rather than ACZ's profit. This could represent either economic nationalism, or simply the growth of subsidiaries into large companies which stand on their own feet. Clearly C is likely to be the most topical scenario.

Some early experiments showed that the policies used could be so 'gentle' as to produce no effect or so 'vigorous' that the group fell apart (financially) from its own internal, policy-generated, pressures. This latter result perhaps deserves a paper to itself - its main interest lies in the fact that one could use the model to assess quantitatively the point at which centrifugal tendencies in a decentralised corporation reach the breaking stress and the group becomes literally unmanageable.

The model produces tables and graphs of well over 100 variables at successive points in time. For example it will produce annual balance sheets, production, stock and reserve figures. We have no space to present them here and merely illustrate graphs, Figs 8-9 for two policies to give the flavour of the model.

It should however, be noted that these are representative values selected for illustration and that the model is capable of producing tables and graphs of any or all of 80-100 variables for each of 180 months. If one were designing policies for a real company a much fuller study of the output would be needed.

For simplicity Figs 8 and 9 show physical aspects rather than financial. There are a number of notable points:-

- a) Dominance by the Operating Companies (The Mines), Fig. 9, leads to higher mineable reserves than does dominance by ACZ in Fig. 8, whereas the converse is true for Discovered Reserves. This is a consequence of the shift in balance between preserving the future of the Group through discovery of new reserves and maintaining the lives of the companies by the creation of mines. Clearly a balance is needed, but where does it lie?
- b) Very strikingly, production capacity is actually lower when the mines dominate than when ACZ does. This counter-intuitive behaviour is a consequence of the Operating Companies' determination to maintain their life spans. A different policy may prove more satisfactory, i.e. the strength of the domination has to be carefully worked out if the end result is not to be worse than the first.

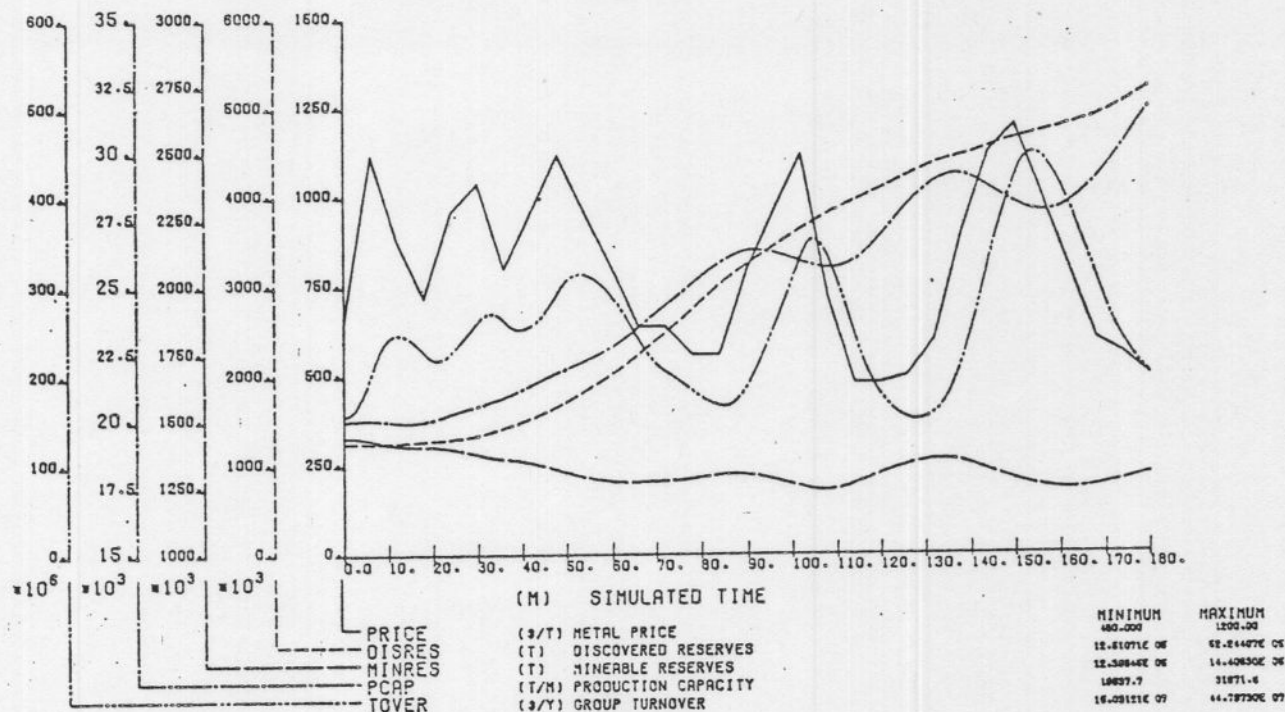


FIG 8 ACZ DOMINANT WITH PATTERN PRICES
'ANGLO-CONSOLIDATED ZINC CORPORATION MODEL'

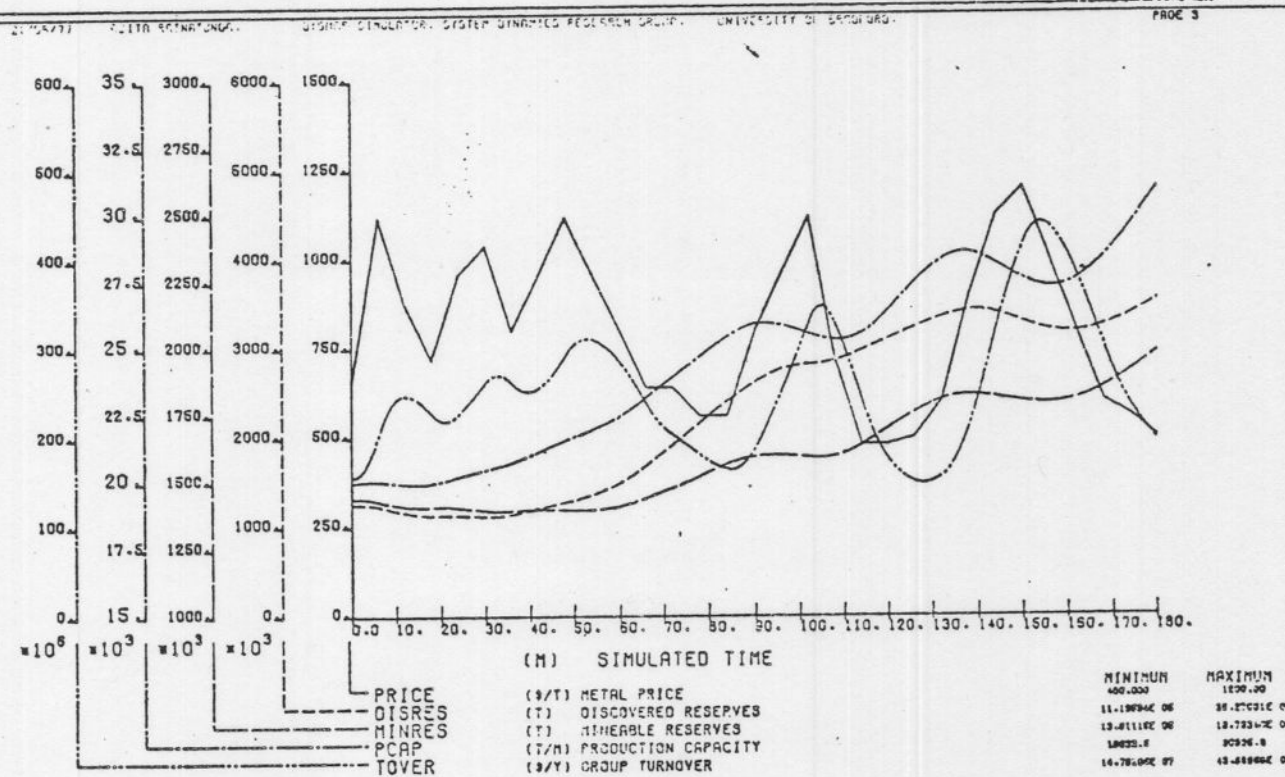


FIG 9 MINES DOMINATE WITH PATTERN PRICES
'ANGLO-CONSOLIDATED ZINC CORPORATION MODEL'

- c) The graph of turnover in Fig. 8 is qualitatively broadly similar to that of Fig. 3 in that there is a period of fairly smooth growth up to month 50 followed by a decline and surge from about 60 - 120. This is as far as we can press the comparison but it does suggest rather strongly that production policy has a strong effect on performance and that production policy ought to be re-examined if the industry is to expect any more price explosion such as that of 1973-1977.

Although it is not shown in Figs. 8 and 9, ACZ's Return on Investment is markedly lower when the mines dominate, as one would expect. One would not, however, have expected mine profits to be lower when mines dominate, but they are.

There is no space to pursue the detail further than this. We sought to show that policy differences produce behavioural changes and the model amply demonstrates that :

- i) it is capable of indicating the extent of such variations
- ii) the variations are by no means equal for all the variables
- iii) the effects of policy can be surprising in that, for example, one might not have predicted that the mines would make lower profits when they dominate than when ACZ do.

The last point stems from the policies followed and shows that one policy, in this case the one to do with mine construction to maintain operating company lifetime, is dominating the others. This suggests that it may be possible to find policies which are within ACZ's control and which could be so designed as to override the policies within the operating companies by which they attempt to dominate ACZ (or, of course, vice-versa, depending on whom one was working for). Put another way, this rather subtle idea suggests that:

- a) the collective ACZ/Operating Company system contains many policies, some within the span of control of each partner.
- b) In the past, ACZ have been able to dictate all the policies by, in effect, making the operating companies follow policies on, say, earnings retention, which were not harmful to them except that they paid little attention to the operating companies' life expectations for the sake of the benefit of ACZ.
- c) Rising economic nationalism, or the growth of the operating companies into large corporations in their own right, may no longer allow ACZ to dictate the operating companies' policies. Accordingly they follow their own objectives and the consequences may not be, overall, most beneficial to ACZ.
- d) There may still remain policies within ACZ's span of control, which the operating companies cannot affect, and which may be capable of being designed so as to override the transfer of dominance to the operating companies which ACZ would otherwise be powerless to prevent.

The model also shows the very long delays produced by the interaction of policies and physical delays. It takes about 8-9 years for the system to settle down after a major change. This has some interesting implications for corporate planning.

OVERALL PERFORMANCE INDICATORS

Although the best way to understand the output of a system dynamics model is a close examination of the graphs and tables, it is sometimes convenient to calculate a performance index, PI, in the form of a single number to encapsulate a whole run on the model. This has advantages and limitations, as discussed in Coyle (1977C) but it does enable overall comparisons to be made between different model runs. The PI's for this model represent the viewpoints, respectively, of ACZ, ACZPI, and the operating companies, OCPI. Both indices are calculated according to the method given by Coyle (1977C) and are so framed as to reward the attainment of desirable final values, while penalising instabilities encountered during the simulated period.

The numerical weights attached to each factor in the PI, and the factors to be considered, have been arrived at from discussion with managers. They represent an amalgam of different views and do not reflect any particular firm's objectives. They could, however, very easily be altered to make them fit any given company.

ACZ's index rewards attainment of high values of total Investment TINV, ACZ's investment, NIACZ, the general level of ACZ's ROI, and the value of the discovered reserves at the end of the run. The ROI factor is regarded as twice as important as the others. It penalises variations in Group turnover, mine profits and ACZ's rate of mining investment; these three factors being regarded with equal disfavour. The attainment of final values is represented as being twice as important as the avoidance of instability. In short, ACZ's PI would favour policies producing smooth growth with a high ROI.

For the Operating Companies, which are more vulnerable to swings and roundabouts, the achievement of final values is only 50% more important than avoiding instability. The PI rewards Total Investment, TINV, and Effective Mine life, EML, with the latter being taken to be twice as important as the former. It penalises variations in Effective Mine Life, Mine Profits, Mine Production and Cash Flow Generated at Mines. The third is regarded as twice as unpleasant as either of the first two and the fourth as three times as important.

In short, the performance index favours policies producing growth and, but far more so, the preservation of mine existence, while penalising policies producing behaviour which threatens continuity of the ability to maintain active existence.

The performance indices represent the author's distillation of views reflecting the divergence of objectives between ACZ and the operating companies in which ACZ is a minority shareholder. The indices have no objective validity but are reasonably indicative of current corporate viewpoints. They could easily be altered to fit an actual company. Their main value at this stage is that they enable us to see at a glance whether or not it is true that, as is often argued in mining circles, 'what is good for the operating companies is good for the International Mining Company'.

The results obtained from the performance index are shown in Table 3 for various policy tests on the model. These tests are by no means exhaustive and there are many other options still to be tested but such a test involves only a few minutes to alter the model and a few seconds of computer time.

The performance indices are calculated from a Base Case which represents fairly well a midway case between ACZ dominating the Group and the other extreme of ACZ having no control over the policies of the operating companies. The Indices have been constructed to be 100.00 for this Base Case and are of the 'more means better' variety, i.e. the higher the Index, the better the policy for that particular participant.

TABLE 3 PERFORMANCE INDEX COMPARISONS

Policy Test Run	ACZ's Index	Operating Companies Index
1. Midway Policies - Base Case	100.00	100.00
2. Low Grading when prices are high	118.14	39.95
3. ACZ Dominant	112.41	56.60
4. Operating Companies Dominant	81.21	138.40
5. Dominance Transfer at Month 84	72.19	118.40
6. Operating Companies Dominant with higher retentions	17.31	104.19
7. Operating Companies Dominant with lower retentions	128.22	165.08
8. Operating Company with 'flat' policies and lower retentions	115.26	73.20

Policy 2, Low Grading, is one in which metal production is actually reduced when price rises, rather than increased as discussed earlier. This is standard practice in the S. African gold mining industry. ACZ do rather better from this policy mainly because the steadier cash flow enables them to have more stable reinvestment. The operating companies do a good deal worse essentially because of the production variations and the associated effect on mine lifetime. This suggests, not that the low-grading option should necessarily be abandoned by the S. African gold industry, but that there is rather more to low-grading than simply calculating the cut-off grade and then mining to that grade. The model could well be used to design a better low-grading policy.

Domination by ACZ in Run 3 naturally leads to an improvement from their point of view, but, equally, the Operating Companies suffer. The converse, in Run 4, gives the opposite result. Remarkably enough, in Run 5, when there is a transfer of dominance at month 84 the results for the Operating Companies are intermediate between those of Runs 3 and 4 but ACZ's performance is worse than either Run 3 or 4. This is due to the shock of the dominance transfer creating such instability in ACZ that overall performance falls off. The detailed results are not shown in Table 3 and in practical modelling one uses a much more sophisticated table enabling one to trace why and where a performance index has improved or deteriorated.

Run 6 represents an even greater degree of domination by the Operating Companies in that not only do they govern the way in which earnings retention is increased to maintain their own existence, but they also normally retain more money in any case. This is crippling for ACZ, but is also worse for the Operating Companies than Run 4 would have been. This demonstrates the close interdependence of the Operating Companies and ACZ and suggests that the Companies cannot afford to do too much harm to ACZ.

The main conclusion from Runs 2 - 6 is that it is manifestly not true that what is good for the Operating Companies is necessarily good for ACZ, and vice-versa. This result is quite contrary to the received wisdom in some of the IMC's. The result cannot be pressed too far as further confirmation is undoubtedly called for but it at least demonstrates the need for further thinking and casts doubt on simplistic views of the mining industry.

In Run 7 we test the situation of the Operating Companies dominating but from a lower normal level of retentions in the sense that, if the need for increased retentions arises, the Operating Companies put their own objectives very firmly ahead of the well being of ACZ, but the base level from which the change takes place is lower than in Runs 1 - 6. In practical terms this means that ACZ follow a practice of setting up new mines of rather lower normal retentions than before, thereby constituting a counter action by ACZ to economic nationalism. In this case both ACZ and the Operating Companies achieve, not only better performance simultaneously, but also the best performance of all the runs presented here. This contrasts with Runs 2 - 6 where, if one gained, the other lost. In the case of Run 7, the improvements come respectively from an increase in ACZ's Final Values and a large reduction in the Operating Companies' instability. This reinforces the comment about the interdependence in the ACZ Group and suggests that the corporate inter-relationships are far more complex than appears from the interlocking of shareholdings and directorships. In other words, in a mining group policies need to be carefully tuned if everyone is to benefit.

Finally, to emphasize the importance of policy, we consider Run 8 in which we use the lower normal retentions of Run 7 but 'flatten' the control policies. This is easily done in the model and is roughly equivalent to the real world situation of the mining company which claims not to have policies at all but simply to react to events and opportunities. The performance for ACZ is fairly respectable but still not as good as in Run 7 when the Operating Companies were dominant. For the Companies the performance is fairly awful due to a large increase in instability.

Clearly, the details of how this process functions can be varied and the consequences of different corporate planning procedures can be measured by the same performance indices discussed in the previous section. The whole area of planning is undergoing further research, but the results of some preliminary runs are given in Table 4.

The Performance Indices in Table 4 are exactly consistent with those of Table 3 and show the effects of different planning procedures with perfectly accurate forecasts of price and with price forecasts which are consistently 20% optimistic and 20% pessimistic. These simple cases are used here for illustration.

The lesson of Run 8 is that mining companies do better if they have control policies than if they don't and the company which claims merely to react would probably do well to get itself some control policies. The lesson of Table 4 is that policy design has unsuspected ramifications and that some policies do markedly better than others. Selecting a mix of policies is not a simple matter but a model of the type described here would take only a matter of a few man months of effort to prepare for a real company and should be capable of producing very considerable benefits. For example, the highest Index for ACZ is some 7 times better than the lowest, though this is not in monetary terms.

CORPORATE PLANNING IN MINING COMPANIES

The basic ACZ model described here is free of 'planning' in the sense that the components of the ACZ group attempt to regulate their current activities but not to attempt to attain specific targets at some future date. As we have shown the degree and form of that regulation affects the performance quite noticeably. Corporate Planning is, however, popular in industry at large and, accordingly the ACZ model was altered to reflect the introduction of some rather simple planning procedures.

The 'planning' in the model consists of a forecast of general price levels at a point in the future. The 'distance' of this point in the Forecasting Horizon and the model can be used to assess how far one should forecast, allowing for the greater errors one may expect from more distant forecasts. In response to the forecast, the Group attempts to expand a contract depending on the magnitude of any expected price changes. The steepness of this response is a policy decision so we can study the extent to which a company should be aggressive or not. The size target so derived is then responded to by the creation of two streams of desired spending; one for production capacity creation, and the other for the construction of new mines. Generally, the required spending will not match the available funds and the conflict is resolved by the policies of ACZ and the Operating Companies.

Situation Examined	Perfect Forecasts		Optimistic Forecasts		Pessimistic Forecasts	
	ACZPI	OCPI	ACZPI	OCPI	ACZPI	OCPI
Planning with Midway Policies 9. Base case from table 3	145.72	226.10	123.39	168.08	160.34	256.71
10. Planning with Low-Grading	116.59	241.94	94.95	212.60	149.64	212.24
11. Planning when ACZ dominant	-209.07	94.96	~ 147.60	100.16	-313.60	- 21.20
12. Planning when Mines dominant	85.43	84.57	92.89	116.08	94.59	- 7.67
13. Planning with no growth objective	99.08	-31.14	99.08	-31.14	99.08	- 31.14
14. Planning with steep growth objectives	76.14	89.82	117.18	110.09	11.83	-1398.9
15. Planning with midway policies, normal objectives, and faster responses	89.86	73.10	92.71	115.76	57.96	- 194.87
16. As in Run 15 but with lower earnings retention by the miners	113.89	87.38	115.76	133.47	72.29	- 191.09

Note ACZPI ACZ's Performance Index
OCPI Operating Companies' Performance Index

Table 4 Performance Indicator Values with Planning

The runs in Table 4 have been numbered from 9 - 16 so that they are not confused with runs 1 - 8 in Table 3. The policies in runs 9 - 12 correspond exactly with those of runs 1 - 4.

If we consider the case of perfect price forecasting it is easy to see that either ACZ or the Operating Companies are worse off with planning than without it when there is domination of one party by the other. However, in the midway case of Run 9, the performance for both is far better than any run in Table 3. Even with low-grading (Runs 2 and 10), ACZ do only very slightly worse with planning and the Operating Companies do very much better. In all cases, the improvement comes from reduced instability rather than higher final values but this is of course, one of the things that planning is supposed to achieve.

Runs 13 and 14 present some interesting contrasts. For each of them all the policies are the same as the mine domination case of Run 12, except that the steepness of the growth objective with respect to price forecasts is altered. In Run 13 it is removed, i.e. the price forecast is ignored - ACZ do slightly better but the companies do far worse. In Run 14 the response to, say a forecast of higher prices is very sharp and high objectives are set. In this case ACZ does worse than in Run 12, but the Operating Companies do a little better.

The point of this is not to recommend any particular forecasting response pattern to mining companies but to stress that the form of the response will have a profound effect on system performance and that attempts to improve the 'accuracy' of the forecast are only a very small part of the story. In short, what matters for system performance is not only the accuracy of the forecast, but also the way in which it is used in the system.

Finally, we consider briefly the effect of forecasting error on the system performance. This can be done by reading Table 4 across the rows. Some rather surprising results emerge. For example, in Run 9, a + 20% error in price forecasting leads to a deterioration of 15% in ACZ's performance and of 26% for the Operating Companies. On the other hand, in Run 12, the same error in forecasting would lead to an improvement of 8% for ACZ and of 20% for the Operating Companies.

Generally, the effects of forecasting error, for good or ill, are felt more severely by the Operating Companies than by ACZ. However, in Run 10, the deterioration in performance is 12% for the Operating Companies with 18% for ACZ.

We have no space for a fully detailed comparison of the effects of optimistic and pessimistic forecasting errors, but we may examine the results in table 4 as follows:-

- a) Corporate Planning in mining companies is probably only beneficial when there is no attempt by one side of the Group to dominate the other. The essence of planning is to harmonise the organisation, dominance is disharmonious so our result accords with common sense.
- b) Our treatment of corporate planning has been rather simplified but a comparison of, say Runs 9 and 15, suggests that the precise mechanism of planning is important to system performance and the comparison between Runs 9 and 16 implies that there are stronger prospects for improving performance by good planning than by changing the basis of financial operations as we did in Table 3. Further work is now in hand to develop planning models which perform better than Run 9.
- c) Forecasting has an effect on system performance and it is by no means true that 'accurate' forecasts are better than 'inaccurate' ones. This is, at first sight, a most surprising result but it is perhaps one of the more profound results to emerge from the system dynamics literature, (Coyle 1977A). This particular model is fairly sensitive to forecast errors but it is often possible to redesign system policies to remove such sensitivity. That does not imply that forecasting is useless and should be abandoned but that larger improvements to performance can often be attained by redesigning system policies than by pursuing the unattainable goal of perfect forecasts which may, in fact, be worse for the system than some errors e.g. the comparison between perfect and optimistic forecasts in Runs 12 and 14 - 16.

- d) Even this fairly simple test on the model demonstrates fairly clearly that pessimistic, or cautious, forecasting is likely to be worse for system performance than either perfect of optimistic forecasts unless the control of the system is fairly moderate as in Run 9.

CONCLUSION

This paper has sought to show how system dynamics modelling can be applied to problems of corporate policy. The emphasis has been to show how one can model some apparently 'political' issues and, more particularly, the form of the results that can be derived from such a model.

We may conclude that:

- a) The policy problems of the mining industry are indeed complex, but that a useful and useable model can be constructed.
- b) In the absence of any attempt at corporate planning the trend towards economic nationalism and dominance of the Group by the lifetime objectives of the operating companies will be harmful to the holding company (Runs 4 & 5, Table 5).
- c) The harm to ACZ can be termed to benefit by careful choice of the basic financial conditions of operation (Run 7 Table 5).
- d) Corporate planning could have beneficial effects providing there is balance in the Group rather than dominance (Run 9, Table 6).
- e) To the extent that Corporate Planning is dependent on medium term price forecasts the effects of forecasting error depend on the system policies, and some policies are markedly better than others (Table 6).
- f) Some planning mechanisms are much better than others (Runs 9 and 15, Table 6).

Further work on these issues aimed at assessing the effects of forecast errors, and designing forecast error sensitivity out of the system, and developing effective corporate planning procedures is in hand and will be reported in due course.

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