On the issue of Roşia Montană gold exploitation An application and extension of the Arrow-Fisher uncertainty model on local issues

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The aim of this article is to analyse the prospects of gold mine development at Roșia Montană, with a focus on the uncertainty regarding this process. We are specifically interested in the issues associated with cyanide spill accidents and how these uncertain events can alter the cost/benefit analysis. Making use of an established methodology, we conclude that the projected gold exploitation can pose considerable risks to the environment, and that an efficient operation would imply either reducing these risks, their effect on the environment, or both. Finally, we also draw from historical knowledge regarding the ancient mine Alburnus Maior, in order to assess the viability of the modern exploitation. We conclude that the modern project could be improved by technological progress, which would seek to maximize the scale of operations, while minimizing both the risk of accidents and their impact on the environment.

Keywords: Montană, uncertainty, environmental damage, technological progress, gold.
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Introduction
The small community in Roşia Montană, in the western part of the Carpathian Mountain chain in Romania has gained international notoriety, mainly due to two reasons: the size of the gold deposit situated in the mountains near the modern settlement and the back and forth game between Romanian officials and private investors wishing to develop the area. While the Roşia Montană issue has many facets which could be analysed, we are strictly interested in the economics of gold mine development there, including the effects on the natural environment.

Although widely recognised as a deposit with a very high potential, the gold production output at the site at Roşia Montană, supposed to occur upon project development, is unclear. A study, conducted under the patronage of the Bucharest Academy of Economic Studies put forward a figure of 300 tonnes of gold and 1,600 tonnes of silver, obtained during approximately 16 years of operation (Bran 2003). The most recent study put forward by Gabriel Resources, the leading figure in the exploitation of the deposit, suggests that around 314 tonnes of gold and 1,479 tonnes of silver will be obtained (Armitage 2012), while a somewhat more recent document put forward by a special parliamentary commision mentioned 247 tonnes of gold and 905 tonnes of silver (Comisia 2013). While there is a certain ambiguity regarding the exact amount of gold and silver to be extracted (which is, up to a point, understandable, due to difficulties in estimating underground resources), the payoff for developing the Roşia Montană mine is clearly significant.

Our article is not, however, concerned with the payoff from developing the mine, at least not in such a specific way. We are interested in how a balance can be struck between developing the mine and protecting against unwanted ecological damages. In this respect, we are interested in the mining method used, *i.e.* gold cyanidation, and how the uncertainty regarding this process can adversely affect *a priori* made cost/benefit analyses. Our analysis follows a surge in regional analysis on natural capital usage (*e.g.* Hamideh *et al.* 2013, Ilie & Zaharia 2007, Bobirca & Cristureanu 2006, Vlasceanu & Ches 2005).

The methodology we make use of in order to analyse the situation at Roşia Montană has been put forward by Professors Kenneth Arrow and Anthony Fisher (Arrow & Fisher 1974), and involves a simple analysis of benefits and costs. What differentiates the model from similar cost/benefit models is the fact that it internalises the problem of uncertainty regarding irreversible environment damage. This is particularly appealing to our chosen case of analysis, since the technology which will be used at Roşia Montană (gold cyanidation) involves a certain degree of uncertainty, regarding the side effects on the natural environment. Besides this rather abstract and theoretical approach to the problem, we also make use of a historical comparison between the ancient gold mine at Alburnus Maior, and the current proposed Roşia Montană exploitation.

The model and its application to our chosen case

As detailed by Kenneth Arrow and Antony Fisher, we are interested in determining if a natural landscape should be developed or preserved. This problem essentially revolves around two issues: what are the benefits that accrue from development and what benefits do we derive from preservation of the natural habitat. It also follows that development implies costs, whereas preservation does not. Naturally, any discussion on natural capital valuation is contingent on our view upon natural capital. In a limited perspective, for example, we can see a forest as a provider of timber and nothing else (at least of value). In a more ample view, we can see the forest as an important component in the local ecosystem equilibrium, with important roles in storm dampening, conserving the water cycle, combating soil erosion, harboring biodiversity, *etc.* While this avenue of research is interesting in itself, we will limit this analysis to what can be thoroughly valuated by economic means. In this respect, we are using the Arrow-Fisher model as follows (Arrow & Fisher 1974):

Define

d as the the unit of land

d_1 the land developed in the first period

d_2 the land developed in the second period

b_p benefits from preservation of d in the first period

b_d benefits from development of d in the first period

β_p expected benefits from preservation of d in second period

β_d expected benefits from development of d in second period

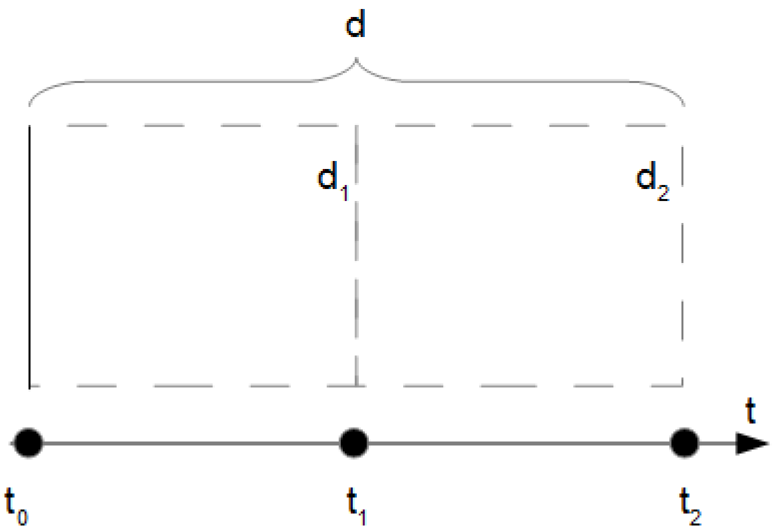
c_1 investment costs in first period

c_2 investment costs in second period

It follows then that if $\beta_d\text{-}\beta_p>c_2$ then $d_2=1\text{-}d_1$, else $d_2=0$ and, ultimately that $E[b_d\text{-}b_p\text{-}c_1+min(c_2,\ \beta_d\text{-}\beta_p)]<E[b_d\text{-}b_p\text{-}c_1]+c_2$, where $E[\ ]$ signifies the expected benefits given by the expression in brackets. *In nuce*, the previous expression means that *the expected value of benefits under uncertainty is seen to be less than the value of benefits under certainty* (Arrow & Fisher 1974), since under uncertainty there is a $P[min(c_2,\ \beta_d\text{-}\beta_p)<c_2]>0$.

The spatial and temporal coordinates used in the Arrow-Fisher paper can be visually described in the following representation:

Figure 1
Spatial and temporal coordinates for the Arrow-Fisher model



Source: own reasoning

Our interest is to determine the feasibility of Roşia Montană project, including both ecological and economical aspects into the analysis. To the rationale hitherto discussed, we add another term, c_{err}, designating costs related to accidents that have a severe effect on the environment. These costs could mean leakage of toxic substances into the environment, water contamination *via* these same vectors, *etc*. Given these new circumstances, the Arrow-Fisher inequation for development becomes:

$E = [b_d - b_p - c_1 - min(c_2, \beta_d - \beta_p) - c_{err}] > 0$ (1)

The new term, c_{err}, presents a series of peculiarities which significantly differentiate it from the other terms. Thus,

Firstly, a correct estimate of the costs brought on by such accidents is a complicated undertaking, due to the fact that:

1. The impact on the environment can vary considerably, contingent on the substances leaked;

2. Some benefits derived from the environment are only weakly quantifiable and/or their replacement costs are impossible to compute due to a lack of human-made substitutes.

Secondly, these costs are not certain, in the sense that their existence depends on the chance of the event happening. Therefore, if accidents are absent, so are the costs incurred. If accidents occur, then the c_{err} value rises sharply în al doilea rând, and this behavior is unlike any of the other variables, whose value can be easily computed, even before undertaking the investment.

These things being said, the condition for development in the next phase (for t_2) is contingent on the chances that such accidents will occur ($P[c_{err}>0]$), but also on the magnitude of the impact on the environment, should such events happen. Including the new term into the analysis, the development of the Roşia Montană mining project is therefore contingent on two terms: the benefits reaped and costs incurred. Mathematically, this is expressed as:

$b_d d_1+\beta_d d_1+b_p(1-d_1)+\beta_p(1-d_1)$ (2)

and

$b_p d_1+c_1+\beta_p d_1+c_{err}$ (3)[2]

Should the analysis conclude that the second term (3) is smaller than the first term (2), development should be avoided. We should, however, have in mind that c_{err} is not a certain event, unlike, for example, the investment costs c_1. If the company decides to go ahead with development, c_1 will exist, while it is entirely conceivable that no costs related to human errors, as they have been defined in this paper, will occur during exploitation. In this respect, our reasoning should be interpreted as a worse-case possible scenario. Given the fact that the environment stands to incur significant damage in the event of such accidents, c_{err} should be integrated into any analysis, as long as there exists a probability different from zero of occurrence.

The degree to which c_{err} will appear is uncertain, since, in essence, these costs are contingent on accidents happening. However, the scale of the damage, should these accidents happen, is large (Townsend & Townsend; Vick 1996, Filas & Gormley 1997; Koenig 2000). Therefore, even though the chance of accidents

2 Given the scale of the operations, we are assuming that as b_d increases, naturally b_p decreases, in other words, that as benefits derived from developing the land increase, the benefits from preserving the land decrease. Therefore, the benefits of preservation are counted as costs, since they are lost once development takes place (we are assuming development benefits do not substitute the benefits obtained *via* preservation). This is an assumption also implicit in the Arrow-Fisher model. It should also be pointed out that this evolution should by no means be considered linear, and it is entirely possible that b_p reaches 0 long before b_d reaches maximum value.

happening might be slim, the fact that there is a chance at all, together with the fact that cyanide accidents have a devastating effect on the environment, needs to be accounted for in any development analysis. Although different in magnitude, the situation is somewhat similar to nuclear power plants. In essence, these are safe methods of harnessing energy and their (normal) environmental footprint is low. However, should accidents happen (and history has many examples of such accidents, ranging from only alarms to full blown disasters), the consequences can be dire, indeed. Therefore, our rationale is that, even though there are only slim chances of accidents happening, the scale of the potential damage warrants attention for these events.

In essence, all future events present a certain degree of uncertainty, this being greater the further we try to pierce the future. Obviously any entrepreneur or policy maker wishing to implement a strategy cannot afford the time to internalise all of these uncertainties into his decision making. The degree to which an uncertain event is internalised into a model is contingent on the conceivable effects of that event, should it become certain. In other words, only high impact uncertain events are considered in any risk assessment. Our cyanide accident event is just one such case, and the costs implied (c_{err}) are significant.

When should the gold exploitation at Roşia Montană commence?

In essence, any gold exploitation attempt at Roşia Montană, or at any other site for that matter, would be more efficient the lesser the chance of a severe environment damage event. There are, however, two other cases, albeit less realistic. Following our reasoning so far, development at Roşia Montană can be undertaken in the following three cases:

$P[c_{err}>0] = 0$, which means c_{err} is eliminated. In this case, the development inequation becomes $b_d d_1+\beta_d d_1+b_p(1-d_1)+\beta_p(1-d_1) <> b_p d_1+c_1+\beta_p d_1$; if positive, development should take place;

$P[c_{err}>0] > 0$, but $c_{err} \rightarrow 0$. The inequation for this case is $b_d d_1+\beta_d d_1+b_p(1-d_1)+\beta_p(1-d_1) <> b_p d_1+c_1+\beta_p d_1+c_{err}$, with the same development condition as in the prior case;

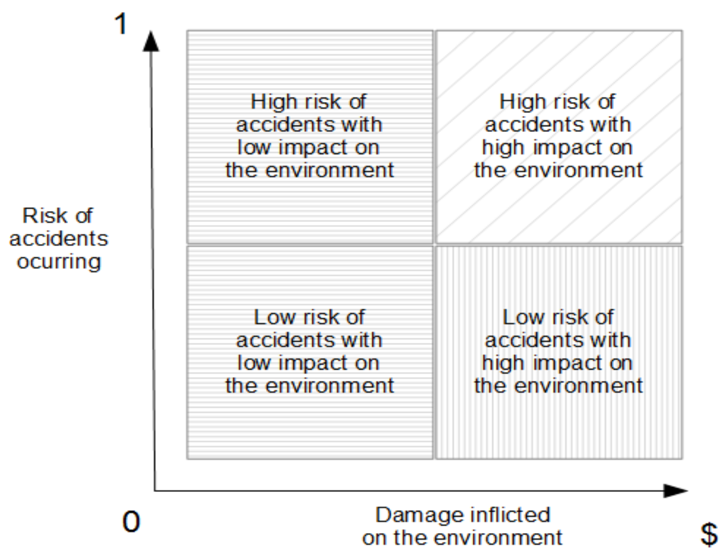
$P[c_{err}>0] > 0$, $c_{err} > 0$, but the benefits from development (b_d & β_d) are so great that they justify both loses incurred from accidents, but also opportunity costs due to lost benefits from preservation of the natural habitat. The inequation is changed thusly: $b_d d_1+\beta_d d_1 <> b_p d_1+c_1+\beta_p d_1+b_p(1-d_1)+\beta_p(1-d_1)+c_{err}$, because cyanide spills can cause environment damage to an extent greater than the physical land developed (d_1) by the company seeking to mine the gold at Roşia Montană.

The first and the third cases are considered unlikely due to the following reasons: for the first case, there are precedents suggesting that the probability of such accidents happening is distinct from zero. As with any human undertaking, there is a risk of failure, therefore, at least at present times, setting $P[c_{err}>0]$ to zero would be rather artificial. For the third case, as the inequation terms suggest, once all benefits from preservation of the environment are accounted for, it would be quite difficult for development benefits to surpass them (to which we would add, of course, the other associated costs)

At any rate, any exploitation should be prepared for costs associated with unlikely, but possible, mining accidents ($P[c_{err}>0]>0$), but seek to reduce the environment damage, should these events occur ($c_{err}\rightarrow 0$). Since at present times, however, gold cyanidation implies risks unequal to zero and the scale of the damage is large, we conclude that a safer option is to postpone mining operations using this technology, until technological advances permit a gold eploitation with either very low chances of accidents happening, or with a neglijible effect on the environment, should these accidents happen. Ideally, the new technology would combine both these features. An alternative, although not business friendly, would be a technology that has an accident risk rate larger than 0, possibly even approaching 1, but that does not produce severe effects on the environment. This situation can be visually depicted in the following graphic:

Figure 2

Possible event outcomes in the Roşia Montană mining operation



From an environmental point of view, the ideal gold exploitation at Roşia Montană is one along the *Y* axis of the graphic, with a small *X* value (graphically depicted as horizontal hatchings). Ideally, this would be a situation with a low risk of accidents happening and a low impact on the environment. The situation in which there exist high risks of accidents that have a low impact on the environment, can also be seen as environmentally friendly. From the business side of things, the lower left hand square would also be the best option, as low risks of accidents prevent any unwanted and possibly unforeseen costs. However, as long as environmental damages are not internalised in the project accounting, the low risk of accidents with a high impact on the environment situation could also be seen as economically viable. This is all contingent on how the cleanup costs are handled, and to what degree these imply restoring the environment to its previous, natural, state. The top right hand corner of the graphic is clearly to be avoided, regardless if we view environmental concerns as being of utmost importance, or if we undertake the business perspective. High risks of accidents would be inefficient for a business, regardless if the costs to the environment are well reflected in the accounting or not.

Costs associated with a cyanide accident are contingent on a great number of factors, a lot more than those involved in computing investment costs and cleanup costs. This implies that c_{err} can be quite high. But the fact that c_{err} is essentially a chance event (meaning there is no certainty it will happen) means that in this particular development there exists uncertainty which, according to the Arrow-Fisher model substantiates the claim that „*the expected value of benefits under uncertainty is seen to be less than the value of benefits under certainty*" (Arrow & Fisher 1974).

A historical perspective on the exploitation at Roşia Montană

Another perspective on this problem would be a brief historical analysis of the Roşia Montană site. The gold deposits have been mined since Roman times (II A.D.), possibly even earlier (ancient name was Alburnus Maior (Protase 2010, Giurescu 2007))

Table 1

A historical comparison between Alburnus Maior and the modern Roşia Montană proposed exploitation

	Gold extraction done in the	
	First centuries of the first millennium	First century of the third millennium
Scale of extraction	Small	Large/industrial
Tools used	Rudimentary (mechanical)	Advanced (chemical)
Risk of accidents	Small	Great
Externalities		
During extraction	Unimportant	High (the local ecosystem is affected in a significant manner – through deforestation and other mining related activities)
After extraction has ceased	Unimportant	Potentially very important (should the environment suffer contamination with cyanide)
Benefits of development	Known	Known
Benefits of preservation	Unknown	Partially known
Investment costs	Low (with no uncertainty degree due to environment damage)	High (with a degree of uncertainty due to possible environment damage)
Gold deposit decay in time	None	

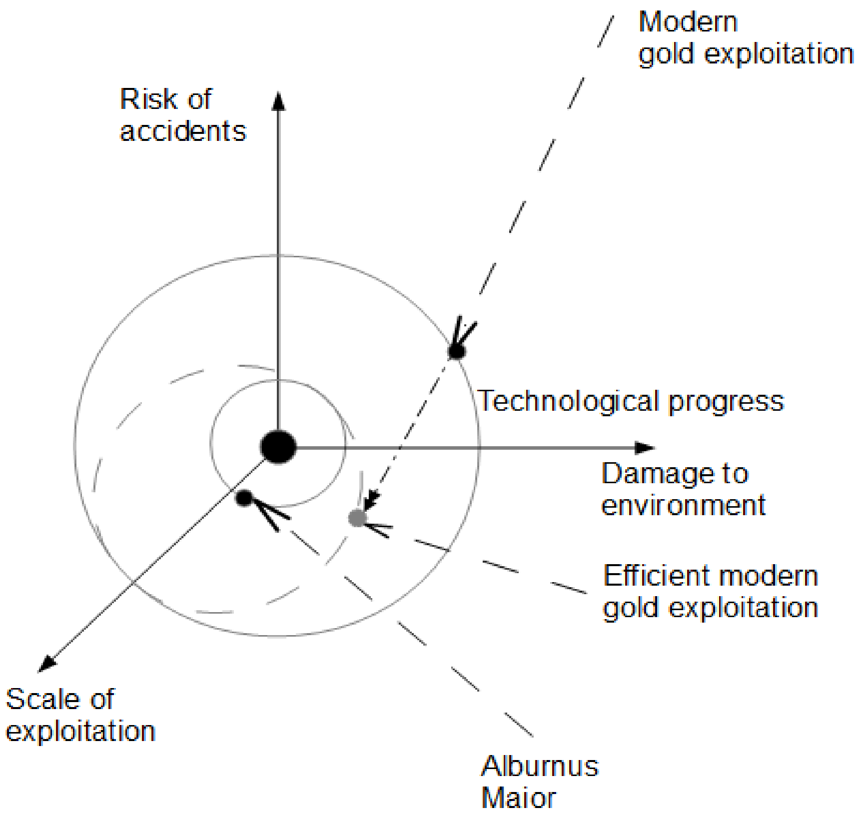
Source: own reasoning; for the ancient mine at Alburnus Maior, see Protase (2010)

The question that one can pose after this table is this: as an entity assesing each of these mining operations, which one should be chosen, with uncertainty reduction as a key criterion? At least with regards to environment externalities, there clearly is no contest: the second century Alburnus Maior mining operation is largely harmless to the surrounding environment, whether we are referring to the effective period of mining, or to the period that follows the ceasing of all mining activities. In compliance with the Arrow-Fisher methodology, there are no irreversible side effects (there is, of course, one irreversible effect, in the sense of gold exhaustibility, but that is obvious).

On the other side, developing a mining operation at Roşia Montană, in the modern sense, implies both uncertainty and an irreversible altering of the natural environment. Therefore, the only unknown in our model would be determing the benefits from preservation of the natural environment. Since these are however borderline impossible to compute, we need to base our analysis on uncertainty and irreversibility. In this respect, we conclude, in accordance with the Arrow-Fisher methodology, that *„if we are uncertain about the payoff to investment in development, we should err on the side of underinvestment, rather than overinvestment, since development is irreversible. Given an ability to learn from experience, underinvestment can be remedied before the second period, whereas mistaken overinvestment cannot, the consequences persisting in effect for all time"* (Arrow & Fisher 1974). Also in accord to the forementioned authors is our conclusion that neither uncertainty nor irreversibility should be discounted from analysis, as external, neutral factors. This can lead to grosse imbalances in any analysis and can serve to paint a significantly brighter picture than in reality. Nor should we fall in the other extreme, and consider uncertainty and/or irreversibility as immutable bans on development, as it can easily be shown that all human predictions contain a certain degree of uncertainty, which rises the further in time we seek to analyse.

If we were to graphically represent the two gold exploitations and a hypothetical efficient modern exploitation, the result would be along these lines:

Figure 3
Comparison between Alburnus Maior, current Roşia Montană project, and a hybrid hypothetical project
Source: own reasoning



As can be seen, the ancient gold exploitation Alburnus Maior is consistent with a very low risk of accident, a largely insignificant damage to the environment, should these accidents occur and a similarly small scale of exploitation. The modern Roșia Montană gold exploitation on the other hand is characterised by a large exploitation, significant risks of accidents and a large potential damage to the environment. It can be argued that while technology has facilitated access to deeper gold veins and a larger scale of exploitation, it has done little to reduce the risk of accidents, in our case cyanide spills, and, if anything, has increased the damage to the environment, should such accidents occur.

From the previous figure, we can deduce that an optimal gold exploitation at Roşia Montană, and indeed anywhere gold cyanidation is used, is one that seeks to maximize the scale of exploitation and minimize the risk of accidents and the damage to the environment. While maximizing the scale of the exploitation is a discussion which has not been addressed in this paper, there follows from our rationale that minimizing the other two variables is a *sine qua non* condition for a sustainable development at Roşia Montană. This is all the more evident since there is no gold deposit decay, and, costs of opportunity being discounted, there is not any loss associated with delaying mining operations until our minimizing condition is met.

Conclusions

The gold exploitation at Roşia Montană presents an unique development oportunity for the local community, for the regional county, for Romania as a country and for the private investors involved. However, the extraction methods involved imply considerable risks to the environments. Should these risks turn to certainty, the costs involved can be severe. In this respect, and drawing from historical information on the Alburnus Maior ancient gold mine, we conclude that in order for development to proceed, the parties involved should either ensure that the costs corresponding to cyanide accidents are very low, should these events occur, or that the chance of these events occuring is in itself neglijible. Although we would not go so far as to say that the costs related to cyanide accidents are a limiting factor in themselves, since these events are contingent on certain probabilities of occurence, we conclude that these costs should be reflected in the cost-benefit analysis. More-so, since there is virtually no gold deposit decay in time, we assert that the development can and should be postponed until technological progress reduces either the chance that accidents occur or that these accidents are grealy reduced in environmental damage. In accordance with the Arrow-Fisher methodology, a proper gold exploitation at Roşia Montană should be carried out once the uncertainty regarding development is significantly reduced, as these chance costs are shown to reduce the expected benefits from development and preservation.

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