The Relevance of Computer Methods to the Economics of the Mineral Industry

SYNOPSIS
This paper describes the various new computer-aided techniques being used by economists in the construction of economic models. It discusses the relevance of these techniques to mining industries. In particular, it describes their role in making it possible to obtain better estimates of future price and demand developments on the markets on which metals are sold, and how these estimates can be used to improve forward planning by mining companies.

INTRODUCTION
Companies in the mineral industry are continually faced with the problem of whether to invest in additional production capacity. Decisions concerning this problem usually depend on the expected rate of return of the proposed investment. This paper describes the latest techniques which are being employed to give accurate short- and long-term forecasts of metal prices in order to arrive at a satisfactory analysis of expected profitability in mining.

With the advent of computer and associated technology, the mineral industry has found means for applying rapidly relatively standard mathematical techniques to large quantities of data in order to make, for example, an accurate estimate of capital requirements. Such technology has been introduced in prospecting and surveying with considerable improvement in efficiency. Also, there has been a quiet revolution in the technical and costing departments. Production methods and schedules and their associated costs can be evaluated accurately well in advance.

However, an accurate evaluation of controllable cost and capital requirements is only one side of the picture. In order to determine the overall viability of an investment, an accurate assessment has to be made also of factors outside a company's control, that is, of future demand and price. Up to the present time this has usually taken the form of extrapolations of existing trends of 'high-low'-type estimates. But the outstanding feature of most commodity markets, including those of many minerals and metals, is that trends are almost a statistical abstraction. In any one year, demand, supply and price are rarely on trend; they are usually well below or well above trend. Simple trend extrapolation will at best be only a first approximation and, therefore, inadequate for many purposes such as estimating likely repayment periods for mine investments.

In recent years, however, quantitative techniques suited to coping with this type of problem have evolved and refined. In essence, these techniques have allowed one to build mathematically-constructed behavioural models of different types of economic systems. As a result, it is no longer necessary to rely on how a market has behaved on average in the past to extrapolate into the future. It is now possible to build mathematical models that incorporate total market behaviour in such a way that one can not only forecast the likely future trend but, more importantly, behaviour around that trend. First governments, and now the private sector, are availing themselves increasingly of these techniques which, when applied discriminately, have more than repaid the investment in their development. Using these techniques to simulate and to forecast future developments in whole economies is a far more complex exercise than coping with the same sort of problem in a commodity market. Admittedly, the interaction of the various elements that make up supply and demand of a commodity can be very involved as well. All the same, it is much easier to analyze a commodity market than it is to analyze whole economies.

Thus the extension of these techniques, made possible through creative employment of the computer, to non-ferrous metals and, indeed, other commodities, is perfectly logical. Some non-ferrous metals exhibit extreme price instability, but this is not just random. In the case of copper for example, 95 per cent of year-to-year price changes have been traced directly to quantifiable movements in supply and demand. This means that movements in prices and other variables can be forecast successfully once the basic behavioural features or characteristics of the market for a particular commodity have been assessed. The key task is to construct a framework or model within which even, say, the price impact of strikes, usually considered a complete imponderable, can be estimated. Evidence of the superior predictive accuracy of computer-based techniques over existing methods generally employed is provided by the Commodities Research Unit's (CRU) short-term price forecasting model for copper. It should be borne in mind that copper is a metal which is subject to particularly wide and sharp price fluctuations. Only two years ago, and to nearly everyone's surprise, the copper price fell from £750 to £450 a ton in the space of eight months. Our model forecast this drop successfully and since price forecasts were first released in 1969, we have, with only one exception, consistently been within six per cent of actual outcomes. In the case of copper, short-term and consumption forecasts, the accuracy has been within even narrower limits.

Statistically-based forecasts cannot, of course, eliminate uncertainty about the future completely, but the quality of forecasts can be improved dramatically by mathematical analysis of the relationships that have determined supply and demand in the past and the ones likely to hold in the future. This scientific approach also allows one to assess the probability of error in advance. The probability assigned to likely future prices can in itself be a guide to policy decisions or forward planning estimates.

BUILDING AN ECONOMIC MODEL
An economic model is a representation of the real world constructed in such a way that the reactions of a given economic system or market to particular stimuli can be investigated artificially. In practice, most economic models will be simplified representations of reality in so far as different economic models focus on particular aspects of the real world. An economic model consists of a system of equations that show how markets, variously defined, work. Of course, design

By R. PERLMAN*
Engineers perform this sort of model building of physical systems like bridges and refineries all the time. The difference between this type of model and an economic model is that the relationships between the variables with which the engineer works may be complex, but are based on known exact physical laws, whereas an economist usually has to identify the relationships for himself, and these are never exact.

This is not surprising given that economic models have to cope with human behaviour. Nevertheless, if economic models are not based on exact relationships what purpose can they serve? In answering this question, perhaps the most important point to bear in mind is that most decisions that anybody takes are based on considerations which are to some degree uncertain. Nevertheless decisions are taken and the process involved in taking these decisions is in essence little different from building an economic model. The more complex the decision and the larger the investment involved, the more important it becomes for the decision-making process to be done formally with all the assumptions and hypotheses defined clearly. In addition, formal as distinct from informal model building has the virtue of clarifying ideas and views, and of generating new ones.

No mining company would invest in a new project until it has been well costed in advance, and this itself is a form of model building. Similarly, mining companies are coming to the view that as well as analyzing, or modelling, the technical aspects of a project, analyses of the market in which the product is sold are just as important, particularly in the case of metals and minerals given the almost endemic instability in their demand and, in many cases, in their prices.

The first step in building a model is to define the purpose of the model. Although a motorist could use a very large scale map for a long-distance journey, one showing only the major roads would serve. On the other hand, a surveyor posting out a plot of land would go to much greater detail as people. It is the same with a metal market. It is of vital importance to a speculator to know within a very small margin what the price of the metal in question is going to be over the next few weeks. The semi-fabricator with a stock problem may wish to know whether prices are going to be significantly higher or lower over the coming months, without caring too deeply about the precise level. For the primary producer on the point of investing, it is very important to know what sort of prices he can expect over the next 25 years, and particularly whether prices during the first 5 to 10 years of a new project will be at levels such that capital and interest can be repaid. The precise level of prices in each of these years is of less importance (provided that they are not at such levels that losses would be incurred) than knowing what the cyclical pattern is likely to be.

Our experience at CRU has been that short-term models have to be very complex, since fundamental supply and demand conditions change and interact with each other slowly, and that the short-lived phenomena such as strikes, stock changes and the like, are equally important. For long-term work, these can be discounted; what is required is accurate simulation of the way the fundamentals will change and interact.

Given that the first stage in model building, that is, deciding what the model is to be used for, has been accomplished, the actual construction work can be broken down into three principal stages.

The first is to specify the model. This means identifying the variables which are important in the real world and roughly how they are related. Basic to this stage and to the construction of model building is a detailed practical understanding of how the particular market operates. This is absolutely essential, for the final model can be only as good as the knowledge on which it is based. The initial specification of the variables and their inter-relationship may be verbal, but it must be translated ultimately into a system of mathematical equations which reflect accurately the way the particular market operates, and which are simple in form.

The second characteristic is desirable because experience at CRU has taught us that complex formulations, even though apparently more realistic, give less accurate predictions. This arises mainly from the point made earlier that economic laws are inherently less accurate than physical laws — a car engine is complex, but it works well because the laws governing its behaviour are known. It is no accident that the early steam engines were simple, because engineers then knew less than they do now. Striking the fine balance between accuracy and simplicity is an art which comes only with experience, and we may expect to see economic models containing more complex relationships as the underlying relationships become better understood.

The other important distinction to be made at the specification stage is between those variables that are exogenous to the model, and those that are endogenous to it, that is, between those variables whose values are taken as given, and those whose values the model is attempting to predict. For instance, a model of a mineral market would almost inevitably take the level of world manufacturing output as given; this is explained by factors quite outside the market in question, and it could not reasonably be required of the model to predict it.

The primary endogenous variables are the supply, demand and price of the metal. As can be seen from the diagram in respect of copper, there are then broken down into their constituent parts such as mine output, scrap, refined metal consumption and stocks. Their interaction is determined by an analysis of how they were linked in the past. These linkages between endogenous variables provide the inner mechanics or behavioural characteristics of the market. The force with which they interact at any one time is then determined by the values assigned to exogenous variables such as the level of industrial activity, strikes and net past consumption which constitutes the potential pool of old scrap.

The next step is the estimation stage, which involves assigning numerical parameters to the relationships in the model. Thus if the model postulates a relationship between demand for the metal and the level of world manufacturing output, it is necessary to specify the precise increase in demand resulting from a given increase in manufacturing output. Assigning the numerical relationship between different variables is generally done on the basis of past experience, and with the help of techniques that will be discussed later. Whatever techniques are used, however, this stage will involve reference to the data on the past behaviour of the relevant variables. The collection and refinement of data are perhaps the most time-consuming part of model building in an industrial context.

The final step is the forecasts themselves. At this stage, a system of simultaneous equations, involving the endogenous and exogenous variables in numerical relationships, is available. Values must be assigned to the future levels of the exogenous variables. In a sense, these are forecasts in themselves, but they are much simpler to make without a model than forecasts of the endogenous variables. Thus, the future world level of industrial activity may be the single most important exogenous variable. This changes irregularly from year to year, but there is a pronounced upward trend and we may reasonably expect that this trend will continue. If we are interested in short-term forecasts, we will turn to the forecasts of next year’s activity produced by the economic forecasting bureaux in the industrialized countries. For long-term forecasts, an extrapolation of the past trend would be more
appropriate. Even if, however, one was to extrapolate to obtain the values for the exogenous variables, this does not mean that the figures produced by the model itself will be growing smoothly. Even if one assumes an even growth in refined copper consumption over the next 10 to 15 years, the inner mechanics of the copper market will, surprisingly enough, still produce fairly marked price cycles.

Once values have been assigned to the exogenous variables, the set of simultaneous equations is solved to give forecasts of the endogenous variables. If the model has been specified correctly, and if the estimation procedure has been carried out correctly and has shown that the equation did in fact represent past behaviour accurately, then the forecasts must necessarily be good, although they will never be absolutely accurate. There is always an element of randomness, and this implies that the forecasts will be subject to a margin of error, even if the assumptions made about the exogenous variables turn out to be absolutely correct. On the other hand, if econometric analysis is used at the estimation stage, the very existence of this inevitable margin of error can be used to specify in advance the probability of the actual outcome deviating from the forecast by more than a specified amount, say, plus or minus five per cent. This question of 'degree of confidence' is touched on in more detail later.

It may well turn out that the forecasts themselves appear totally unbelievable in the light of past behaviour. This in itself can be illuminating. Closer examination of the forecasts may indicate that some aspect of the real world which was excluded a priori from the model on the grounds of lack of importance is, in fact, important and should be included, or it may turn out that the forecasts are to be believed. Thus very few people in the copper industry in 1963 (when the price was 30 cents per pound) would have believed that the price would more than double during the next six years, as it in fact did. However, we at CRU some time ago constructed a simple model of the copper industry using information and data available only up to 1963 which indicated precisely this.

A question frequently thrown at those who build economic models in metal markets is how one can cope with an imponderable variable such as strikes. The strike pattern in copper, for example, has become a built-in characteristic of supply, but it may be that in any one period there is likely to be an unusually large, or an unusually small, proportion of the metal lost in stoppages. Assumptions about this can be made and once this is done the effect of a strike loss on the price of the metal can be assessed, the loss of production/price relationship being a known characteristic. Only in three of the last 15 years have strike losses in the case of copper been appreciably more than two per cent of annual refined output, and in each of the three years when strike losses were greater than two per cent the loss was due to strikes in America where the possibility of the strike occurring was certainly known in advance. Thus in the case of these large strikes it is possible with the help of a model to form some judgement ahead of time about their likely impact on prices. Smaller strikes, on the other hand, can be dealt with fairly easily by allowing for what might be called a normal strike loss. Strike losses greater or smaller than the normal we have found to
be unimportant in determining the underlying movement in copper prices over any one year and even over six-month periods.

Of the four stages of model building, namely, defining the purpose, specifying, estimating, and forecasting, in only the last two is the computer used. If, as is usually the case, econometrics is the estimation technique used, computing facilities are a sine qua non, since the mathematical operations involved, inversion and multiplication of possibly very large matrices, are internally time-consuming if done by hand, but easily carried out by a computer.

TECHNIQUES OF ECONOMIC MODEL BUILDING: ECONOMETRICS AND INDUSTRIAL DYNAMICS

There are two broad approaches to the estimation of economic models, namely, the econometric and the industrial dynamics approach. These two approaches are quite separate and although these have been considered as alternatives, we at CRU prefer to regard them as complementary. The aim of both techniques is, however, similar: a set of quantified relationships between the key economic variables, such as consumption, production and price.

Broadly defined, econometrics is the quantitative side of economic science. On this definition, all economic models are econometric, but in the last decade the term has been reserved increasingly for a set of statistical techniques (in particular regression analysis) that extract from the past data a relationship between the variables of interest. However, it is not as simple as this, since there are many more complicated techniques available than simple regression analysis, and each one will be appropriate in a different set of circumstances. Part of the econometrician's task is to select the right tool for the problem.

The range of problems to which econometric analysis may be applied is limited in the main by data availability. If the estimation procedure is to be successful, data must be available on the past history of at least most of the important variables on a consistent and continuing basis. Moreover, the inaccuracy in the data must be not more than slight. At CRU we have found that the chief factor limiting the accuracy of our short-term copper price forecasts has been the lack of data on semi-fabricators' stocks outside the USA. One of the reasons that an initial stop to an international body could take in any mineral industry towards the goal of price stability would be the collection and publication of more comprehensive series.

A particular technique associated with econometrics and useful in the forecasting of demand for a product or commodity in the short to medium term, is input-output analysis. In order to produce, say, a further $1m. worth of vehicles, the additional production of $100 000 worth of steel, $30 000 worth of plastics, $20 000 worth of copper, and $20 000 worth of rubber, amongst others, will be required. Moreover, since these ratios depend on the technology embodied in existing capital equipment, they will change only very slowly. In many countries these ratios (input-output coefficients) have been estimated accurately by government economics departments and are available for use by private industry.

The large amount of data required for econometric analysis is not always available, neither are econometric techniques always suitable even if these data are available. In some instances the data available may all refer to a period in which the institutions, practices or general state of the market were very different from those currently experienced. Clearly, relationships estimated on the basis of such data will not be appropriate. The pattern of demand for lead will, for instance, change markedly if the use of lead-free petrol becomes prevalent, and allowance would have to be made for this in a model of the lead market.

Thus, it becomes apparent that full-scale econometric models are of great use only in the relatively short and possibly medium term when institutional and technological changes are likely to follow an already established pattern and for markets where data are at least fairly readily available. In the longer term, industrial dynamics provides an alternative to econometrics. The approach of the industrial dynamist is, as is implied by the name, to specify a dynamic model of the industry, but without particular regard to the problems of estimation which lie at the forefront of the econometrician's mind. If one were asked to define the alternative approaches in a single sentence, perhaps the following would approximate to the truth: the econometrician attempts highly precise estimates of models which approximate only the market structure, whereas the industrial dynamist attempts 'reasonable' estimates of precise models of the market structure.

It would, however, be a mistake to view econometrics and industrial dynamics as competitive techniques. This view has arisen in some circles since the two sets of techniques are generally used by two distinct groups of people: only economists tend to know much econometrics, while many who practise industrial dynamics come from an engineering or business school background. In fact, simple econometric techniques are usually used by those working with industrial dynamics in making the "reasonable" estimates of the parameters in their models. Similarly the econometrician should adopt industrial dynamics where data are either absent or inadequate for the purposes of estimating a model.

An example of an industrial dynamics model in which many of the crucial relationships are estimated econometrically is provided by the CRU long-term copper model, already referred to. The object of this model is not, as is the case with the short- to medium-term model, to produce accurate price predictions at any moment in time, but to anticipate the general pattern of developments, including price movement, over the next two decades. The consumption and production relationships and the price formation mechanism are the results of econometric estimation, for these reflect technological and institutional effects which are either not expected to change significantly or are expected to alter in a fairly systematic manner. But the relationships governing investment, depending as it does on available finance, producers' stock-holding behaviour, and the cut-back of production to prevent prices falling to 'unacceptably' low levels, are either not easily estimateable or are liable to differ from previously observed relationships. Thus, the investment process must be constructed through the use of industrial dynamics. Interestingly enough, although the investment decision process had to be built up in this way, when finally completed it was found to forecast annual mine capacity since the early 1980's (no earlier data are available) very closely indeed.

Industrial dynamics is also highly dependent on the computer, but in a somewhat different manner to econometrics. Econometrics depends heavily on the computer at the estimation stage, but the resultant models are often (not always) manipulated fairly easily on a hand calculating machine. Conversely, parameters of industrial dynamics models may well have been estimated on calculating machines, or even slide rules, but the complete model would be unmanageable without the aid of a computer. Indeed, such a model will generally be presented as a computer package.
USING ECONOMIC MODELS

Project appraisal

There are three aspects to evaluating the relative merits of alternative projects. First, the projects must be costed. This is the domain of the experienced engineer and the finance specialist and this process is itself increasingly amenable to computer utilization. The second aspect is revenue forecasting, and this is, increasingly, the domain of computer-assisted economic analysis as outlined above. The third aspect is profit appraisal, which involves considerably more than calculating the difference between forecasted revenue and costs.

The basic reason is that profits now are worth more than profits in a few years time, since in principle, at least, current profits can be invested to earn interest. There are several ways in which future profits can be discounted. A crude but simple way is to find out to what extent gross revenues will exceed gross costs in, say, the first ten years of the life span of the alternative projects. The one which gives the greatest gross profit is preferred. This technique may be partially justifiable if the future is so uncertain that forecasts of costs and/or revenues more than 10 years hence are totally unreliable. But even within a 10-year period, the difference in timing of annual profits should, and can, be taken into account explicitly.

There are several ways of doing this; the two main ones are called, collectively, discounted cash flow (DCF) methods. One of the two, the 'internal rate of return' (IRR) variant is the most widely used because of its greater familiarity, but the other, net present value (NPV) is preferred by some on theoretical grounds.

With the IRR approach, the cash flow is calculated for each year of the life span of the project. Cash flow means essentially the difference between after-tax profits and running costs plus loan repayments (if any). Thus depreciation allowances are included in the cash flow as these accrue to the company which may dispose of them as it sees fit. The cash flow will be strongly negative at first, since money is being disbursed to purchase capital equipment, shafts are being sunk, overburden is being stripped and so on, but nothing is being sold. Gradually, the cash flow becomes positive, and may well remain positive for the rest of the life-time of the project, unless a major item of capital equipment has to be replaced.

The next stage is to find that discount rate which will exactly balance the positive and negative cash flows. The reason for this will become clearer later.

Suppose the cash flow in year one is $a_1$, in year two, $a_2$, and so on for the $T$ years of the project life. (Remember that the early values of these will be negative, the later ones positive). The problem is then to find a value of $r$ such that the series:

$$\frac{a_1}{(1+r)} + \frac{a_2}{(1+r)^2} + \frac{a_3}{(1+r)^3} + \ldots + \frac{a_T}{(1+r)^T}$$

exactly sums to zero. This involves solving a polynomial of order $T$, where $T$ may be 25 or more. Iterative methods are generally used, and the programming process for a digital computer is simple, whereas hand calculations would be excessively tedious. There will be more than one root (a value of $1+r$) to such an equation, but most are imaginary and can be ignored. There will be multiple real roots if the sequence of $a$'s changes sign more than once but this can be taken into account by means of rules beyond the scope of this paper. If there is only one sign change, there can be only one real positive root. Suppose the value of $r$ turns out to be 0.12. This implies that the IRR of the project in question is 12 per cent, that is, it is equivalent to investing an equal sum of money in, say, industrial bonds yielding 12 per cent per annum compound. If the IRR of an alternative project is 15 per cent, then the second project, everything else being equal, will be preferred to the first. If the IRR is eight per cent or less, then the company would probably be better off investing its money in a safe security, or acquiring a profitable subsidiary.

In practice, more than one IRR computation for each project would be made on the basis of different forecasts of costs and revenues. This raises the question of the sensitivity of forecasts to the particular assumption made about the exogenous variables, and to the inevitable margin of error involved in econometric forecasts. This inevitably involves the degree of confidence to be attached to the forecasts themselves.

Decision theory

By 'degree of confidence' here is meant one of two things. Forecasts based on econometric analysis have the property that the probability of errors of any magnitude can be calculated in advance, assuming that the analysis was correct in the first place, and the market structure does not change in the interim. This aspect is clearly very important. It is small comfort if, after being told that the rate of return on a project is 25 per cent, that if there is an error of five per cent in one of the critical forecasted variables, then the rate of return will be negative, and that, furthermore, there is an even chance that there will, in fact, be an error of five per cent in the forecast of the variable.

The other interpretation of 'degree of confidence' is more subjective. It relates to the relative probability which individuals attach to the likelihood of various outcomes. This comes about as a matter of course, for the future is not so much unknown as uncertain. If it were truly unknown, we would have no idea, for example, whether Portugal would be using more steel next year than the U.S.A. or vice versa, but in practice, we 'know', or are very confident about, the answer.

Both types of 'degree of confidence' involve information relevant to an investment decision, but at first sight it is difficult to see how this information may be utilized. The analytic technique which does this is known as 'decision theory' and may be illustrated by means of an example. An ore may be treated in one of two ways. The old, reliable and well-costed way would give a rate of return on the project of 15 per cent. The new method, if it worked as it was supposed, would give a rate of return of 25 per cent. If it is a total failure, it would have to be scrapped and replaced by the old technique, driving the overall rate down to eight per cent. On the other hand, it may work, but not as well as advertised, bringing the rate somewhere between eight per cent at worst, and 25 per cent at best. Suppose that experienced engineers estimate that there is an 80 per cent chance of the new technique working properly, a 20 per cent chance of its not working at all, and no chance that it would work at somewhere between these extremes. Then the 'best' estimate of the rate of return would be 0.8 x 25 + 0.2 x 8 or 21.6 per cent: still better than 15 per cent for the old technique. Of course, if the two rates turned out to be identical, one might well choose the older technique, where there is no chance of a lower rate, or still choose the new technique because of the possibility of higher returns. But the choice would be a question of attitudes towards risk, not risk itself.

The advantage of econometric and allied techniques in this context is clear. The relative probabilities are computed automatically, and do not have to be guessed at, but, in either case, the problem is simply one of finding out the probabilities of the various outcomes, weighting the concomitant gains or losses by them, and isolating that decision which gives the highest net probable gain. This may sound straightforward, but, in practice, every set of possible decisions
is associated with a set of variously likely outcomes each of which in turn gives rise to other variously likely outcomes until from a single decision, a veritable tree of possibilities emerges. To trace the best path along the branches of such a decision tree is mathematically very simple, but invariably very tedious. In fact, it is precisely the sort of problem which the digital computer is best adapted to solving.

**Simulation**

So far, most attention has been paid to the use of models for forecasting on the assumption that the real world will continue much as before. But this is not necessarily so. At this moment in time, copper is sold on a more or less competitive basis, whereas aluminium sales are influenced very strongly by decisions made by the six leading aluminium producers. This is not to say that the practice of the aluminium producers is monopolistic, or that their influence is at all detrimental, but there is no doubt that the pricing bases for copper and aluminium are very different. Now, this may change. We are entering a period of probable surplus in copper, and the price may reasonably be expected to stay at levels which are low compared with those of the late 1960’s. If the industrialized countries of the world do not soon recover from their present rather depressed levels of activity, or fall back even further, the price of copper (which is determined on a free market) may well sink to levels at which profits are seriously threatened, especially in view of the large loan repayment programmes to which many major companies are financially committed.

This situation has arisen repeatedly in the past, and the response has been much the same. The major producers agree, formally or informally, to cut back sales by means of production controls, stock-piling, export quotas, delaying expansion plans, temporary closure of high-cost mines and the like. There are many options open; all that is required is agreement on the means. Since these support operations differ in type each time, and since each operation generally lasts only a few years, conventional econometric techniques (which require an unchanged structure and much data) are of little avail.

Similarly in aluminium, the emergence of large over-capacity may mean that the pricing basis for aluminium will become more competitive. Econometric models based on the past structure of the industry would, therefore, not provide good forecasts.

This is a situation in which simulation techniques of the industrial dynamics type come into their own. Industrial dynamics (takes the structure of a market as known (this is a *sine qua non*), numerical parameters are then set out rather than estimated, but the end-product is a system of equations whose form may be highly non-linear and which interact in a complex way. As the name suggests, the equations are specifically dynamic: the leads and lags between the interaction of different variables are crucial to the structure. As a result, this technique is ideally suited to simulation of an event, or events, the structure of which is ‘known’ or can be predicted, but for which little factual information in the form of data is available. Thus, simulations may be made of the various types of hypothetical future situations in aluminium in order to obtain information about possible price movements.

Forecasts made using industrial dynamic techniques do not usually have the accuracy of those made by econometric models when applied to the same structure. This is because the greater precision of the numerical parameters of the econometric model more than counterbalances the greater approximation to reality at the specification stage. On the other hand, industrial dynamic techniques may be applied in cases where econometric analysis is not feasible. Forecasts based on industrial dynamics also forecast turning points and the amplitude of cycles rather well.

This paper has outlined an area in which the advent of the computer can and will make an increasing contribution to improving decision-taking and forward planning in the various mining industries.