Using systems modelling to examine the relationship between environmental policy and mining company decision making

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ABSTRACT

This paper presents a system dynamics model that allows the user to examine the effects of changes in host government minerals policy on the investment and operating decisions of mining firms. The emphasis throughout the model simulations is on the effects of environmental policy because of the significant effect it has on international mining. The model, comprising over 180 interrelated variables, provides a means of examining the effectiveness of varied environmental, fiscal and corporate policies on the flow of investment funds and mineral resources between a number of simulated mining firms and competing countries.

INTRODUCTION

Economic growth is a very complex process. It follows from a long series of small, seemingly unrelated actions, in which the environment continuously yields to pressures which favour further economic growth. For example, a mineral reserve is exploited to meet demand, a new road is built to ease resultant traffic congestion and land is rezoned to reduce the rising cost of housing. Each action eases the way for further growth, which creates new pressures to be tackled by further actions. This stepwise approach to problem solving creates a reinforcing feedback loop towards increasing rates of growth until, in time, the resultant problems become increasingly difficult to solve. It might be argued that environmental management is concerned with solving such problems, when they have environmental impacts, and before they become critical.

However, current practice in environmental management often fails to deal with the complexities of environmental systems and a number of paradigms have been proposed to provide an improved way of tackling issues related to economic growth and its environmental consequences [Margarum *et al*, 1995]. One such paradigm, commonly termed the systems perspective, provides a set of related tools and techniques which emphasise a holistic and long-term perspective on environmental concerns. System tools such as archetype templates and causal-loop diagrams can aid policy makers in understanding how a system's structure is often responsible for producing particular patterns of behaviour. Such techniques are useful aids in the understanding of complex interrelationships between the parts of the system [O'Regan *et al*, 1997].

Contemporary desktop computers allow the use of simulation software to trace the behavioural implications of these interrelationships. Through the generation of quantitative mathematical models, model builders are forced to make explicit their assumptions relating to a specific problem. In the process of building the model they have an opportunity to resolve any contradictions or ambiguities and, in so doing, greatly improve their mental models of the problem in question. On completion, policy makers have at their disposal a tool for testing the relative merits of various policy alternatives. Simulation models are generally agreed to be particularly suited to one class of system, the complex dynamic system. Complex dynamic systems are characterised by non-linear coupling of variables and inherent time delays and, as such, cannot be properly comprehended by the unaided human mind [Forrester, 1969 & Brown, 1975]. By this definition, all economic-environmental systems are complex dynamic systems, and, managing the environmental consequences of economic growth would benefit from the application of a systems perspective as outlined above.

MODEL OVERVIEW

The most recent Irish government publication pertaining to the mining industry, published in April 1995, is the *National Minerals Policy Review Group (NMPRG) Report*. This report begins by stressing the need to "recognise the complexity and interdependence of the factors which have influenced investment in the minerals sector in Ireland over the past three decades" [NMPRG, 1995, p5]. Mining is a complex dynamic system, with decisions taken in one organisation (government), having a direct effect on other organisations (mining companies), and, consequently, many problems in the overall system are caused by the lack of integration that is typical of multi-organisational systems. Figure 1 presents the high-level sector map depicting the organisational boundaries in the underlying system dynamics model which forms the basis for this paper.

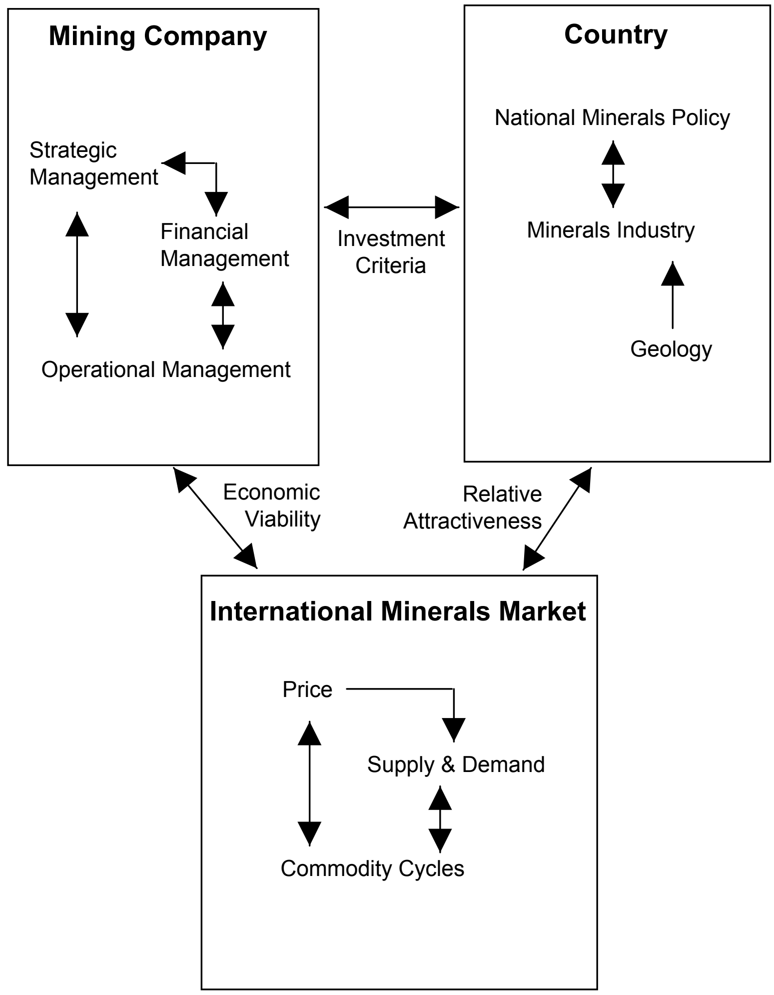

Figure 1 : Organisational boundaries in underlying system dynamics model

The *NMPRG Report* was commissioned to "report on measures necessary to maximise the contribution of the Minerals Industry to the National Economy, while ensuring that mining is carried out in an environmentally acceptable fashion" [NMPRG, 1995, p5]. Given that most of the current exploration licences are held by multi-national companies, this means attracting an increasing share of international exploration funds at the expense of other competing countries. The high mobility of mining investment is often cited in the literature. Consequently, the concept of relative attractiveness is particularly appropriate. In a free market a mining company will concentrate its exploration investment budget in countries that present the most attractive investment opportunities. This creates a positive feedback loop towards further exploration activity, until, eventually, some limit is reached, thus reducing the particular country's relative attractiveness. In times of shrinking minerals markets companies have shifted their investment to more stable regions, reflecting the fact that, in their opinion, these countries have become relatively more attractive as the companies themselves become more risk averse. This is an important point, as it shows that the concept of relative attractiveness is a dynamic concept. The Irish government can control the minerals policy within its own boundaries but, in order to remain competitive, policies must constantly evolve to be at least equally attractive as the mineral policies of other countries.

Whether a profit can be gained from a mineral deposit is dependent on a number of physical and economic factors. Once discovered, the physical characteristics (tonnage and ore grade) can be established with considerable accuracy and these tend to remain relatively fixed. However, economic factors such as price, capital and operating costs, transportation costs and taxation rates change continuously. In addition, technological innovations, local government legislation, environmental and social changes can dramatically affect the economic viability of a mineral deposit. Therefore, what constitutes a viable deposit is a dynamic concept and varies depending on place and time.

MODEL OUTPUT

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 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 (see figure 2).

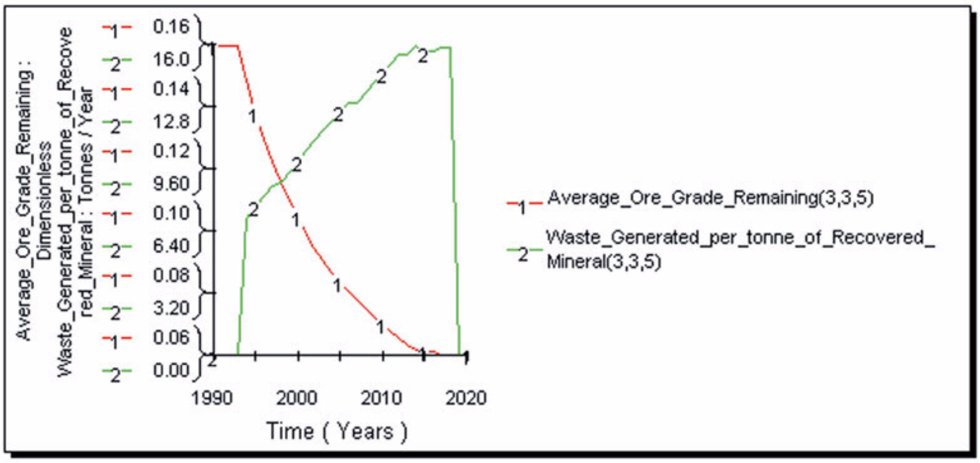

Figure 2 : Waste generation per tonne of recovered mineral

Figure 3 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). 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 improvements to metal recovery facilitates the development (or reopening) of lower grade deposits which were not previously economically viable.

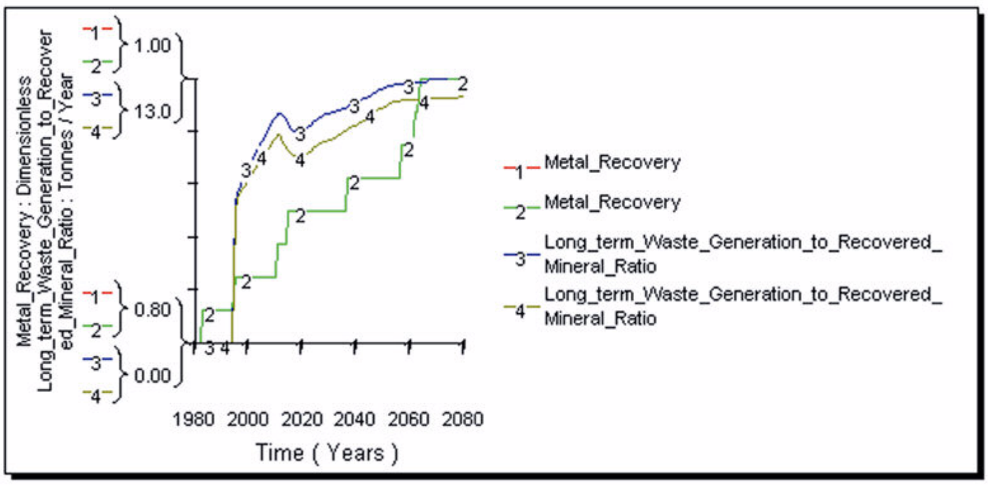

Figure 3 : The impact of improvements to metal recovery

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 4 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.

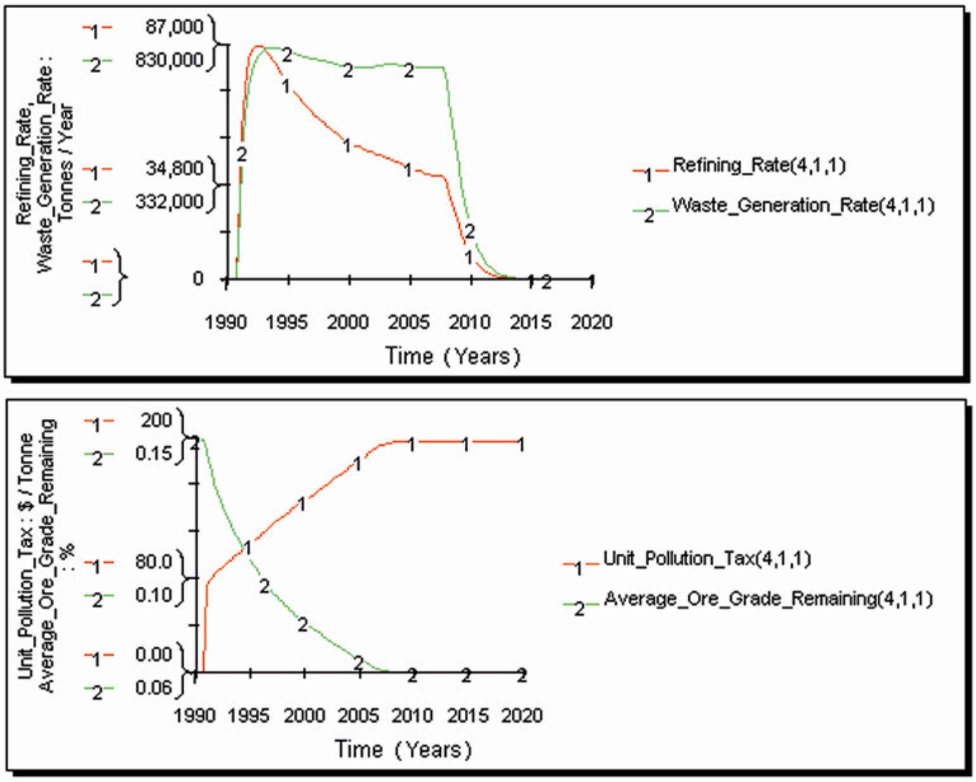

Figure 4 : Unit pollution tax

CONCLUSIONS

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. Through the compression of time, it 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. The behaviour-over-time graphs used to present model output provide a powerful means of exposing system complexity and, thus, increasing understanding. For example, the model can be used to show 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, are made explicit through the variable definitions. These assumptions (definitions) can be modified and the resulting changes of behaviour patterns examined. The model can also be used to show how the feedback mechanisms inherent in system structure influence behaviour patterns over time. For example, the security of tenure sub-model shows how perceived security of tenure, and thus, exploration spending, changes over time as a non-linear function of prior government refusal of mining licences.

Not only is the model suitable for showing the effect of alternative policies, but it is equally suitable for showing the effect of a particular policy in different situations. For example, an increased planning delay has a significant effect on retained earnings only if it prevents the mine from exploiting favourable market conditions.

In its present iteration, the model comprises a set of interrelated sub-models which together capture the most important dynamics impacting the flow of international minerals investment funds. It shows how environmental policy traverses both organisational and national boundaries and how its effect is dependent on the relative attractiveness of competing countries as well as prevailing market conditions.

REFERENCES

Brown, G.S., 1975. *Collected Papers of J.W. Forrester*, Productivity Press, Oregon.

Forrester, J., 1969. *Urban Dynamics*, The Massachusetts Institute of Technology, Cambridge, U.S.A.

Margarum, R.D., Born, S.M., 1995. Integrated Environmental Management: Moving from Theory to Practice. *Journal of Environmental Planning and Management*, Vol. 38, No. 3, p371-391.

National Minerals Policy Review Group, 1995. *A New Minerals Policy*, The Government Stationery Office, Dublin.

O'Regan, B., Moles, R., 1997. Applying a Systems Perspective to Environmental Policy. *Journal of Environmental Planning and Management*, Vol. 40, No. 4, p535-538.