Modelling the impact of environmental policies on minerals investment

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Abstract: This paper describes an application of the tools and techniques of the system dynamics method to the complex problem of understanding those factors which impact the flow of international mineral investment funds. The theoretical underpinning of the paper is a simulation model developed in Powersim in the system dynamics tradition. The model, comprising over 180 variables, provides a means of examining the effects of varied environmental, fiscal and corporate policies on the flow of investment funds and mineral resources between 4 simulated mining firms and 4 competing countries. It attempts to expose – to policy makers – the complexity of the dynamics of international mineral investment, in the hope that future policy-making efforts will incorporate an understanding of this complexity, particularly in relation to the economic impacts of environmental policy.

Keywords: Mining, Simulation Modelling, System Dynamics, Environmental Policy

1. INTRODUCTION

The aim of this paper is to provide a high-level overview of a detailed computer simulation model developed in the system dynamics tradition. The model examines the complexity and interdependence of the factors impacting the relative attractiveness of a country as a location for minerals exploration and development and comprises a number of tightly coupled system dynamics sub-models;

The mining firm is viewed as a particular case of a typical business entity, which is assumed to have the objective of maximising profits. The mining firm sub-model attempts to capture the essential decision making structures which determine how (and where) its profits are re-invested through further exploration and development activity.

Individual countries compete for mineral investment funds, either directly through specific minerals policies, or indirectly through prevailing government and economic conditions. Domestic environmental policies may have a large impact on the relative attractiveness of a country to the mining industry. The objective of this sub-model is to expose those factors which directly impact on the investment decisions of mining firms.

Base metals are traded on the **international commodity markets**. These markets, which can be considered exogenous to both individual firm behaviour and government policy, are subject to fluctuations which impact on the performance of mining firms and the relative attractiveness of mineral producing countries (NMPRG, 1995).

A hypothetical mining firm might decide to invest a proportion of its exploration budget in a particular country, on the basis of the prevailing investment climate in that country. It is more likely that it will spread its investment among a number of countries as a function of their relative attractiveness, in which decision making process environmental regulation represents an important factor. Furthermore, the firm's decision mechanisms do not exist in isolation, but are dependent on the activities of its competitors, reflected in the behaviour of the international minerals market.

2. MODELLING COMPLEXITY

A computer simulation model provides a powerful means of exposing system complexity and, thus, increasing understanding. The model described here shows how exploration spending is a function of the relative attractiveness of individual deposits in competing countries. This relative attractiveness, as defined by the expected net value of exploration, changes over time as determined by the interrelationships between many other factors such as the host government environmental regulatory and planning requirements, the level of taxation and the availability of accurate geological information. The exact nature of these complex interrelationships, as assumed by the model, is made explicit through the variable definitions. These assumptions (definitions) can be modified and the resulting changes in behaviour patterns examined.

The greatest advantage in adopting system dynamics as an analytical tool is that it exposes the many interrelationships (structure) which influence the behaviour of a complex system. In a complex system, such as the flow of mineral investment funds, the same change to environmental or fiscal policy does not always have the same effect. Instead, the effect is dependent on the 'state' of the system at a particular point in time. Through its effectiveness at capturing and exposing the state of the system, this model improves on more conventional methods for evaluating policy effectiveness.

3. MODELLING POLICIES AND DECISIONS

System dynamics fosters a feedback view of management as a process which converts information into action. This process is, in essence, a decision process and success depends on selecting the right information and using it effectively. From this perspective, a policy is a guiding rule, an aid to decision making. The decision process is complicated by the fact that information about the outcome of actions taken is never immediately available. [Forrester, 1994, p52].

Through a quantitative analysis of existing data, the model exposes, within the context of the problem area, the underlying assumptions used as a basis for policy formulation and corporate decisions. Furthermore, through the compression of time, the model provides a means of taking these assumptions to their logical conclusions. Exposing assumptions in this way leaves less room for misinterpretation and provides a solid basis for enhancing the understanding of system structure.

4. MODEL VARIABLES AND RELATIONSHIPS

The model contains over 8,000 individual model objects (array elements and scalars). Almost all of these objects are dependent variables, that is, their value at any particular time is determined mathematically based on the current 'state' of the system. System state is defined by the collective values of the level variables in the system, of which there are 31. These level variables, together with the 24 model constants act as initial conditions for the model and can be changed at the beginning of, or during, the simulation run to reflect particular circumstances such as changes in corporate or government policy. Many of the levels are derived variables (as opposed to fundamental variables) in that their values are directly dependent on the values of other levels. Some of the most significant level variables and constants are as follows;

Table 1. Selection of key model parameters

Actual_Geology
Available_Resources
Average_Ore_Grade
Book_Value_of_Mine
Cash
Cumulative_Income_Reserves
Debt
Discovery_Delay
E_Cost_of_Exploration_Effort
Equity
Expected_Demand
Expected_Price
Exploration_Spending_by_Country
Extracted_Ore
LME_Inventory
Metal_Recovery
Mineable_Reserves
Paid_in_Capital
Perceived_Geological_Potential
Perceived_Ore_Grade
Proven_Reserves
Refined_Mineral
Regulatory_and_Planning_Requirements
Retained_Earnings
Waste
Exploration_Budget_Allocation
Construction_Delay_Normal
Costs_of_Local_Inputs
Interest_Rate
Perceived_Political_Stability
Perceived_Security_of_Tenure
Percentage_Profits_Reinvested_in_New_Mines
Planning_Delay_Normal
Pollution_Tax_Rate
Price_Normal
Profits_Reinvisted_in_Exploration
Taxation_Percentage

As zinc is the most commonly mined mineral in Ireland it was chosen as a basis for parameter values in the construction of the model. The structure of the model is captured through the relationships between the variables. Many of these relationships are simple (proportional) in nature and therefore easy to define. Non-proportional relationships are modelled through the use of multipliers or graph functions. The main use of a multiplier in a system dynamics model is to act as a changing (dynamic) pressure on decision making. This is in contrast to the static, normal, value which takes effect when the system is in equilibrium. For example, the decision of how much to invest in exploration, represented by the Exploration_Budget, is defined as the product of static and dynamic pressures as follows:

Exploration_Budget =
*Exploration_Budget_Normal **
*Expected_Price_to_Exploration_Budget_*
*Multiplier * Market_Share_to_*
Exploration_Budget_Multiplier *(1)*

Exploration_Budget_Normal represents the typical exploration budget, all other things being equal. The size of the exploration budget is affected by changes in expected price. This price pressure, which cannot be ignored, is modelled through the use of an expected price to exploration budget multiplier. When the expected future price equates to the long-term median price ($1,235/tonne), then expected price neither has a positive or negative pressure on the size of the exploration budget, point 1 on the y-axis. However, as the expected price of a tonne of the mineral exceeds $1235/tonne, then there is an incentive (pressure) to increase the size of the exploration budget to maximise gains from expected improvements in market conditions. Similarly, when price is expected to fall, there is an incentive to reduce the exploration budget as it is perceived that there will be less opportunity for profit. Figure 1 shows the graph function for the Expected_Price_to_Exploration_Budget multiplier.

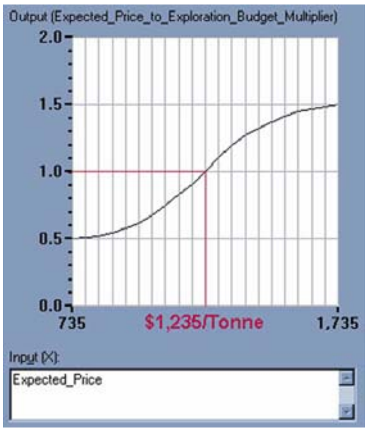

Figure 1. Modelling the effect of expected price on a firms exploration budget

5. MODELLING METHODOLOGY

It is beyond the scope of this paper to present a detailed context for the model. Instead, emphasis is placed on modelling methodology and the reader is referred elsewhere for a detailed discussion of the dynamics of the minerals industry [O'Regan & Moles, 2001].

The system dynamics development process is iterative in nature. There is no initial template upon which to base the model structure. Instead it evolves over time as more accurate information becomes available as to the relative importance of the various information flows which feed the critical decision points in the system. In a system dynamics model such as the one described here, the state of the system (as defined by the collective values of all level variables) is changed over time as a result of actions carried out to implement management decisions (defined by the values of rate variables in each time-step). These management decisions are in turn driven by the current system state as well as any guiding polices (defined as model constants).

Developing a system dynamics model to expose the dynamics of management behaviour (as opposed to purely physical models) involves identifying the key decision points in the system. These decision points form the basis of system sub-models in that they may be developed and tested in relative isolation. However, once each of the decision sub-models is sufficiently complex to accurately capture the real-world decision processes, and at a level of abstraction deemed suitable to meet the objectives of the model, then the next main task (and another source of project evolution) is to capture the feedback between the various decision points or sub-systems. In this respect, much of the significant dynamics in a complex system arises from delayed feedback between decision points, particularly when the feedback crosses organisational boundaries. For example, the decision on where to explore in the future is significantly affected by the success or otherwise of previous exploration efforts. This information is captured in the model through the difference between perceived and actual geology. Actual_Geology is a component of the main mining process model and is specific to the individual country (and deposit). Perceived_Geological_Potential, on the other hand, is specific to the individual firm and the difference between the two values is determined by the particular firm's prior exploration activity in the country in question, other firms' exploration activity and, most importantly, the delays involved in making the results of the exploration activity available (the accuracy of the geological information). It is very important for the model to distinguish between perceived and actual information as actual information is almost never available to act on immediately, and so decisions must be made on perceived values (see Figure 2).

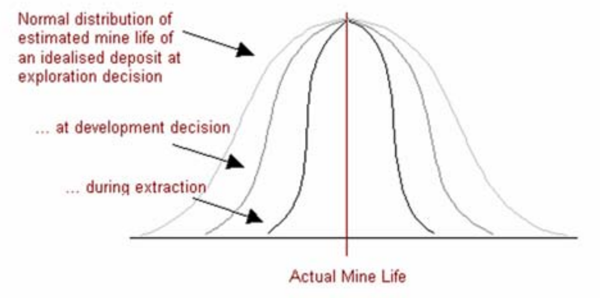

Figure 2. Decisions are based on perceived (not actual) information

6. OVERVIEW OF CAUSAL FEEDBACK STRUCTURE

There are two critical reinforcing feedback loops which are primarily responsible for changes in this system. At the micro level of system structure, the price/unit operating cost ratio is a fundamental determinant of the extraction decision of the individual mine. At the macro level, cumulative retained earnings drive the flow of exploration funds in, and between, countries. These reinforcing feedback loops interact through the effect of unit operating costs on mine profitability.

Figure 3 shows a highly aggregated causal-loop diagram depicting this feedback structure. The main determinant of the nature of the reinforcing feedback, be it positive or negative, is the demand for the mineral and, consequently, price. In times of favourable market conditions, there is an excess of investment funds which are allocated primarily according to the principle of relative attractiveness. However, when market conditions become unfavourable, economic viability is determined on a per-mine basis and is significantly impacted by the individual policies, including the environmental policies, of the host governments.

7. SAMPLE MODEL OUTPUT

The model as presented here is the present state of an iterative evolutionary process. Initial plans were modified and the model's scope redefined on a number of occasions as a result of an increased understanding of the systems methodology, which only comes with prolonged experience in the model development process and as a result of changing expectations in relation to the availability of critical data.

The model represents a microcosm of the international zinc industry in which four multi-national mining firms explore and develop up to 20 mines each in 4 different countries, over a 100 year period. Model behaviour is a complex function of initial conditions and changing policy over the simulation period. To increase variety, and so better simulate reality, countries are

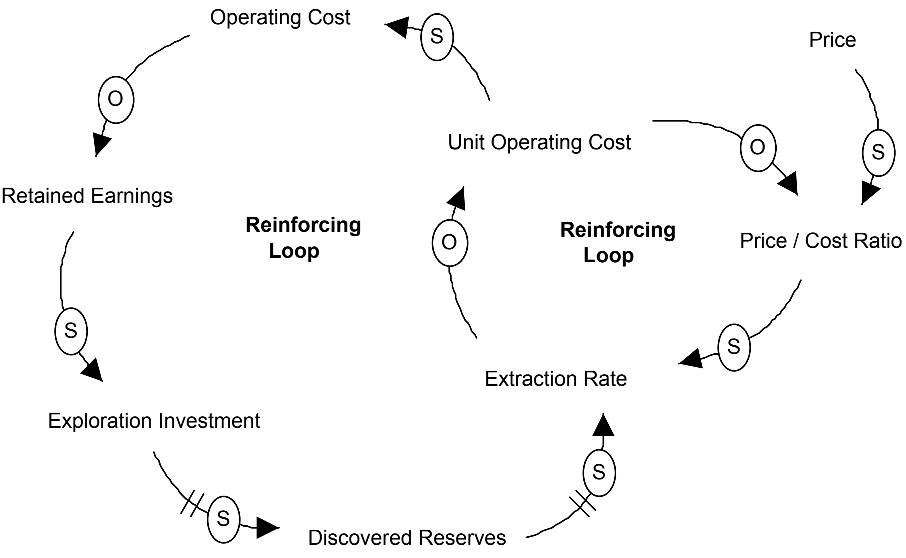

Figure 3. Critical feedback loops in the system

assigned different initial conditions regarding geology, environmental regulatory and planning requirements, exploration costs and the cost of local inputs. Firms vary according to their growth goals, risk aversity and the price sensitivity of their extraction policies.

As an example of model output, consider the generation of waste at an individual mine. As minerals are recovered solid waste is generated. The quantity of this waste generated is directly dependent on the average ore grade of the deposit as well as the metal recovery. On the assumption that higher grade ore is extracted first, the decreasing average ore grade over the life of the mine results in an increase in the quantity of waste generated per tonne of recovered mineral. With a constant metal recovery rate, the waste generated per tonne of recovered mineral increases over the short-term time horizon of an individual mine, as well as over the longer term on a global scale, due to decreasing ore grade. Figure 4 shows the ratio of the total amount of waste generated to mineral recovered with a constant metal recovery of 80% (lines 1 and 3) and with a step-wise improvement in metal recovery (lines 2 and 4).

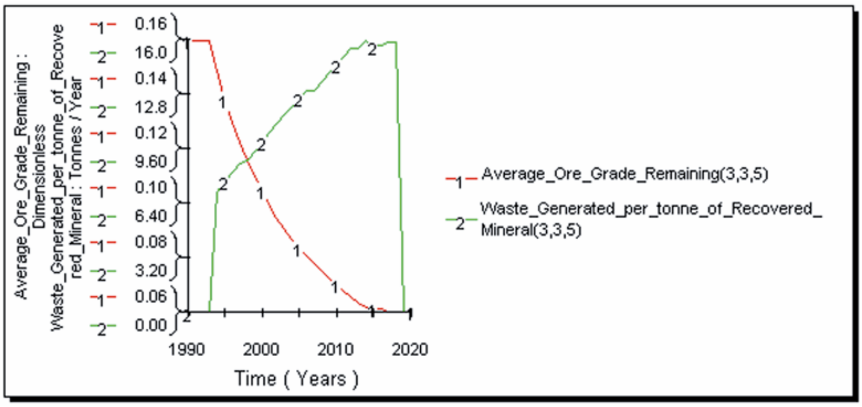

Figure 4. Waste generation for simulated deposit

The improvements to metal recovery result in a downward shift of the waste generation to recovered mineral ratio over the period of the simulation. However, the trend in the waste generation to recovered mineral ratio continues to increase over time. This is because the improvement in metal recovery facilitates the development (or reopening) of lower grade deposits which were not previously economically viable.

The model can be used to examine the effects of command and control environmental policies. However, apart from direct environmental regulation, governments also have the option of imposing fiscal penalties or using market based instruments to protect the environment. These may take the form of pollution taxes imposed by the government on a per unit of waste produced basis.

If the host government imposes a pollution tax on an operating mine, this will increase its unit operating costs. As the tax is on a per unit of waste basis, the ore grade will affect the total amount of tax payable, as the waste generated per tonne of metal recovered is dependent on the ore grade.

Figure 5 presents output from a simulation run where a pollution tax of $10/tonne of waste is imposed on mining operations in Country4. From this figure, it can be seen that although refining rate declines over time, due to decreasing ore grade, the waste generation rate remains relatively constant over the life of the mine. This is because the same quantity of ore (and resultant waste) is required to recover an ever decreasing quantity of mineral. Similarly, unit pollution tax (pollution tax per tonne of recovered mineral) increases as average ore grade declines. This results in an increase in both unit and actual operating costs and has a negative effect on mine profitability. Thus, as a pollution tax affects the profitability of a mine, it affects the ore grade that can be economically recovered, and as marginal mines with lower ore grades generate more waste per tonne of mineral, a pollution tax may be seen by some governments as an effective means of discouraging the development of such mines.

A further example of model output, examining the effect of increased planning delays on retained earnings is given in the oral presentation.

8. CONCLUSIONS

In a simple system or mental model, cause and effect are closely related in space and time. From such a perspective, increased planning delays would simply result in increased planning costs. However, increased planning delays may, under adverse market conditions, have a significant impact on mine profitability, far in excess of the original increase in planning costs. Not only does the model provide a means of evaluating the effects of alternative policies but, equally

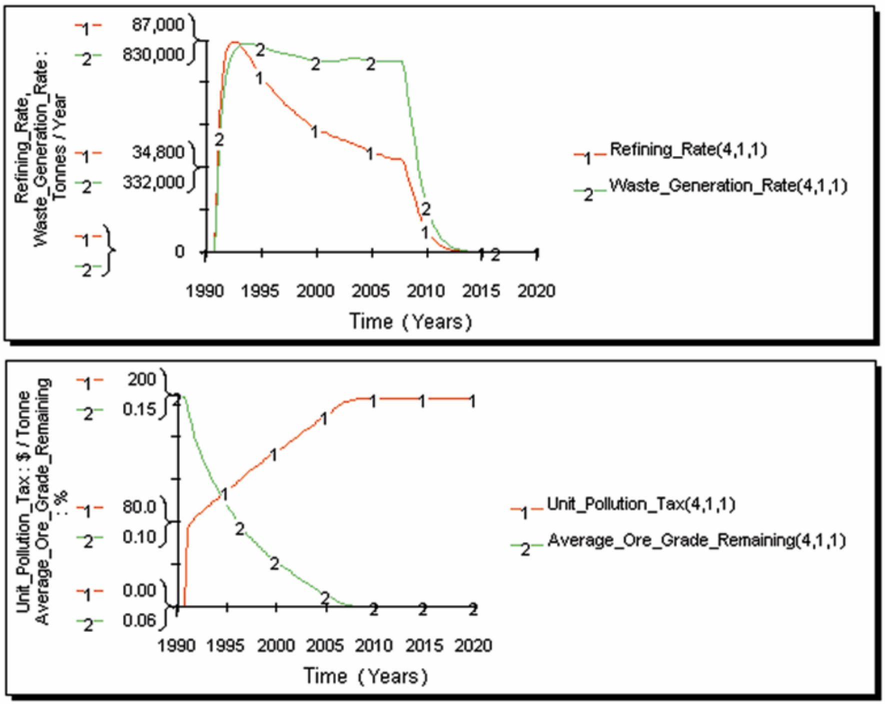

Figure 5. Pollution tax and waste generation

importantly, it provides a very powerful means of evaluating the effects of the same policy under different conditions.

Furthermore, the multi-dimensional aspects of this model allows the user to test different sets of assumptions and policies at the same time, by setting different parameter values for each of the mining firms and countries in the simulation. In this way, the dynamics of relative attractiveness may be exposed through the flow of exploration funds between countries.

The model as presented here is the present state of an iterative evolutionary process. Initial plans were modified and the project's scope redefined on a number of occasions as a result of an increased understanding of the systems methodology, which only comes with prolonged experience in the model development process and as a result of changing expectations in relation to the availability of critical data. Many of the important dynamics presented in verbal models have been exposed. As a result, the numerous interrelating factors which impact the effects of government mineral policies may be examined afresh, using the systems methodology.

It is not the authors' expectation that policy makers or decision-makers within the industry will adopt their model representation in its entirety as a basis for future decision making. Neither is it expected that they will necessarily accept all the premises on which it is based. Instead, to allow this work to be developed in the future, it is hoped that this model will be used as a foundation for further development. In the future, specific components of the model may be dis-aggregated to address particular problems which are deemed important by policy makers and/or the mining firms.

9. REFERENCES

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