Simulation Framework for Economic Modeling of Mineral Resources

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Abstract

This paper describes an approach to include uncertainty over the commodity price when modelling the economic attributes of a mine plan for a mineral resource. The approach starts with a method to generate price paths from a broad historical set to establish a set of price paths, where the NPV is calculated for each path to generate a distribution for the NPV. It goes on to describes how to use this distribution to compare different mine plans in a manner that is similar to stress testing.

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JEL Codes: C00 General; C02 Mathematical Methods; G1 General Financial Markets;

Simulation Framework for Economic Modeling of Mineral Resources

Mineral exploration is the process of overcoming great uncertainty in the nature of a deposit of metals and the push towards certainty carries through into the economic modeling of mineral resources. This modeling is very important for the financing of mining projects and is heavily regulated by governments in Canada and Australia, for example. Nonetheless, a mine faces great uncertainty when it is actually put into production. There are lots of ways to model this uncertainty, but this paper focuses on a big one: commodity prices.

There is a helpful discussion on the topic in a speech by Justin Anderson (2013) that characterizes the standard approach to resource valuation for oil and gas projects and how to include uncertainty. As with oil and gas, it is common for a mine plan to use a fixed price for metals throughout the model when calculating an estimate of Net Present Value (NPV). The use of current price as the best predictor for the future price reflects a conservative attitude that is appropriate and allows the experts to focus on things in the mine plan they can actually control.

For contrast, consider an extreme example where the mine plan includes some stochastic process for commodity prices, uses different runs of that model to generate price paths that correspond to the length of time of the mine life, and then works out the optimal mining activity at every point in time for each price path. There may be some academic appeal to identifying the optimal production plan in any circumstance to give a sense for the upper limit of profitability for a particular mine, but it requires a heroic assumption about the miners' foresight over commodity prices. Furthermore, the fact that there are an infinite number of possible price paths from a stochastic process requires some care in the numerical implementation of such an approach. A different way forward can be found in Upadhyay & Askari-Nasab (2017), who present a mine operational optimization tool that includes simulation.

In passing, I will point out that Whittle Consulting (n.d.) draws an analogy of mine plans to flight plans in aeronautics: if things start going haywire, then you don't want to have to scramble and figure out what to do – you want to have a plan in place! This leads to an approach where you generate several mine plans under different price scenarios so that you have a plan in place for a crash, rally, or flat market conditions.

The article here considers a simulation exercise that picks up where the mine plan leaves off. It is more in line with stress testing, where we take some price paths based on historical episodes and simulate how a particular mine plan performs in those given conditions.

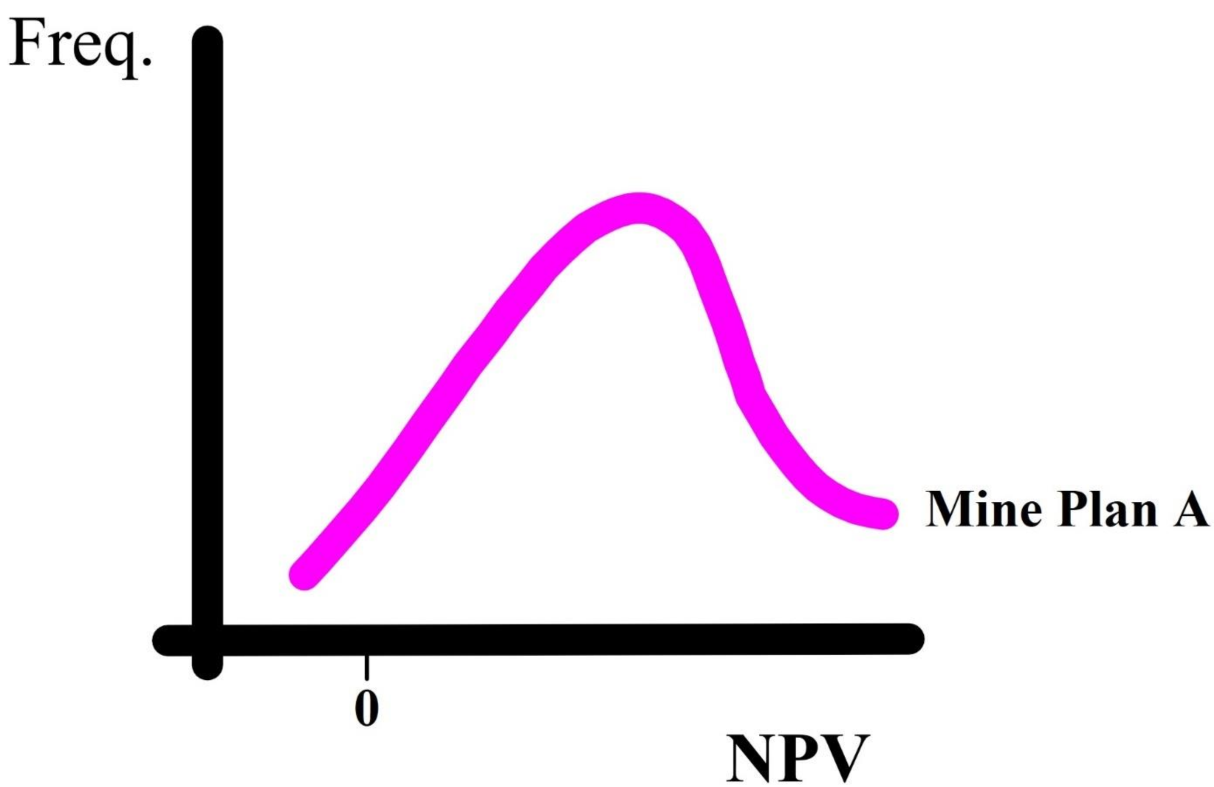
Simulation Framework

The uncertainty in this approach is based on variations in the commodity price over time. I refer to a price path as the relevant prices over the life of the mine used to calculate NPV. It's the same old NPV – just with changing metals price. There are a lot of important detail around how to generate this price path over the life of mine, but I will describe it simply here.

First establish which price is relevant to the mine plan and then gather data for that price over a broad historical period. Draw sub-intervals from that broad price history to match the length of the mine plan and use a rolling window or moving average method to generate different price paths: One path starts in one year and goes for next 10 years over life of mine; the next path starts one year ahead and goes on for another 10 years; and so on. These paths are overlapping, which will create some quirks in the results of simulations that may be troubling for statistical theorists, but I believe the use of overlapping paths is appropriate as it reflects the fact that mines are often started as soon as possible rather than based on market timing. It's hard to say just where you are in the cycle when you start a mine, so it's important to consider the economic performance of a new mine over various different episodes in history.

A more complicated way to generate price paths is to resample historical data. It is possible to estimate some statistical properties and use those to simulate various price paths, which gets into some important debates in the area of time series econometrics like whether commodity prices are a random walk or not.

After generating a set of price paths, it is time to simulate the economic performance on the mine plan under each of those particular paths separately. Use the current market price to calibrate the initial price in the model to current conditions in the market, and then use the price paths to run the simulation forward. Each price path generates a single value for the NPV of the mine plan. From a set of price paths, you generate a distribution of NPV for that mine plan.

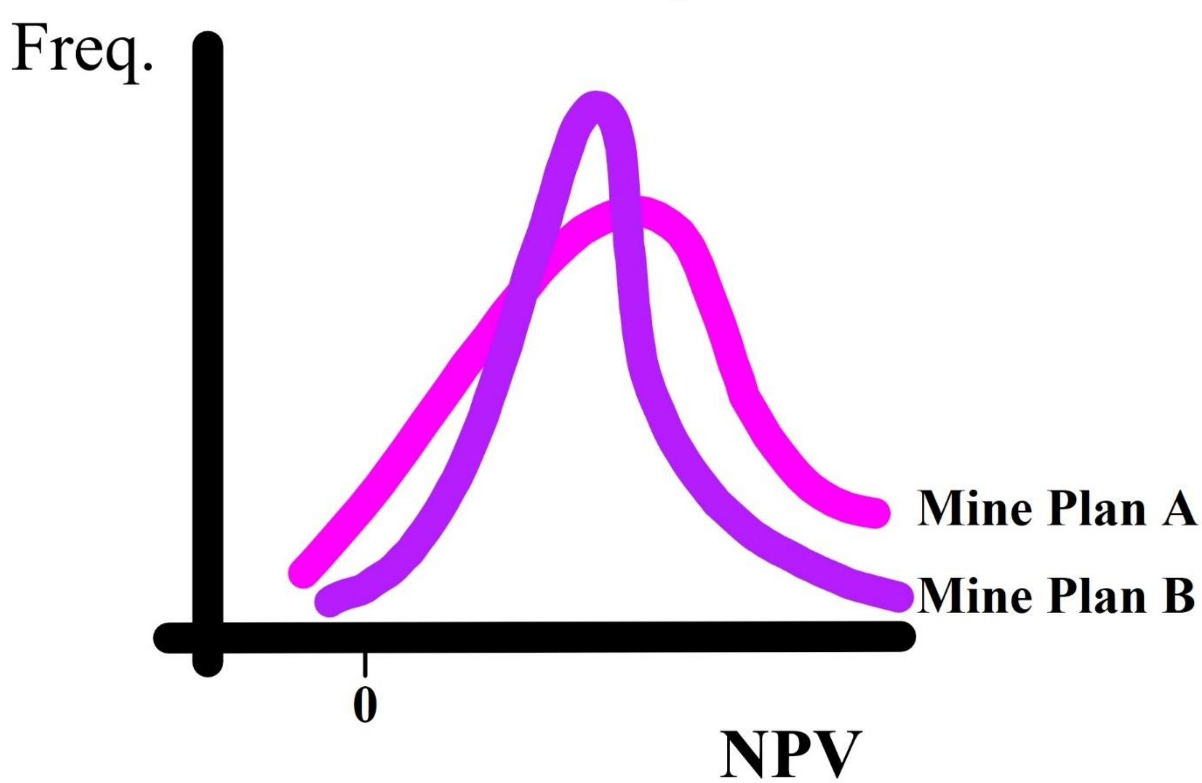


What good is this distribution of NPV? Well, it provides a basis for probability statements about the profitability of the project. For example, it has a 0.1% chance of having a negative NPV under historical market cycles. It also allows for statements about the magnitude of profitability based on quantiles, such as the median value for NPV.

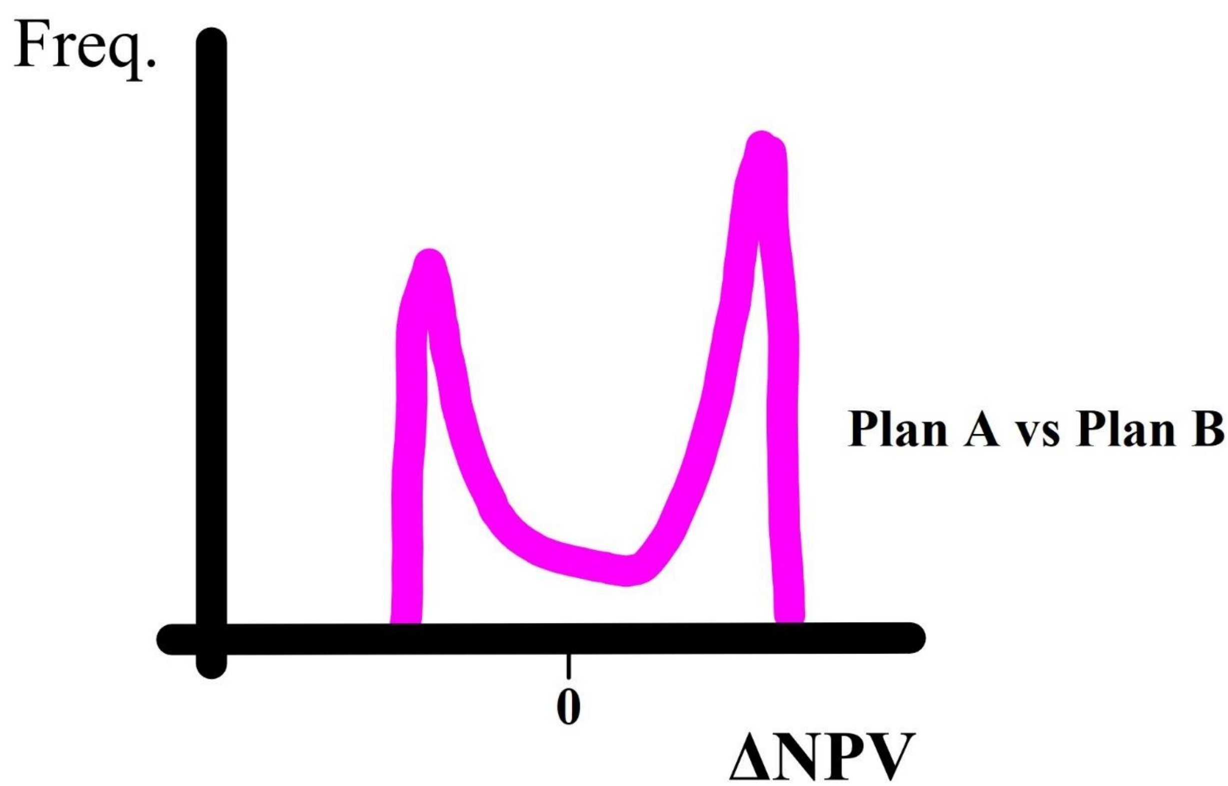
What's more, this distribution conveys a sense for the difference between extreme outcomes versus typical ones from this mine plan. It would be possible to dig down further into the extreme outcomes to determine what is special about these paths that really drives the extreme outcome. For example, the simple answer that "commodity prices went down and put the mine out of business" is unsatisfactory and can be improved on. As in the case of a flight plan from Whittle Consutling: If you see the price falling in year 5 of production, then what do you do? Again, this can be seen as a type of stress test.

Comparing Mine Plans

Assuming you have multiple mine plans in hand, it is possible to repeat the exercise by using the same price paths for each mine plan and comparing NPV outcomes. When you're comparing different mine plans, I would start with an informal visual inspection of the two distributions because something obvious may jump out at you. For example, one plan may be skewed to the downside. Things may be clear in some cases, but I would typically expect mixed results where one plan is better than another in some cases but not all.



It is possible to formalize the comparison of the distributions by calculating the distribution of the differences in NPV. I would refer to this as a path-wise difference because it entails calculating the difference in NPV between two mine plans for one particular price path and repeating that calculation to estimate the distribution of the differences, rather than calculating difference in distributions themselves.



The distribution of differences may convey something obvious about projects, such as an example of a "Pareto Improvement" where one mine plan is always better than another. It may also reveal more subtle aspects, like some asymmetry between the two plans. Furthermore, it is possible to compare one particular mine plan to several alternatives by repeating this calculation to see if there are any clear ways that the one plan is superior or inferior to the others.

Discussion

Although this modelling approach includes variability in prices, it is somewhat unsatisfactory because it doesn't allow for variation in costs or other aspects of the mine plan. If a subject area expert is willing to venture out on a limb and specify cost paths or paths for other key variables, then it is possible to include that in this approach.

And what about the option of optimizing the mine plan relative to some set of price paths – you could, but should you?

This path-specific optimal mine plan is helpful as a conditionally-optimal mine plan, but has some challenges. For example, when do you abandon one conditional plan and shift to another? If management are willing to make some prediction about commodity prices, then they may be able to justify such approach but I fear that this may be difficult to justify ex-post.

I suspect that you almost always want to be careful about how much you react to price changes, anyways. You really want a mine plan that's robust, which you can stick to through thick and thin. It may be too much to expect that from one single plan, but I'd leave it up to the professionals at Whittle Consulting for guidance as to how to develop such a mine plan and when to revise it.

The comparison of a mine plan and a flight plan is very instructive, and it is important to note that it is possible to include a fairly sophisticated or conditional mine plan in the simulation framework I have introduced here. It may be a challenge to setup the simulation framework, but it is not a wicked computational problem. And for analysts who make the effort, I think it will become clear that a plan that is adaptive to a crashing commodities market is going to have a very different NPV distribution than one that isn't!

If one mine plan scales back and tries to shut down gracefully in the face of falling prices, then it will have a very different outcome from another plan that just keeps going until it reaches a catastrophic failure. Those outcomes will only be apparent in a relatively low-probability set of possible price paths, but it will be apparent in the distributions of the difference of NPV. The creation of those mine plans is beyond me, but I believe this simulation framework will make it more clear.

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