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Towards sustainable mining (part II): Accounting for mine reclamation and post reclamation care liabilities

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ABSTRACT

Valuation of mining investment opportunities typically focuses on revenues (i.e., amount of ore, mineral grade, and commodity prices), pre-production capital expenditures (CAPEX), and recurring operating expenditures (OPEX). Less emphasis is generally placed on longer-term costs that are harder to quantify, such as decommissioning, closure, and reclamation. Less emphasis still is placed on valuation of the very long term (or perpetual) costs of post-reclamation care (PRC) and long-term management (LTM) that should follow mine closure and reclamation, primarily due to technical and environmental uncertainties and the widespread practice of discounting, which renders the present value of distant future costs virtually nil particularly when typically high discount rates are used. Following on from the discussion of mine asset valuation in Part I (Espinoza and Rojo, 2017) of this two-part dissertation on sustainable mining, Part II discusses the inherent issues with the current practice of valuing project opportunities and accounting for PRC liabilities and LTM within the mining sector. The paper argues that mining sustainably starts with recognizing all potential future liabilities (routine and non-routine) through the life of a mine, ensuring that sufficient funds are available to address these liabilities, and investing these funds appropriately. Decoupled net present value (DNPV) analysis, which separates risk from the time value of money and treats risks as a cost to the project, is presented as a robust alternative to current accounting practices. This method can identify the effects of individual risk factors on the value of a project. A hypothetical example taken from the mining literature is used to compare the DNPV method with net present value (NPV) and modern asset pricing (MAP) analysis, and clearly illustrates the unsustainable consequences of using risk adjusted discount rates to value long term mining investments.

1. Introduction

Reclamation and post-reclamation are important considerations in the valuation of mining assets, because mining involves generation of inordinate amounts of waste per unit of extracted mineral, which is concentrated in the form of spent heap leach pads (HLPs), tailings storage facilities (TSFs), or waste rock dumps (WRDs). The scale of modern mining operations and quantities of waste generated dwarfs all other industrial waste management activities, and arguably represent the most significant barrier to sustainability (Mudd, 2009a). For instance, the 2008 reported worldwide average grade of commercial copper ore was 0.8% (8000 g/Mg), which means that about 5.7 t of waste is generated for every 100 pounds (lbs.) of copper extracted (Mudd, 2009b). Assuming copper grades have remained relatively constant, at about 18.3 million tonnes in 2013 (CDA, 2015) worldwide copper production gives rise to over 2.25 billion tonnes of waste annually. The average grade of gold ore is even lower at about 0.0001% (1 g/Mg), meaning over 30 t of waste is generated for every troy ounce (tr oz.) extracted (Korelin Economics Report, 2012). Although only 2,700 t of gold were mined in 2013 (NRHR, 2013), at nearly 2.7 billion tonnes annually gold mining nevertheless generates more waste than copper mining. Modern surface mining operations typically involve the disturbance of large tracts of land as open cuts to extract ore, with resulting waste deposits encompassing hundreds of hectares. As a result, mines are enormous: examples include La Quebrada Copper Mine in Antofagasta, Chile (1,000 ha), Bingham Canyon Copper Mine in Utah, USA (3,000 ha), and Yanacocha Gold Mine in Cajamarca, Peru (9,000 ha).

To compound the scale of the problem, because of the chemical processes used to extract mineral from ore (for example, copper is leached out using sulfuric acid, while gold uses cyanide-rich solutions as a leaching agent), the waste generated can be quite toxic. These aggressive leaching processes take place over large HLPs or via industrial processes that dispose of finely ground tailings in TSFs.

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Residual sulfide minerals in HLPs and TSFs are susceptible to oxidation and resulting acid mine drainage (AMD), which is harmful to human health and the environment (HHE) and poses a potential threat to local water resources (Plumlee, 1999). In many instances, the excavation process itself exposes virgin material susceptible to AMD; as a result, surface water management at WRDs is needed to minimize AMD. The sheer size of HLPs, TSFs, and WRDs means that very large quantities of contaminated contact water in the form of surface water runoff and/or leachate percolating through the deposits will require treatment over the very long term (i.e., long after mineral extraction activities at the site are terminated), adding significantly to the true cost of decommissioning and closing a mine. Ongoing water management and treatment will be required until the mine does not pose a risk to HHE. Very long term post-reclamation care (PRC) activities and costs should thus be carefully evaluated and included in the total extraction cost of a given mineral when deciding whether or not a proposed mining project would be profitable. Further, an environmental impact assessment (EIA) should be performed in an attempt to value lost local amenities, access, and/or ecological resources and charge these to the pre-development cost of the project (Davis, 2002).

2. Accounting for reclamation and post-reclamation care

Different from many other business activities, mining is by its nature a temporary activity, generating revenues during a finite (sometimes relatively short) period but potentially incurring liabilities that can last a very long time or even in perpetuity (e.g., Allan, 2016). Developers need a good understanding of this if they are to attain a socially responsible and sustainable mining operation. While practices vary by company and continue to evolve, mine reclamation (i.e., engineered closure) plans and cost estimates are now increasingly prepared through self-imposed standards for corporate governance or as a regulatory requirement to prevent unfunded environmental legacies being imposed on future generations of taxpayers who derive no benefit from the years of active mining (Ackerman, 1998; Mudd, 2009a). Policies for reclamation and management of long-term liabilities have been developed (e.g., Cowan et al., 2010), and providing for sustainable reclamation and PRC has been considered from a technical perspective (e.g., Fourie and Tibbett, 2007; DeJong et al., 2015). This poses many challenges with regard to the very long-term performance of construction materials and engineered systems. However, assuring financial sustainability is equally challenging. Although some companies treat mine closure as a continuous process, thereby accounting for some reclamation and PRC expenses during the mine's operational lifetime, in many cases these activities are assumed to occur far in the future and their estimated costs are artificially reduced by the use of popular simplified valuation methods such as net present value (NPV), discounted cash flows (DCF), and internal rate of return (IRR). Because these methods combine the time value of money and risk in a single factor (the discount rate) which is increased to account for risk, the results of the analysis are often misleading. In other words, where estimating the present value of future liabilities associated with projects with very long duration, the distant future costs are rendered virtually nil by discounting (Zeckhauser and Viscusi, 2008). This can lead to design and operational decisions that are detrimental to society and shareholders alike.

The shortcomings of the NPV method have been recognized by many industry experts (e.g., Salahor, 1998; Samis et al., 2006; Guj and Garzon, 2007), including with regard to valuation of mining assets and liabilities (e.g., Davis, 2002). Alternative valuation methods (e.g., real options valuation or modern asset pricing methods) have been proposed to correct for some of these shortcomings (e.g., Laughton et al., 2000). Nevertheless, NPV, DCF and, IRR remain the valuation methods of choice. As a result, inappropriate funding is often set aside for reclamation and PRC activities (Boyd, 2001; Chambers, 2005), beguiling mines into selling a valuable commodity at prices that do not account for the actual total cost of production. This promotes unsustainable mining practices that are not environmentally protective and may leave future taxpayers exposed to significant liabilities if the company dissolves or the mine permit expires. This problem is exacerbated when expensive-to-operate mines are rushed into production in response to high commodity prices only for a subsequent downturn to force bankruptcy and sudden closure.

The lack of consistent reclamation and PRC standards across the mining industry further aggravate problems with liability valuation and hinders development of sustainable practices between global competitors. Closure and PRC obligations and timeframes are typically not well defined and, although provision of financial assurance for mine closure and rehabilitation is required in many countries (Sassoon, 2009), bonding levels vary from the complete cost of mine cleanup in some US, Canadian, and Australian jurisdictions to less than 40% in others, while Ghana requires only 5–10% of the estimated cost to be provided (Miller, 2005). It is typically assumed that it will take less than 10 years to shut down a mine and complete reclamation, although it is acknowledged that water monitoring and treatment "may take longer." However, as discussed previously, the actual PRC period required could be several decades to a century or more. In essence, this means that society will sooner or later bear the unfunded PRC costs. The only questions are which future generation (i.e., timing effects) and what region (i.e., location effects) will be saddled with these costs. Examining location effects first, some mining activities have a predominantly local/regional effect (e.g., mining coal to fire a nearby power plant). In this case, ignoring (or understating) future liabilities will affect the same locality that took advantage of the extracted mineral. However, current generations will be the beneficiaries of cheaper energy at the expense of future generations that will be saddled with the resulting environmental liabilities, effectively transferring wealth from the future society to the present, but within the same region. On the other hand, extraction of commodities such as gold, copper, iron, or oil is, in most cases, a local/regional activity with a global effect (i.e., resources are extracted locally and consumed globally). Resource extraction is undertaken by large corporations who enter into host agreements with national/subnational authorities and pay royalties for mining rights. In such cases, understanding future liabilities associated with mining activities and accurately including these in the total production cost becomes more critical. Otherwise, global consumers are not only benefiting from an artificial reduction of future liabilities (i.e., transferring wealth from future generations) but are also leaving understated environmental liabilities to the local society hosting the mine. The problem is more acute if said future society belongs to a developing or emerging economies with insufficient resources to take care of the potential environmental legacies. For many such economies, revenue associated with the mine in the form of royalties, jobs, and local economic activity represents a significant percentage of gross domestic product (GDP) and is difficult for current generations to decline. Enforcement of tougher environmental standards along with stricter accounting practices are politically hard to enact as such measures could risk a reduction in GDP and hence the wealth of current generations. Citizens from future societies do not get to cast their votes in today's elections to voice their dissatisfaction.

This paper is forward looking and does not seek to address the major legacy of mining-impacted land for which the gap between disturbance and rehabilitation is significant (Anderson, 2002). Despite rising community expectations and modern legislation (Mudd, 2009a), generational and locational wealth transfer remains prevalent in many modern economic activities (Kralj, 2013) and mining is certainly not the exception in this regard. It is also not the intent of this paper to imply that mining corporations are underhand at extracting profits at the expense of future society. Indeed, there is a growing trend within the mining industry to act with greater environmental and social responsibly as evidenced by recent improvements in mine reclamation standards and recognition of PRC activities and costs (e.g., Javier, 2015). However, despite these laudable changes, their impact can be obliterated by the continued use of valuation tools such as NPV to allocate resources for future mine reclamation and PRC activities. As noted previously, the main problem associated with NPV is the muddling of risk and the time value of money which becomes increasingly troublesome as the investment horizon increases (Espinoza and Morris, 2013). The problem is further aggravated by the widespread belief held by many investment advisors that the shortcomings of NPV can be addressed by using sophisticated modeling techniques such as Monte Carlo simulation along with scenario analyses (e.g., Berhe et al., 2016). This simplistic approach is bound to fall short. To implement sustainable mining practices and avoid artificially reducing future long-term liabilities, risk need to be separated from time and explicitly accounted for in the cash flows.

3. Valuation of mining investments

Valuation of a mining opportunity can be quite complex and involve professionals from several disciplines to assess the expected annual revenues and expenditures associated with different mining activities. Evaluation of a mining investment opportunity also requires an assessment of the risks (technical and market) associated with both revenues and expenditures throughout the mining cycle. The first step is to estimate the value of the mineral reserve (R), which depends upon the estimated quantity of ore (M), the mineral concentration or grade (g), and the price of the commodity (P_t). A straightforward estimate of the value of a mineral reserve is calculated as $R = gMP_t$. Because monetizing the value of a mineral reserve may take several years of ore extraction and processing, a more realistic estimate of R requires consideration of the rate (q) of extraction. This rate defines the characteristic of the investment, including: the projected life of the mine ($T_m = M/q$); the annual revenues over the life of the mine ($V_t = gqP_t$); and the appropriate size of capital expenditures (CAPEX) as well as annual operating expenditures (OPEX). The rate of extraction may be accelerated or slowed to reflect high or low commodity prices, or even halted if prices fall below a floor relative to the production cost.

Because mining investments typically require large capital investments and are subject to significant technical and market uncertainties surrounding revenues and expenditures, investors (and stakeholders) need to understand the risks associated with the project if they expect to participate profitably. Understanding of these risks is also paramount in assessing whether or not to take on a new mining investment opportunity or to expand an existing one.

3.1. Revenues

Understanding revenue risk is the focus of the Part I companion to this paper (Espinoza and Rojo, 2017) and will not be elaborated on here. In brief, revenues are subject to technical risk regarding the quantity and grade of the ore, properties that are predicted from interpretation of specific geological evidence and data from field investigations. The degree of uncertainty is inversely proportional to the amount and quality of geological information collected (i.e., collection of more/better samples lowers the predictive uncertainty). The degree of uncertainty generally remains constant through the project unless more geological information is collected that results in a revision of previous interpretations. Revenues are also subjected to market risk and this can be significant. Commodity prices vary randomly with time and unless purchase agreements for the projected quantity of mined minerals are established, revenues will be subjected to market volatility. Depending upon the investor's domestic currency, the projected annual revenues may be also subjected to currency risk.

3.2. Expenditures

As depicted in Fig. 1, the total cost of mineral extraction should include: (1) initial and recurring CAPEX (e.g., site facilities, leases, heavy equipment, water treatment plants, ponds); (2) OPEX (e.g., excavation of overburden and ore, ore processing, water management, leachate treatment, royalties); (3) reclamation costs (i.e., closure design and construction); (4) PRC costs for routine and non-routine events; and (5) long-term management (LTM), a term borrowed from the solid waste landfill industry to define the minimal level of custodial care needed once it has been satisfactorily demonstrated that active controls (e.g., pumps) are no longer necessary to protect HHE such that the property has achieved a state of "functional stability" (ITRC, 2006; Morris and Barlaz, 2011). LTM includes some *de minimis* level of perpetual care to protect against disturbance of buffer zones or passive barriers (e.g., vegetated soil covers for HLPs, TSFs, and WRDs) and satisfy institutional controls and deed restrictions on reuse of the property (Crest et al., 2010). Separating PRC and LTM costs in this way is useful, as PRC is a fixed (albeit long-term) obligation incurred by the mining operation and should be funded accordingly while LTM is a perpetual activity that, in participation with stakeholders, may be funded through alternative means such as beneficial reuse of the repurposed property (Dutta et al., 2005; Gupta and Morris, 2013) or proper investment of the accrued funds. While highlighting the need for LTM, this paper focuses on funding for reclamation and PRC costs.

In the past, the mining industry only considered expected CAPEX and OPEX (items 1 and 2 above) in estimating total extraction costs and gave scant regard to items 3 through 5. However, because of the sheer size of mining operations (aerial extent and volume of excavation and waste deposits), neglecting and/or minimizing these potential expenses could result in significant environmental legacies being passed onto unsuspecting local/regional stakeholders. Although the mining industry now does a better job of including mine reclamation and limited-term PRC costs (items 3 and 4) in the cost of doing business, estimating appropriate financial accruals to cover these costs still represents a challenge. Except for a few isolated cases, the mining industry mostly ignores the likelihood that PRC (item 4) may be needed over the very long time, leading to exhaustion of PRC funds before functional stability has been achieved. The need for perpetual LTM (item 5) thereafter is completely ignored. Again, much can be learned from the landfill industry's consideration of ongoing LTM following completion of regulated post-closure care (e.g., Espinoza and Morris, 2015; Bagchi and Bhattacharya, 2015). The problem is aggravated by the fact that mine reclamation and PRC/LTM activities take place in the distant future, the exact timing of which may be unknown due to uncertainties in the total operational life of the mine. To make matters worse, estimates for PRC costs only include routine care because non-routine care (e.g., repairing cover systems after a massive storm event) are hard to quantify and current accounting practices in most countries do not require corporations to account of non-routine costs or deviations from initial estimates of routine care costs (i.e., contingent liabilities).

In accordance with modern accounting practices in industrialized countries such as the USA, only "probable and estimable" environmental liabilities are generally accounted for and reported in the financial statements of publicly-traded companies (Gauthier, 2005). Unfortunately, despite the use of technical jargon, rather than using probability theory to describe the likelihood of future potential events based on industry data and the opinions of subject matter experts, issues are often obscured by the introduction of loosely defined categories of likelihood (e.g., "probable", "reasonably possible", and "remote") without providing specific guidance on the meaning of these terms. As a rule of thumb, probable events are typically those with a 70–80% (or higher) chance of occurring, reasonably possible events are those with a chance of occurrence between 10% and 70%, while remote or rare events are those with less than 10% chance of occurring (Everett-Garcia, 2013). If a liability cannot be reasonably estimated or its occurrence is deemed remote, then a corporation is not required to accrue for the contingent liability. It is not difficult to see from this

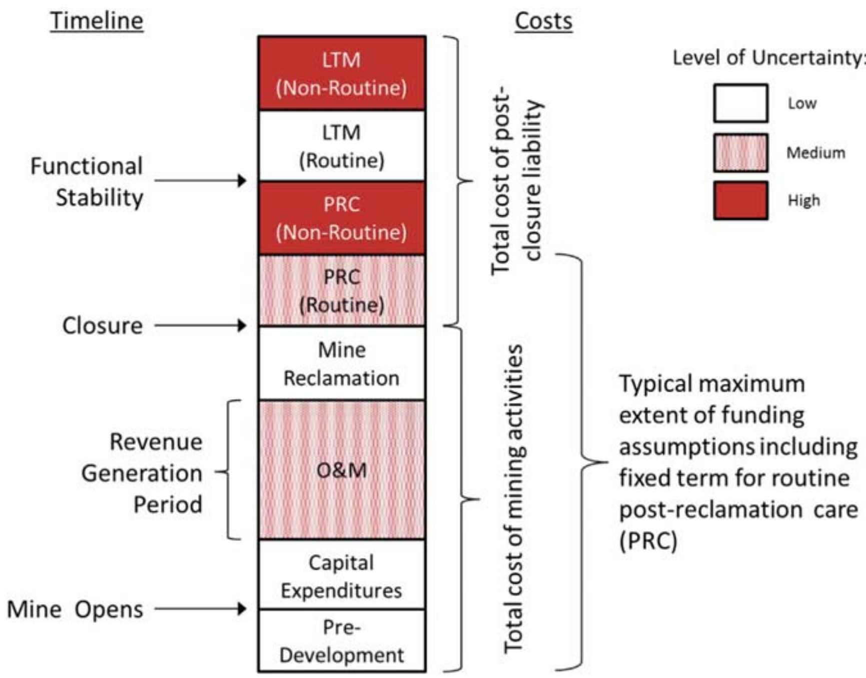

Fig. 1. Pricing of mineral extraction.

practice that accruals to address difficult-to-define environmental liabilities associated with "improbable" or "inestimable" events are insufficient, despite the high statistical likelihood of their occurring sometime in the future when a very long time horizon is considered. For cases where such events bankrupt the company, future taxpayers (often in remote, economically disadvantaged locations hosting the mines) will be left to address these environmental issues.

In summary, because of the long history of mining experience with extraction activities, pricing of CAPEX and OPEX as well as their variability are well understood and can be implemented in a cash flow analysis with relative ease. However, to better predict the total cost of mineral extraction, the cost of mine reclamation, PRC, and LTM as well as contingent liabilities should also be incorporated in the analysis. To that end, mine owners need to understand the reclamation design constraints and identify the main elements that drive the design (e.g., closure capping, surface water management, and treatment of leachate and AMD). Once these elements of mine reclamation have been defined, the long-term integrity requirements for each of the elements need to be well understood such that appropriate O & M activities can be specified and budgeted for to ensure that they will fulfill their intended functions through the LTM period.

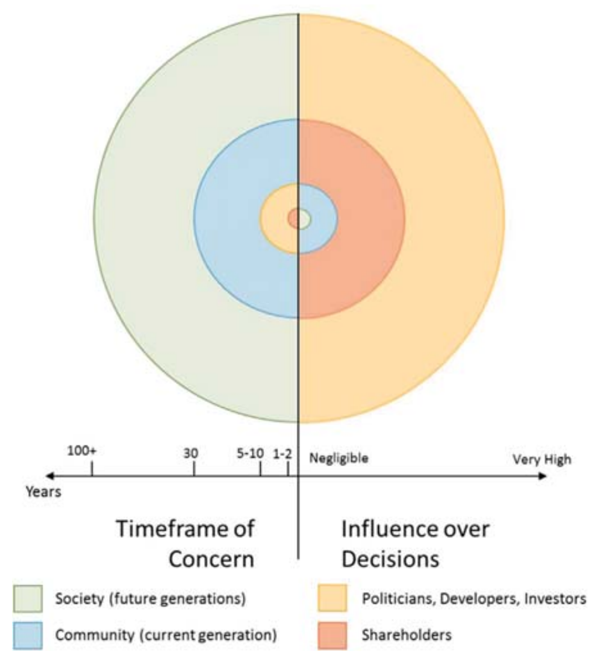

Fig. 2. Misaligned project development horizons.

4. Towards sustainable mining

Because mining is an activity with a limited life span, careful planning by the host society is necessary to avoid squandering of the valuable resources being mined and to prepare society for a future when such resources have been exhausted. Mining involves the interaction of a wide variety of stakeholders (e.g., corporations and their shareholders, local and regional governments, elected officials, regulators, NGOs, and the general public), each with misaligned perspectives, goals, time horizons, and level of influence over project development (Fig. 2). For instance, shareholders are interested in year-on-year profitability. Elected officials may favor mining activities that provide the largest royalties during their administration (typically 5–10 years), even if the proposed mining operation activities are not positive for the long-term sustainability of the region. Mining is a capital intensive activity that requires large upfront investments and is typically executed by the private sector whose main interest is to maximize their returns during the project lease period (typically 10–30 years). Even within the host society, the current generation may favor mining activities that offer them higher short-term royalties at the expense of future generations.

In order to participate in mining in a sustainable and socially responsible manner, and to realign and reconcile the interests of all stakeholders, a change in mindset is needed. First of all, the assumed lifespan of the mine should be extended to include the PRC and LTM periods (Fig. 1). This is an important consideration in particular for the host society to avoid being saddled with future liabilities. Second, because this extended lifespan will be rather long, accumulated funds should be actively invested to ensure that there are sufficient funds to take care of such long-term liabilities. Placing these funds in conservative investment vehicles that barely keep up with inflation will soon put unnecessary pressure on mine owners as the funds required to sustain PRC and LTM may be unreasonable large to the point that mining would be unfeasible. Royalties obtained by the hosting society should be invested in strengthening existing competencies or developing new ones to prepare for a future without such revenues. Neglecting the fact that mining is an economic activity with a limited life span will invariably result in a long-term social liability to be addressed by future generations if existing sustainable competencies (e.g., agriculture) were replaced in favor of a more lucrative (albeit temporary) economic activity.

In summary, mining sustainably starts with recognizing all potential future contingent liabilities (routine and non-routine) through the life of a mine and ensuring that sufficient funds are available to address these liabilities. Further, these funds need to be invested appropriately. Current accounting practices should be modified to encourage acknowledgment of contingency risks as well as rare events. The costs associated with non-routine natural hazards are contingent upon such events taking place. Site-specific vulnerability curves (i.e., expected repair costs for a given event) should be developed for the closed facility to establish the financial risk associated with potential hazards. Analysis of these events shows that they are rare; therefore, the probability of their taking place in any given year is rather small. This means that, although an event could be quite costly to repair, its associated risk (i.e., the expected repair cost averaged over the total care period) is small because of its low probability of occurrence. As a result, setting aside funds for responding to rare non-routine hazards at an individual mine would be impractical. As an example, consider a potential $10 million repair cost for a 500-year storm event: holding such a large sum in the small chance it will be needed would be inefficient, yet setting a low accrual rate to reflect the low probability of occurrence would yield insufficient funds if the event actually occurs, or occurs too soon. Alternative options for managing these types of risks are to obtain insurance coverage or to pool funds among several similar facilities, as has been suggested for landfills (Tsang, 2007).

5. Potential reclamation and post-reclamation costs: an example

To illustrate how reclamation and post-reclamation (i.e., PRC and LTM) costs could impact the valuation of a mining opportunity, a hypothetical case study of a copper mining asset published by Samis et al. (2003) is used as an example. A detailed analysis of the investment opportunity considering the active life of this asset is presented in the Part I companion to this paper. The financial analysis was performed using three different methodologies: NPV, modern asset pricing (MAP) and decoupled net present value (DNPV). Table 1 reproduces the cash flow analysis for the initial 24 fours years, with costs in domestic currency ($) and foreign currency (F) at an exchange rate in 2003 (the time of the analysis) of $2= F1.[1] As shown in the table, the investment schedule assumes that it would take four years to develop the mine and 20 years to extract the mineral. Closure and reclamation is assumed to occur in the last year of mine operation (year 24) with post-reclamation commencing thereafter in year 25. In the original example, reclamation costs were assumed as a one-time charge of $12.5 million and F18.5 million, equivalent to $50 million (Line 06, Table 1).

To further illustrate the effect of reclamation and post-reclamation costs in a mining investment analysis, a bottom up cost estimate is subsequently derived taking into consideration the physical attributes of the spoils created during the mineral extraction process. For this hypothetical example, mining will involve the excavation of 400 million tonnes of ore. Assuming an in-place density of 1.6 Mg/m^3 and mineral recovery using a HLP, the excavated ore would occupy a volume of 250 million m^3 (mcm). If the ore is piled over a lined 400ha square HLP with side slopes of 2 H:1 V, the height of the leach pad would be approximately 72.5 m. Assuming effective porosity (n) of 0.3, the bed volume (BV) of the in-place material would be 75 mcm (7.5×10^{10} L). The BV is the reservoir of free liquids present in the saturated pore spaces and available for flushing contaminants from the waste (Beaven, 2000). Because the HLP process involves the use of aggressive chemicals to leach minerals out of the ore, after the valuable minerals have been extracted to the economically viable extent, the site is left with huge piles of contaminated soils over lined leach pads.

At a minimum, all mine reclamation plans should thus include an engineering design and process for minimizing pollution potential and rendering these piles safe to HHE in the long term. A simple reclamation plan may include the placement of a 60 cm thick soil cap to minimize contamination of contact rainwater runoff, reduce generation of AMD, and control the amount of water infiltrating the pile and emerging as basal leachate to be treated. The uppermost 15 cm of the cap is typically topsoil, a minimum thickness necessary to allow permanent establishment of vegetation. For the 400 ha HLP hypothetical example, this cap design would require 2.4 mcm of traditional soils (i.e., 1.8 mcm of general fill and 0.6 mcm of topsoil). At $12/m3 for topsoil and $3/m3 for general fill, closure would cost $12.6 million just in placement of the soil cover, without inclusion of other reclamation costs such as regrading of side slopes, water management and treatment, and general site restoration. These costs are substantial as discussed next.

HLPs are typically designed to maximize mineral production at minimal operational expense, with little consideration of the work that may be needed for their future reclamation. Thus, ore is placed with steep side slopes to maximize volume per unit of lined area. In order to construct a cover, the HLPs would likely need some regrading to flatten the slopes. If the 400 ha HLP was originally constructed with 2 H:1 V slopes for operational purposes, reshaping side slopes a more accommodating 3 H:1 V would require regrading about 7.4% of the total ore volume (i.e., 18.5 mcm of earth movement). At $2/m^3$, that would add $37 million in reclamation expenses. Considering that mine reclamation at this example facility would involve a number of activities in addition to closure of the HLP, the total budget of $50 million in Table 1 is looking increasingly meagre, particularly once treatment of leachate collected from the HLP is considered.

Turning attention to water management and treatment, the budget required to manage impacted water after a mine has been closed can have a significant effect on the financial analysis. Because mine tailings and other spoils are not expected to degrade biochemically, it is reasonable to assume that any reductions in their residual contaminant load will be achieved by flushing. Standards specifying goals for flushing are generally lacking, although a solid waste rule codified in Ontario, Canada (MOE, 2008) established flushing as a goal for waste stabilization in landfills. The rule requires that a final cover system be designed to allow infiltration in excess of 15 mm/year in order to achieve controlled flushing and reduce the contaminating life span (CLS) of the landfill to a reasonable timeframe ranging between 30 and 50 years (Rowe, 2005). Performance is measured based on removal of chloride, a conservative anion. Using research from the landfill industry as a guide (Beaven and Powrie, 1995; Knox, 1996; Beaven and Walker, 1997; Röhrs et al., 2001), flushing waste with between one and seven BVs may be required to reduce concentrations of inorganic contaminants in leachate to within acceptable limits. In our hypothetical example, assuming that the excavated ore can be reasonably stabilized by flushing only one BV, this would generate 7.5×10^{10} l of leachate to be treated. Based on the goal of 1.3 cents per liter for cost-effective leachate treatment using constructed wetlands at a US landfill project reported by Goldemund et al. (2008), it is reasonable to assume

[1] The example in Samis et al. (2003) is described in terms of Foreign Monetary Units (FMU) where the mine is located and Domestic Monetary Units (DMU) where the currency of the equity provider's home country is located. In this paper, the DMU is assumed to be the dollar currency ($) and the FMU is denoted by F.

Table 1
Example valuation of a mining opportunity (in millions of 2003 currency).

	Stage	Development					Operations and Reclamation						Post-Reclamation	
	Time (years)	0	1	2	3	4	5	6	7	... 22	23	24	25	 124
01	Copper Production (10^6 lbs)						224.67	224.67	224.67	224.67	224.67	136.56		
02	Operating Revenues (Real)						$179.73	$179.73	$179.73	$179.73	$179.73	$109.25		
03	Total OPEX (Real) – Millions						**$89.87**	**$89.87**	**$89.87**	**$89.87**	**$89.87**	**$54.63**		
04	Foreign (F)						F33.70	F33.70	F33.70	F33.70	F33.700	F20.48	F5.00	F5.00
05	Domestic ($)						$22.47	$22.47	$22.47	$22.47	$22.47	$13.66		
06	Total CAPEX (Real)	**$97.20**	**$178.25**	**$194.4**	**$113.45**	**$16.75**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$50.00**		
07	Initial (F)	F36.45	F66.83	F72.90	F42.53	F6.08								
08	Initial ($)	$24.3	$44.6	$48.6	$28.4	$4.6								
09	Closure/Post Closure (F)											F18.75		
10	Closure/Post Closure ($)											$12.5		
11	**Net Cash Flows (Real)**	**-$97.20**	**-$178.25**	**-$194.40**	**-$113.45**	**-$16.75**	**$104.94**	**$106.02**	**$106.83**	**$109.47**	**$109.49**	**$16.56**	**-$10.00**	**-$10.00**
12	COST OF RISK													
13	Commodity						$37.37	$39.79	$41.62	$57.08	$57.62	$35.33		
14	Currency		$14.73	$18.65	$11.25	$1.59	$8.51	$8.10	$7.64	$2.23	$2.04	$2.17	$0.25	$0.00
15	Decoupled Net Cash Flows	-$97.20	-$192.98	-$213.05	-$124.70	-$18.34	$59.06	$58.24	$57.58	$61.64	$62.06	-$13.24	-$10.25	-$10.00
16	ADD. COST OF RISK													
17	Grade Risk						$2.92	$2.93	$2.95	$2.99	$2.99	$1.82		
18	OPEX Risk						$3.49	$3.49	$3.49	$3.49	$3.49	$2.12		
19	Temporary Shutdown						$0.75	$0.76	$0.76	$0.77	$0.77	$0.47		
20	Permanent Shutdown						$3.32	$3.18	$3.03	$0.51	$0.31	$0.12		
21	Decoupled Net Cash Flows	-$97.20	-$192.98	-$213.05	-$124.70	-$18.34	$47.77	$47.11	$46.57	$42.41	$42.27	-$25.46	-$10.25	-$10.0

Note: Assumed parameters and details regarding development of the cash flows for years 1 through 24 are provided in part I companion paper.

lower-bound treatment costs of about 1 cent per liter, which would represent a total cost of $750 million. This assumes that excavation of ore does not expose materials or result in large WRDs that are also susceptible to AMD, which would also need treating. More challenging is estimating the timeframe over which flushing might take place. For a 400 ha HLP containing 250 mcm of ore with total BV of 75 mcm, infiltration of 18,750 mm of water would be needed to flush the waste with at least one BV. Assuming a soil cap design that permits net infiltration of 15% of precipitation and rainfall of 1,000 mm/year, this would take 125 years. Thus, it is fully conceivable that the minimum timeframe for treatment is on the order of 100 years. Assuming long periods (even perpetuity) for water treatment activities at closed mines is not uncommon (Sassoon, 2009; Allan, 2016; Humphries, 2016).

6. Financial analysis

Based on the above, it is reasonable to assume total post-reclamation costs on the order of $1 billion, yielding annual expenses of $10 million for 100 years starting in year 25 that should be included in the financial analysis. For this hypothetical example, to simplify the analysis, it is assumed that the operating PRC expenditures are all in foreign denominated currency, shown as F5 million annually in Table 1. To complement the initial financial analysis presented in the Part I companion this paper, the effect of PRC expenses are subsequently evaluated using the three methods described therein, namely NPV analysis, the MAP methodology, and DNPV.

6.1. Net Present Value (NPV) analysis

Table 1 reproduces the cash flow analysis originally developed for this investment opportunity, with the last two columns represent the additional PRC expenditures estimated above and incurred from year 25 through 124. The calculated NPV without these additional annual expenses (NPV_0) was estimated at $132.8 million. The recommended nominal discount rate for this investment opportunity was 10% and the inflation rate for the domestic currency was 1.5% (Samis et al., 2003). Hence, the real discount rate (i.e., net of inflation) used in the NPV analysis is 8.5%. There are no projected revenues after year 24, only PRC expenditures. In a NPV analysis, all cash flows are typically discounted at the recommended constant discount rate (i.e., 8.5%). For this example, this would imply that the yearly PRC expenses of $10 million incurred after year 25 would be discounted using a real discount rate of 8.5%, assigning a $1 billion liability a present value (PV) of only $16.6 million (Eq. (1)). It follows from Eq. (1) that the further into the future PRC expenditures are projected to be spent, the lower its discounted value.

$$PV = \sum_{t=25}^{T=124} \frac{10}{(1+0.085)^t} = \$16.6 \tag{1}$$

Thus, the impact of the PRC expenditures on the value of the investment opportunity is minimal. Subtracting the estimated PV of the PRC costs ($16.6 million) from NPV_0 ($132.8 million), the final NPV including the cost of 100 years of leachate treatment is $115.6 million, a marginal reduction in the value of the investment. Following this approach, the investment opportunity would be deemed viable.

Note that if a PRC fund of $16.6 million had been set aside at the beginning of the project, the accumulated sum at the end of year 24 should be $117.6 million ($16.6\times[1+0.085]^{24}$). Thereafter, an expected PRC cost (real) of $10 million per year would be drawn from the PRC fund for the next 100 years. The implicit assumption in a NPV analysis is that the PRC fund would earn an annual real return of 8.5% (10%

nominal) from the time of set aside through the duration of the PRC. Although an 8.5% real rate of return assumption might be appropriate during the operating life of the mine (assuming that every year the proceeds from investing in the mining operations are transferred to the PRC fund), it could not be sustained after the mine is closed unless the funds were actively invested.

6.2. Modern Asset Pricing (MAP) analysis

The MAP method is an alternative approach to valuing investment opportunities that takes advantage the availability of futures to account for risk. For this example, the two main risks were considered to be commodity prices and currency exchange. For both variables, quoted future prices were available and applied to the MAP analysis. At the time PRC expenditures are analyzed, the mine is closed and its value is no longer affected by commodity prices. Thus, the only risk affecting the cash flows is foreign exchange risk. The value of the investment opportunity using the MAP method considering the active life of the mine was estimated at $262.4 million. Consistent with the MAP methodology described by Samis et al. (2003), to eliminate currency risk expenditures in foreign currency are expressed in US dollars using futures. Thus, the future annual expenses in foreign currency (A_t) can be expressed in dollar terms as $A_t \times FX_t$, where FX_t is the foreign exchange currency factor at a future time t given by Eq. (2):

$$FX_t = FX_o \exp((r - r_F)\, t) \tag{2}$$

Where r_F and r are the foreign (12.5%) and domestic (US) nominal risk free rates (3%), respectively, and FX_0 is the foreign exchange rate at time zero (i.e., $2/F in 2003). It follows that because the foreign risk free rate is higher than the US risk free rate, future expenses in dollar terms decay exponentially. According to the MAP methodology, once expenses are converted to dollar denomination using FX_t, foreign exchange risk is eliminated. Thus, the resulting future cash flows associated with PRC costs from years 25 through 124 can be discounted using the real risk free rate (3–1.5%), which yields a discounted value of $6.2 million. Eq. (3) reflects the analysis performed to estimate the value of the PRC expenditures following the MAP methodology.

$$MAP = \sum_{t=25}^{T=124} \frac{5 \times\ 2 \times \exp(-0.095\ \ t)}{(1 + 0.015)^t} = \$6.16 \tag{3}$$

In this example, the use of future prices to convert foreign currency to dollars to eliminate foreign exchange risk has the effect of reducing the value of the liability, thus making the investment more valuable. As a result, as was the case with NPV, the value of a long-term $1 billion liability is heavily discounted to a negligible value of $6.2 million in 2003 dollars. Again, when comparing this amount to the initial MAP value of $262.4 million, the investment opportunity would be deemed viable. As in the case of NPV, it follows from Eq. (3) that the further into the future PRC expenditures are projected to be spent, the lower its discounted value.

6.3. Decoupled Net Present Value (DNPV) analysis

For risk-averse investors, risk should always reduce the value of an investment proposition independent of the source of risk (i.e., revenue risk or expenditure risk); that is, the effect should be the same. The main difference is that investors are long on the revenue side (i.e., profit if revenues go higher) and short on the expenditure side (i.e., profit if the expenditures are reduced). Risk needs to be treated consistently whether it affects revenues (i.e., reduces the value of the revenues) or expenditures (i.e., increases the value of the expenditures). To address this, Espinoza and Morris (2013) and Espinoza (2014) introduced the DNPV methodology. DNPV analysis separates risk from the time value of money, treating risk as a cost that reduces the value of the revenues and/or increases expenditures. This allows the calculated cost of risk to be subtracted from estimated cash flows, rendering the resulting cash flows riskless.

In this example, the DNPV of the investment opportunity without the additional PRC costs ($DNPV_0$) and considering only currency and commodity risk was estimated at $189.8 million. The inclusion of additional risks (e.g., ore grade, OPEX, temporary shutdown, and permanent shutdown) reduced the DNPV to $46.1 million (calculated in the Part I companion paper). To illustrate the ability of DNPV to account for long-term cash flows and the associated risk in a consistent manner, the effect of the future annual PRC expenditures to the calculated $DNPV_0$ is discussed next. To simplify the discussion, it is assumed that there is only one risk: foreign exchange risk. Because in this example the cash flows are negative (reflecting PRC expenditures), currency risk would be associated with the potential for the foreign currency to appreciate against the dollar, thus making it more expensive (in dollars terms) to afford the PRC costs.[2] In accordance with Samis et al. (2003), the variability of FX_t (Eq. (2)) is modeled using a non-reverting log normal process (i.e., geometric Brownian motion) with annual volatility (σ) of 40%. In accordance with the DNPV methodology, currency risk for a dollar denominated investment is associated with foreign currency appreciating against the dollar (i.e., requiring more dollars to buy the foreign currency), which can be represented by a call option with an exercise price of $2/F. The call option can be estimated using the Black and Scholes closed form solution with a convenience yield equal to the difference between foreign and domestic risk free rates (i.e., 9.5%) along the other parameters listed above (i.e., σ=40%, r=1.5%). Fig. 3 shows the variation with time of the value of the call option (c_t) as a percent of the exercise price ($2/F) from year 1 to 100.

For illustrative purposes, the estimated call option (as a fraction of the exercise price) for years 1, 10, 25, 50, and 100 is calculated as 11.02%, 9.19%, 2.52%, 0.24%, and 0.002%, respectively. Over the first 10 years, the risk of currency appreciation is relatively high at nearly 10% of the exercise price but then decreases exponentially to negligible values. For years 25, 50 and 100, the cost of risk associated with the annual PRC expenditures of $10 million are calculated to be $252,371, $24,325, and $185, respectively. This indicates that the further into the future, the smaller the probability of foreign currency appreciation against the dollar.

The decoupled present value (DPV) of the PRC cost discounted back to year zero using a real risk free rate of 1.5% can be estimated at $368.6 (Eq. (4)):

$$DPV = \sum_{t=25}^{T=124} \frac{(10 + c_t)}{(1 + 0.015)^t} = \$366.11 + \$2.44 = \$368.55 \tag{4}$$

Thus, the DNPV considering the PRC cost and only accounting for the commodity and currency risks analyzed in the previous section is -$178.8 million ($189.8-$368.6), well below both the NPV and MAP analysis. If the additional risks described previously are taken into consideration, then the DNPV of the mining project becomes -$322.43 million ($46.1-$368.6). The present value of the annual currency risk from years 25 through 124 discounted at 1.5% is merely $2.44 million. This low value indicates that the risk of foreign currency appreciation against the dollar is quite small, marginally increasing the total cost of risk for the entire investment from $1,039.6 million (as calculated in the Part I companion paper) to $1,042.1 million.

Hence, the reduction in the value of the project is mainly due to the inclusion of the PRC cost. As illustrated, one of the main attributes of DNPV is its ability to monetize all the different risks associated with the investment opportunity and compare them under the same metric (i.e., dollar terms). In addition, because risk and the time value of money are

[2] If currency risk was associated to revenues (i.e., getting paid in foreign currency), the risk would be associated with devaluation of the foreign currency.

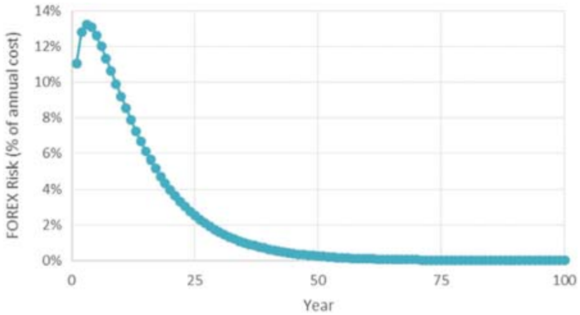

Fig. 3. Variation of currency risk with time.

not mixed, long-term cash flows are not artificially reduced to negligible values. Different from the NPV and MAP methods, the present value of the liability using the risk free rate are reduced to reasonable values. The implicit assumption in a DNPV analysis is that the PRC fund would earn an annual nominal return of 3% (1.5% real) from the time of set aside through the duration of PRC. This assumption is not considered aggressive as a real rate of return of 1.5% is available from US treasury bills with maturities of 10 years or older.

Other risks such as taking more than one bed volume to flush the contaminants (i.e., longer PRC period than anticipated) or costing more than 1 cent per liter to treat the contaminant could be easily incorporated in the DNPV methodology. To illustrate this, assume that the PRC expenses are represented by a triangular distribution with a minimum, most likely, and maximum value of $9 million, $10 million, and $11 million, respectively (Fig. 4). In this case, the cost of risk is represented by the center of gravity of the area greater than the expected value (Espinoza and Morris, 2013). The cost of risk associated with higher annual PRC costs is estimated as $167,000 (1.67% of $10 million) per year. Thus, discounting the cost of risk from years 25 through 124 using a real discount rate of 1.5%, the net present value of the risk associated with higher expenses than anticipated is $6.1 million. As was the case of currency risk, this risk is negligible compared to the other identified project risks.

7. Summary and conclusions

This paper examines potential costs for mine reclamation and PRC as well as the timing of these costs, which is important for establishing correct accruals and to avoid understating future liabilities. A hypothetical example taken from the mining literature is used to compare the authors' proposed DNPV valuation method with two other popular techniques (NPV and MAP). Using the inferred physical characteristics from the example (i.e., aerial extent and volume), PRC expected expenses were estimated at $10 million per year (in 2003 dollars) for years 25 through 124 represents (i.e.., an expected $1 billion cost). If PRC expenses are expected to increase 1.5% annually on average due to inflation and a 10% discount rate assumed, then the amount required in year 24 to cover the PRC expenses for another 100 years would be

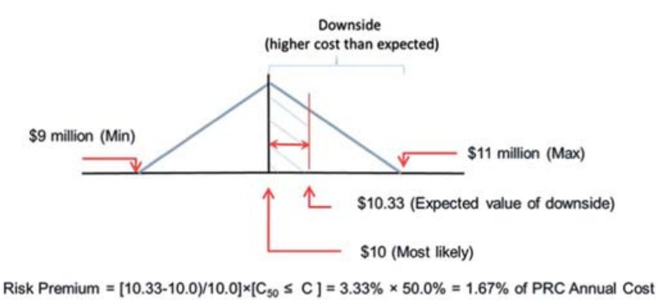

Fig. 4. Risk distribution for routine annual PRC costs.

$117.6 million (2003 dollars) based on NPV analysis. Moreover, because the expenses are incurred in year 24, this amount is further discounted in year zero to $16.6 million when the go/no-go decision is made. The use of NPV to decide whether or not to invest in this opportunity would have indicated to go ahead despite the $1 billion liability. In theory, for the assumed discount rate, the calculated PRC fund could last in perpetuity. However, a shortcoming of NPV analysis is the basic (and often overlooked) premise behind this calculation that all monies that are not used to cover PRC expenses in any given year are invested to attain a nominal return on investment (ROI) of 10% (i.e., 1.5% inflation plus 8.5% real ROI). This ROI on the PRC fund must be achieved year in, year out. Thus, during the 20 years when the mine is active, an initial PRC fund of $16.6 million would be expected to grow to $117.6 million. If the PRC funds are to be accrued annually during the operation of the mine, which is typical, NPV analysis would suggest that the required annual accrual would be $2.24 million. However, if these PRC funds are invested in fixed income securities with negligible real returns instead of an aggressive investment portfolio capable of returning the required 8.5%, then the mine would only accrue $44.8 million (i.e., 20×2.24), thereby accumulating a deficit of $72.8 million by the time of closure. Even if the mine reassesses its PRC obligations every year, and adds to the PRC funds annually to compensate for the accumulating deficit, the mine would have accumulated only 54% of the required $117.6 million after 15 years of operations. Keeping in mind that by the time the mine is closed in year 20, there are no more revenues and only expenses to be incurred, the mine would have only five years to accumulate nearly 46% of the PRC funds. At this point, the PRC fund would have to be very aggressively invested to attain the necessary annual returns or the additional funds would need to be obtained by transferring significant revenues from operations. Of course, similar issues exist in terms of discounting $1 billion in PRC expenditures in years 24 through 124 to $117.6 million in year 24. The problem is further aggravated by the fact that, in any given year, either the PRC expenses could be higher than estimated (technical risk) or the nominal ROI could be lower than the expected 10% (market risk). The problems with NPV are further complicated by the fact that higher discount rates are customarily used to account for higher risks, which distorts valuation of long-term liabilities. In the simple example presented herein, increasing the discount rate to, say, a nominal 12% (10.5% real) would reduce rather than increase the PRC funding estimate in NPV terms to $8.7 million in year zero. Further, if in an attempt to avoid market risks the $117.6 million accrued to cover PRC expenses is conservatively invested with average returns approximately equal to the rate of inflation, the PRC fund would be exhausted after only about 12 years. This is not a trivial issue since accruals for future liabilities are routinely determined using this type of analysis. Where responsibility for the mine is transferred back to the local society following closure, insufficient funds will have been accrued to account for future liabilities.

To stay ahead of inflation and generate sufficient income for PRC expenses over the very long term (or perpetuity if necessary), funds cannot be invested solely in low yield debt securities such as government bonds but will have to include investments in higher yield investments such as stock equities, corporate debt, or revenue-generating capital projects. To help fund long-term PRC, and certainly to fund LTM, income derived from beneficial reuse of the property (e.g., hosting solar renewable energy projects, irrigation projects, livestock grazing) should also be sought as appropriate to site conditions.

The second method discussed in this paper (MAP) assumes that the main risks are associated with market risk and future prices are a reasonably proxy for such risks. The calculated risk factor (Eq. (2)) to account for foreign exchange risk is equivalent to discounting the $10 million annual PRC expenses using a 9.5% discount rate from year 25 through 124. Following the MAP methodology, these amounts are discounted to year zero using the real risk free rate (since the yearly funds are not increased by inflation). Thus, according to MAP, the necessary PRC funds in year zero should be only $6.1 million. As in the previous case, the use of MAP as a decision tool would have indicated to go ahead despite the $1 billion liability. The main source of error in this valuation stems from the application of the currency risk factor to the annual expenses. As discussed, applying currency risk in this way has the effect of unduly reducing the value of future liabilities. In general, risk should increase expenses or reduce revenues; in other words, risk should be treated as a cost to the project that reduces cash flows. This premise is correctly reflected in the DNPV methodology that treats risks as costs to be either subtracted from project revenues or added to expenses with resulting decoupled cash flows discounted by the appropriate risk free rate.

The example presented clearly illustrates the negative effect of using risk adjusted discount rates to value long term mining investments. Popular valuation methods, NPV in particular, significantly discount the value of future liabilities, unduly increasing the apparent present value of a mining investment. Failing to understand and accrue funds for future reclamation and PRC expenses puts a significant burden on future generations inheriting said liabilities. Because DNPV analysis separates risk from the time value of money and treats risks as a cost to the project, this method clearly identifies the effects of individual risk factors on the value of a project. In valuing PRC liabilities for mines, this approach can thus inherently compensate for market risk (i.e., currency exchange lower than expected) as well as technical risk (i.e., routine/non-routine care costs higher than expected). Depending on the source of each risk and the availability of data to evaluate it, these costs could be estimated using: (1) probabilistic/stochastic methods based on probability density functions (PDFs) constructed from available empirical data; (2) subjective industry-specific information obtained from technical experts; or (3) option pricing techniques developed in the financial industry to estimate the risk of traded commodities (Espinoza, 2011). Because mine reclamation and PRC expenses are incurred when the revenue-generating potential of the facility is nearly or completely over, accruing and managing an appropriate PRC fund to ensure it will cover both routine and non-routine expenses over the very long term is key to avoiding transfer of these costs to future stakeholders.

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