

When does Hoskold misstate extractive-asset value? Reserve dynamics, mine-plan evidence, and managed non-renewability

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Abstract

This article asks when the classical Hoskold formula is an adequate shortcut for an extractive asset and when a richer state space is required. The argument is not that Hoskold is wrong: its validity depends on the valuation object, the information available, and the effort justified by the decision. We derive generalized, reserve-replacement, managed-reserve, and capacity-aware versions that add cash-flow timing, endogenous economic life, finite-horizon continuation, and throughput constraints while nesting the classical rule. Empirically, a single-producer benchmark of 10 Agnico Eagle operations tests institutional fit to publicly disclosed reserve-based mine plans, while a 50-operation, five-producer gold sample tests construct consistency against standardized DCF comparators built from the same expanded information. Classical Hoskold has the lowest mean absolute percentage error in the disclosed-plan benchmark (10.3%), closely followed by generalized Hoskold (10.9%). Across the larger sample, mean values relative to classical Hoskold are 0.98, 1.20, 1.24, and 1.00 for the generalized, reserve-replacement, managed-reserve, and capacity-aware versions. Against replacement-adjusted DCF, mean error falls from 24.3% under classical Hoskold to 11.7% under reserve-replacement and 8.7% under managed-reserve Hoskold. These results are conditional on the public-data design and do not establish market value. They show that formula choice should follow the asset definition: classical Hoskold remains defensible for a fixed booked-reserve plan; extensions are applicable only when conversion inventory, continuation, or capacity constraints are part of the object being valued. Full project DCF remains necessary for bankable decisions.

Keywords: Hoskold; valuation; reserves; capacity; mining; depletion; DCF

JEL codes: Q31, Q32, G12, H54

1. Introduction

Valuation is one of the quiet transmission mechanisms of resources policy. The number attached to an extractive asset influences royalty and tax disputes, compensation claims, public-asset accounting, expropriation cases, takeover pricing, project finance, and the political narrative

around what a mineral endowment is “worth”. In depleting industries, that number is especially sensitive to the analyst’s theory of scarcity. A capitalization rule that treats the operative stock as a simple countdown will not give the same answer as one that recognizes reserve replacement, productive capacity, or finite-horizon continuation value.

The classical Hoskold formula offered an early and elegant solution to the valuation of wasting assets. By separating the required return on capital from the return of capital through a sinking fund, it translated depleting income streams into a tractable capitalization rule for mines, collieries, quarries, royalties, and similar assets. The formula remains historically important and still appears in administrative appraisal, teaching, and practical valuation discussions (Hoskold, 1877, 1903; de la Cruz, 1980; Hellewell, 1987; Torries, 1998).

The issue is not that the classical rule is algebraically wrong. Rather, it is exact for a deliberately narrow information set and valuation object: annual distributable income is approximately flat, asset life is known and exogenous, reserve additions are negligible, and the terminal date is an economic endpoint rather than the beginning of a new development phase. Modern extractive industries often violate one or more of these scope conditions. Reserve declarations are endogenous inventory statistics, productive capacity can constrain current output independently of reserves, and a positive usable inventory may remain at a policy horizon even though the underlying geology is non-renewable (Hotelling, 1931; Pindyck, 1978; Arrow and Chang, 1982; McKelvey, 1972; CRIRSCO, 2019). The empirical question is therefore not whether Hoskold should be discarded, but when the available evidence justifies moving to a richer representation.

This article therefore addresses three questions. First, under what conditions does classical Hoskold materially diverge from state-variable-aware valuation shortcuts? Second, which omitted margin matters most empirically: cash-flow timing, conversion inventory, continuation value, or capacity scarcity? Third, how should method choice depend on the object being valued, the information available, and the effort warranted by the decision? These questions matter because policy settings often require transparent and standardized rules even when full project DCF is infeasible, unavailable, disproportionate to the decision, or contested.

The paper makes three contributions. First, it derives a nested ladder of Hoskold formulas and identifies the state variable added at each step. The ladder is also an information-and-effort hierarchy: the original formula, the extensions, and full DCF are not universal competitors, but

methods suited to progressively richer evidence and more demanding decisions. Second, it compares the formula family with publicly disclosed mine-plan lives for 10 Agnico Eagle operations, explicitly treating the exercise as an institutional-fit benchmark within one producer’s planning and disclosure regime. Third, it applies the formulas to 50 operating gold assets and asks whether admitting conversion inventory, continuation, or a throughput proxy moves the shortcut toward a DCF comparator defined over the same expanded object. Separating these benchmarks prevents an extension from being labelled “better” merely because it capitalizes a broader asset.

The empirical design is intentionally conditional. The disclosed-plan benchmark asks which formula best approximates a reserve-disciplined institutional object. The larger cross-section asks whether a state-aware shortcut moves closer to a DCF comparator built from the same widened information set. The paper therefore distinguishes empirical fit from asset scope and interprets numerical differences as evidence conditional on the selected sample, cost proxies, parameter scenarios, and benchmark construction.

The remainder of the article is organized as follows. Section 2 places Hoskold in the valuation and non-renewable-resource literature and reframes it as a limiting case of managed non-renewability. Section 3 derives the extended formulas. Section 4 describes the 50-asset sample, the 10-asset external benchmark, and the construct-consistency tests. Section 5 reports the empirical results. Section 6 develops policy and appraisal implications. Section 7 discusses limits and scope. Section 8 concludes. The appendices provide selected derivations and supplementary tables.

2. From classical Hoskold to managed non-renewability

2.1 Classical Hoskold (H) as a limiting-case capitalization rule

The classical Hoskold rule capitalizes a finite stream of average annual income A at a rate made of two components: a risky return on capital i and a safer sinking-fund factor $SFF(n, j)$ that returns capital over n years at rate j . The result is the familiar dual-rate capitalization formula.

The classical Hoskold formula (H) is

$$V_H = \frac{A}{i + \frac{j}{(1+j)^n - 1}}. \quad (1)$$

This formula may also be written in terms of the sinking-fund factor

$$\text{SFF}(n, j) = \frac{j}{(1+j)^n - 1}, \quad (2)$$

so that

$$V_H = \frac{A}{i + \text{SFF}(n, j)}. \quad (3)$$

This expression is coherent when the operative economic object is a finite and largely predetermined depleting stock. Historical mining appraisal developed several related capital-recovery conventions, including Ring, Inwood, and Hoskold, and later literature clarified both their discounting foundations and their limitations (Hoover, 1909; Dran and McCarl, 1974; de la Cruz, 1980; Gentry and O’Neil, 1984; Hellewell, 1987; Ellerman, 1994; Annels, 1991; Torries, 1998). If the risky and sinking-fund rates coincide, Hoskold collapses to ordinary DCF. If annual income is flat and life is exogenous, the classical formula is internally consistent. Those assumptions, rather than the algebra itself, are what become fragile in modern extractive systems. Classical Hoskold should therefore be treated as a valid limiting case, not as an erroneous rule to be universally replaced.

2.2 Managed non-renewability and the missing state variables

A more realistic extractive system does not move directly from “stock in the ground” to annual income. Firms and governments manage at least three operational margins: the reserve inventory that is currently economic to mine, the broader identified opportunity set from which reserves can be created, and the productive capacity that converts reserves into current output. This distinction is embedded in mineral and petroleum classification systems and in the practical sequence from exploration to reserve conversion to production (McKelvey, 1972; U.S. Bureau of Mines and U.S. Geological Survey, 1976; Society of Petroleum Engineers et al., 2018; CRIRSCO, 2019). It also underpins the managed-stock interpretation developed in mineral economics (Anonymous, 2016, 2019, 2026).

The simplest reduced law of motion is a reserve-balance identity: reserves tomorrow equal reserves today plus reserve additions minus extraction. This is consistent with the exploration literature, in which discoveries, information, prices, and development decisions make the economic stock endogenous (Pindyck, 1978; Peterson, 1978; Arrow and Chang, 1982; Lasserre,

1984; Quyen, 1988, 1991; Polasky, 1992). Current output may also be limited by installed capacity rather than geology alone. In that environment, the one-stock Hotelling model is a limiting case in which additions are negligible and capacity is slack, not a complete description of the managed asset (Hotelling, 1931; Gordon, 1967; Dasgupta and Heal, 1979; Adelman, 1990; Krautkraemer, 1998).

This reserve-balance logic changes the interpretation of reserve life. A reserve-to-production ratio is an inventory ratio, not automatically an exhaustion clock: exploration, delineation, feasibility, prices, and development can lengthen or shorten it. Capacity adds a separate scarcity margin. Mine scale, reserve coverage, and unit costs are empirically related, but the relevant bottleneck may be the plant, haulage, power, water, or logistics system rather than the orebody itself (Crowson, 2003; Taylor, 1986; Long, 2009). In policy settings, observed price-cost wedges can therefore reflect reserve scarcity, capacity scarcity, or both.

2.3 Analytical expectations and article contribution

These observations generate a simple expectation for Hoskold-type valuation. Timing corrections should matter when income is uneven. Life corrections should matter when reserves are actively replenished. Continuation-value corrections should matter when a positive usable inventory survives the chosen policy horizon. Capacity corrections should matter when throughput, not booked reserves alone, constrains current extraction. The article places those corrections inside one coherent family and tests them under a common public-data design. The broader point is not that one formula is universally superior. Classical Hoskold, its extensions, and full DCF form an information-and-effort ladder: the method should match the valuation object, the evidence that can credibly support it, and the materiality of the decision.

Table 1 summarizes the resulting formula ladder. The important point is not that each step always adds value. It is that each step corresponds to a distinct empirical margin, and each margin has a different policy setting in which it becomes the relevant shortcut.

Table 1. Formula ladder, operative scarcity margin, and appropriate use.

Formula	What it adds	Observable empirical driver	Most appropriate use	Limiting case
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Formula	What it adds	Observable empirical driver	Most appropriate use	Limiting case
Original Hoskold (H)	Average annual income and fixed life	Flat income. Fixed booked-reserve horizon	Low-information check for a fixed disclosed reserve plan. Legacy appraisal	DCF when $i = j$
Generalized Hoskold (GH)	Explicit annual cash-flow timing	Actual annual forecast path (stylized in this study)	Intermediate-information dual-rate shortcut when annual forecasts exist	Original if yearly cash flow is constant
Reserve-replacement Hoskold (RRH)	Endogenous fractional life through reserve creation	Convertible inventory or observed reserve additions	Object expressly includes technically and economically supported conversion inventory	Original if reserve additions are zero
Managed-reserve Hoskold (MH)	Exact finite-horizon continuation value	Documented residual inventory and continuation beyond the policy horizon	Finite-horizon valuation with an evidenced continuation asset	Terminal-value DCF if $i = j$
Capacity-aware Hoskold (CKH)	Throughput-constrained income and life	Rated/observed capacity and bottleneck evidence; $Q^K/Q - 1$ is only a proxy here	System with credible throughput constraints or spare capacity evidence	Original if $Q^K = Q$

3. Extended Hoskold formulas

3.1 Generalized Hoskold (GH): explicit timing within the Hoskold logic

The first extension removes the average-income restriction while retaining the Hoskold capital-recovery interpretation. Let Π_t denote net distributable cash flow in year t . Accumulating each year's cash flow to the horizon at the safer rate j yields a generalized dual-rate capitalization rule. This is the right benchmark when the analyst wants to keep the Hoskold interpretation but no longer wishes to erase ramp-up, decline, closure, or partial final-year effects.

Define

$$\Phi_N(j) = \sum_{t=1}^N (1+j)^{N-t} = \frac{(1+j)^N - 1}{j}. \quad (4)$$

Then the generalized Hoskold formula (GH) is

$$V_{GH} = \frac{\sum_{t=1}^N \Pi_t (1+j)^{N-t}}{1+i\Phi_N(j)}. \quad (5)$$

This can also be written as

$$V_{GH} = \frac{A_H^{(j)}}{i + \Phi_N(j)^{-1}}, \quad (6)$$

where

$$A_H^{(j)} = \frac{\sum_{t=1}^N \Pi_t (1+j)^{N-t}}{\Phi_N(j)}. \quad (7)$$

is a safe-rate weighted equivalent annual income.

Generalized Hoskold is therefore best read as a timing correction and a bridge formula. It nests the original rule when yearly cash flows are constant, and it collapses to DCF when the dual rates converge. It is not designed to outperform risky-rate DCF as a separate theory of value. It is designed to stop classical Hoskold from treating very different annual paths as though they were the same average annuity.

3.2 Reserve-replacement Hoskold (RRH): endogenous economic life

The second extension asks what happens when the exhaustion date is not fixed in advance. Once reserves evolve with both extraction and reserve additions, the economically operative life depends on net depletion rather than on current booked reserves alone. A finite stock may remain geologically non-renewable while the usable reserve inventory is actively replenished over the horizon that matters for valuation.

Let S_t denote reserves at time t , q_t denote extraction in year t , and z_t denote reserve additions in year t . Proved reserves then evolve according to

$$S_{t+1} = S_t + z_t - q_t, \quad (8)$$

The exact discrete exhaustion date is the first positive integer period in which the reserve stock becomes non-positive:

$$N^d = \min\{n \geq 1: S_n \leq 0\}. \quad (9)$$

If extraction and reserve additions are constant,

$$q_t = q, \quad z_t = z, \quad (10)$$

and the iteration of the stock equation gives

$$S_t = S_0 - t(q - z). \quad (11)$$

Therefore, when extraction exceeds reserve additions, the exact discrete exhaustion date is obtained using the ceiling operator. Here, $\text{ceil}(x)$ denotes the smallest integer greater than or equal to x . It converts fractional economic life into the first discrete period in which reserves become non-positive:

$$N_d = \text{ceil}\left(\frac{S_0}{q-z}\right), \quad q > z. \quad (12)$$

Define the reserve-replacement ratio

$$\rho = \frac{z}{q}. \quad (13)$$

For capitalization, it is convenient to use the corresponding fractional economic life

$$n^e = \frac{S_0}{q-z} = \frac{S_0/q}{1-\rho}, \quad 0 \leq \rho < 1. \quad (14)$$

The classical reserve-life ratio is the special case with no reserve additions. Positive replacement lengthens fractional economic life, and that life tends to infinity as reserve additions approach extraction from below. If additions equal or exceed extraction, the constant-flow system has no finite exhaustion date without a later change in policy, economics, or geology.

The reserve-replacement Hoskold formula (RRH) becomes

$$V_{RRH} = \frac{A}{i + \frac{j}{(1+j)^{n^e} - 1}}. \quad (15)$$

The exact discrete exhaustion period and the fractional capitalization life are related by

$$N^d = \text{ceil}(n^e). \quad (16)$$

The policy significance of Eq. (15) is immediate. Classical Hoskold embeds the special case of zero reserve additions. When the valuation object includes economically credible reserve additions, imposing zero additions is restrictive rather than neutral: it shortens economic life, raises the sinking-fund burden, and lowers capitalized value. The theoretical reserve-addition flow should therefore be distinguished from the inventory-conversion proxy used in the empirical application.

3.3 Managed-reserve Hoskold (MH): finite-horizon valuation with continuation value

Many policy and financial valuations are conducted over a fixed horizon τ rather than over the literal exhaustion date. Depending on the mandate, the analytical horizon may be 10, 15, 20, or 25 years, followed by a residual value for documented remaining reserves and, where justified, a portion of additional identified inventory. The present application uses $\tau = 10$ years as a transparent base scenario, not as an industry norm, and reports longer horizons in the sensitivity analysis. Whenever the valuation horizon ends before economic exhaustion, forcing terminal reserves to zero is generally inappropriate.

The reserve-replacement extension still presumes that full capital recovery occurs at the exhaustion date. A broader managed-non-renewability perspective allows a different possibility: reserves, identified opportunities, and capacity may remain strictly positive at the chosen policy horizon. In that case the terminal date is not an exhaustion date, and a residual or continuation value must be recognized.

Let the evaluation horizon be τ , not necessarily equal to the exhaustion date. Let the future value at year τ of the remaining economically operative asset be L_τ . Then the sinking fund need only recover $V - L_\tau$ rather than the full original capital V .

Thus

$$V - L_\tau = \sum_{t=1}^{\tau} (\Pi_t - iV) (1 + j)^{\tau-t}. \quad (17)$$

Rearranging,

$$V[1 + i\Phi_\tau(j)] = L_\tau + \sum_{t=1}^{\tau} \Pi_t (1 + j)^{\tau-t}. \quad (18)$$

Therefore, the managed-reserve Hoskold formula (MH) with terminal value is

$$V_{MH}(\tau) = \frac{L_\tau + \sum_{t=1}^{\tau} \Pi_t (1+j)^{\tau-t}}{1 + i\Phi_\tau(j)}. \quad (19)$$

Again, this nests important special cases. If $L_\tau = 0$, it reduces to the generalized Hoskold formula. If, in addition, $\Pi_t = A$, it reduces to the classical Hoskold formula. And if $j = i$, it becomes terminal-value DCF exactly:

$$V_{MH}(\tau) = \sum_{t=1}^{\tau} \frac{\Pi_t}{(1+i)^t} + \frac{L_\tau}{(1+i)^\tau} \quad (20)$$

Managed-reserve Hoskold is the natural dual-rate counterpart to terminal-value DCF. The exact construction coincides with reserve-replacement Hoskold when the replacement-adjusted life does not exceed the policy horizon. For longer-lived assets, it values the first-stage cash flows and the continuation asset with the same terminal-value identity. When the two rates coincide, the result is ordinary DCF and is recursively consistent. When the rates differ, sensitivity to the chosen horizon reveals the well-known lack of dynamic consistency in dual-rate capitalization; that dependence should be reported rather than hidden.

3.4 Capacity-aware Hoskold (CKH): throughput as a separate valuation margin

The fourth extension recognizes that a given reserve inventory can support different current income streams depending on the rate at which the ore body, plant, or logistics system can be monetized. In modern mining, this is not a secondary detail. Throughput constraints, blending limits, recovery bottlenecks, and haulage or processing bottlenecks frequently shape the income base that any capitalization rule is trying to value.

Here, q_t^d denotes reserve-driven desired output in year t , K_t denotes installed productive capacity, and q_t denotes effective output. The capacity constraint is

$$q_t = \min\{q_t^d, K_t\}, \quad (21)$$

Equation (21) makes effective output the smaller of desired output and installed productive capacity.

For the constant-flow specialization, let S_0 denote initial reserves and set $q_t^d = q^d$, $K_t = K$, and $z_t = z$ in every year t , so z is the constant counterpart of z_t . The resulting effective life is

$$n_K^e = \frac{S_0}{\min\{q^d, K\} - z}, \quad (22)$$

provided $\min\{q^d, K\} > z$.

Let A_K denote annual income generated by capacity-adjusted output. Substituting A_K and n_K^e into the classical capitalization rule gives the capacity-aware Hoskold formula (CKH):

$$V_{CKH} = \frac{A_K}{i + \frac{j}{(1+j)^{n_K^e}}}. \quad (23)$$

Capacity-aware Hoskold (CKH) matters most when the public record reveals a plausible throughput margin beyond current production. In that case, the extension adjusts both annual income and effective life. When capacity is not binding or cannot be measured credibly, it collapses back toward the original rule. This makes it a targeted correction rather than a universal replacement.

4. Data and empirical design

4.1 Sample, public documents, and standardization strategy

The empirical exercise uses 50 operating gold assets across 15 countries and five major producers: Newmont (18 assets), Agnico Eagle (10), Harmony (15), Kinross (6), and Barrick (1). Gold is used not because the theory is commodity-specific, but because large producers disclose comparatively consistent site-level operating data and reserve inventories. The common observation year is 2024. Inputs are drawn from company annual reports, reserve and resource statements, and operating reports (Agnico Eagle Mines Limited, 2025a; Barrick Gold Corporation, 2025; Harmony Gold Mining Company Limited, 2024a, 2024b; Kinross Gold Corporation, 2025a, 2025b; Newmont Corporation, 2025a, 2025b). The resulting values are standardized operating-asset capitalization proxies, not bankable project NPVs or estimates of transaction value. This controlled design is intended to reveal how formula structure changes valuation under a common public-data information set.

Table 2 reports the scope of the sample and the common assumptions. The benchmark price of \$2,400/oz is a round normalization close to the realized-price range disclosed by the sampled producers for 2024. It is not a long-run gold-price forecast. The risky rate $i = 12\%$ and sinking-fund rate $j = 4\%$ provide a common dual-rate base and are varied in sensitivity. The conversion factor $\theta = 35\%$ is a middle scenario between the 15% and 55% cases, not an estimate of the probability that a particular resource will become a reserve. The 10-year managed-reserve horizon is likewise a base convention, with 5-, 15-, and 20-year alternatives reported. Finally, the 10% closure haircut is a stylized final-partial-year adjustment. Holding these inputs common helps isolate formula structure, but the results remain conditional on this scenario design.

Table 2. Sample coverage and standardized assumptions.

Item	Value
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Item	Value
Sample	50 operating gold assets
Companies	Newmont (18), Agnico Eagle (10), Harmony (15), Kinross (6), Barrick (1)
Country coverage	15 countries across the Americas, Africa, Europe, and Oceania
Common benchmark gold price P	\$2,400/oz (common 2024 normalization)
Risky rate i	12% (10% and 15% in sensitivity)
Sinking-fund rate j	4% (3% and 6% in sensitivity)
Reserve-conversion factor θ	35% of exclusive M&I inventory (scenario; 15% and 55% in sensitivity)
Managed-reserve evaluation horizon τ	10 years (5, 15, and 20 years in sensitivity)
Closure haircut h	10% in the final partial year (stylized)

4.2 Variable construction and empirical implementation

Set A , the annual average income, as

$$A = (P - C)Q, \quad (24)$$

where P is the common benchmark gold price, C is a site-level operating-cost proxy selected from the closest publicly disclosed measure, and Q is 2024 attributable gold production in ounces. The cost hierarchy uses Newmont’s costs applicable to sales, Agnico Eagle’s total cash costs on a by-product basis, Harmony’s cash operating cost, Kinross’s production cost of sales, and Barrick’s total cash costs. All-in sustaining cost is excluded because it mixes operating performance with sustaining capital and other items not disclosed consistently at asset level.

These cost measures are not fully harmonized. Reporting boundaries and the treatment of by-products and co-products, particularly silver, vary across companies. Absolute dollar values and value-weighted summaries should therefore be interpreted more cautiously than within-asset comparisons. The primary outcomes are formula ratios and paired differences for the same asset. Because every Hoskold variant is homogeneous of degree one in annual surplus A , applying the same asset-level margin scales the competing values proportionally and substantially reduces the influence of cost-definition differences on the unweighted ratios. This algebraic protection does not eliminate data risk, but it makes the cross-formula comparison less sensitive than a comparison of absolute asset values.

The classical reserve-life term is constructed from booked reserves:

$$n = \frac{R}{Q}, \quad (25)$$

where R is attributable reserves in ounces. To implement reserve replacement transparently, the fractional replacement-adjusted life is defined as

$$n_{RR} = \frac{R + \theta M^{ex}}{Q} = \frac{R/Q}{1 - \rho_{eq}}, \quad \rho_{eq} = \frac{\theta M^{ex}}{R + \theta M^{ex}}. \quad (26)$$

where M^{ex} is an exclusive proxy for additional measured and indicated inventory and θ is a common scenario conversion factor. This proxy should not be read as observed reserve replacement or as a project-specific conversion probability. Actual reserve additions can reflect exploration, revised prices and costs, mine redesign, metallurgical information, permitting, capital allocation, acquisitions, and other mechanisms. Sensitivity to θ is therefore central to interpretation. Equation (26) provides the bridge to the flow formulation in Section 3.2: converting a finite inventory θM^{ex} is equivalent, for life calculation, to a constant replacement ratio ρ_{eq} equal to converted inventory divided by post-conversion reserves. When public resources are exclusive of reserves, M^{ex} equals disclosed measured and indicated inventory; when they are inclusive, the empirical proxy is given by Eq. (27).

$$M^{ex} = \max\{M - R, 0\}. \quad (27)$$

For the empirical capacity illustration, current production is compared with output implied by disclosed processed tonnage T in kilotonnes, head grade g in grams per tonne, and metallurgical recovery η :

$$\hat{Q}^K = \frac{Tg\eta}{31.1035}. \quad (28)$$

where Q^K is measured in thousand troy ounces. With T measured in kilotonnes and g in grams per tonne, the thousand-unit factors cancel and the denominator converts grams to troy ounces. The throughput-reconciled output proxy is then

$$Q^K = \max\{Q, \hat{Q}^K\}. \quad (29)$$

so the empirical capacity-aware formula departs from the original only when the disclosed throughput-grade-recovery identity implies output above reported production. Processed tonnes are not rated installed capacity, and public reports may distinguish recovered, produced, sold, or

payable ounces and may recognize inventory or refining timing differently. Small reconciliation gaps can therefore arise without unused engineering capacity. The positive-gap subset is treated only as a conservative consistency signal, not as proof of spare capacity. A full capacity appraisal requires design throughput, utilization, bottleneck, recovery, expansion-cost, and product-accounting data.

The original Hoskold formula is, therefore, implemented as

$$V_H = \frac{A}{i + \frac{j}{(1+j)^{n-1}}}. \quad (30)$$

The generalized Hoskold formula requires an explicit annual cash-flow path. Because the cross-section contains only one observed year, the timing exercise is deliberately stylized rather than a reconstruction of each company's life-of-mine schedule. The imposed path preserves the same total undiscounted surplus as the original annuity while allowing a fractional final year and a closure haircut. Let

$$N_c = [n], \alpha = n - N_c + 1, n = N_c - 1 + \alpha, 0 < \alpha \leq 1. \quad (31)$$

where N_c is the number of modeled calendar periods and alpha is the fraction of the final period. Define the scaling function

$$\kappa(n, h) = \frac{n}{N_c - 1 + \alpha(1-h)}. \quad (32)$$

where h is the closure haircut. The empirical yearly path becomes

$$\begin{aligned} \Pi_t &= \kappa(n, h)A, t = 1, \dots, N_c - 1; \\ \Pi_{N_c} &= \kappa(n, h)A\alpha(1 - h). \end{aligned} \quad (33)$$

Substituting this path into the generalized formula yields the value used in the workbook. By construction, the generalized and original versions differ only because the former respects timing and a partial final year, not because it changes total undiscounted cash flow.

The reserve-replacement version uses the fractional conversion-adjusted life n_{RR} in place of n :

$$V_{RRH} = \frac{A}{i + \frac{j}{(1+j)^{n_{RR}-1}}}. \quad (34)$$

The managed-reserve implementation applies the terminal-value identity in Eq. (19) exactly. If the replacement-adjusted life does not exceed τ , no continuation survives the policy horizon and

managed-reserve Hoskold equals reserve-replacement Hoskold. If it exceeds τ , L_τ is the Hoskold value at year τ of the remaining life, and the first-stage cash flows plus continuation are capitalized with the same dual-rate identity:

$$V_{MH} = \begin{cases} V_{RRH}, & n_{RR} \leq \tau, \\ \frac{A\Phi_\tau(j)+L_\tau}{1+i\Phi_\tau(j)}, & n_{RR} > \tau, \end{cases} \quad L_\tau = \frac{A}{i + \frac{j}{(1+j)^{n_{RR}-\tau}-1}}. \quad (35)$$

Finally, the empirical capacity illustration uses throughput-reconciled output and the corresponding reserve life:

$$A_K = (P - C)Q^K, \quad n_K = \frac{R}{Q^K}. \quad (36)$$

This implementation has three virtues. First, every formula difference maps to an auditable driver in the workbook: stylized timing, finite conversion inventory, continuation share, or a throughput-reconciliation gap. Second, the managed-reserve formula applies the terminal-value identity rather than adding a separately discounted residual. Third, the design is deliberately conservative and standardized: reserve conversion uses a common factor, and the capacity term changes value only where disclosed technical data generates a positive gap. The last term should be interpreted as an illustration of the capacity margin, not as a substitute for rated-capacity engineering data.

4.3 Benchmark design: disclosed mine plans and standardized DCF comparators

The first benchmark is external to formula construction. Agnico Eagle's 2024 Annual Information Form reports estimated production end dates for 10 operating complexes: LaRonde (2034), Canadian Malartic (2042), Goldex (2032), Detour Lake (2052), Macassa (2031), Meadowbank (2028), Meliadine (2032), Fosterville (2036), Kittila (2036), and Pinos Altos (2028) (Agnico Eagle Mines Limited, 2025b). Measured from year-end 2024, these dates define public mine-plan lives. A plan-life Hoskold benchmark holds annual surplus and both rates fixed while replacing the reserve-life proxy with the disclosed plan life. All 10 observations come from one producer, so the benchmark tests institutional fit within a single planning and disclosure regime rather than representativeness across the global gold industry. It remains an informative but deliberately limited test of which shortcut best matches the reserve-based object the company has published.

The second benchmark is a construct-consistency test, not an external estimate of market value. It asks whether a shortcut moves toward a DCF comparator after the valuation object is deliberately widened using the same public information. For reserve conversion and continuation, the comparator discounts annual surplus over the replacement-adjusted life. For the throughput illustration, it uses capacity-adjusted surplus and life on the positive-gap subset. Because the same expanded state variables enter both the extension and the comparator, this design isolates formula structure but does not constitute independent validation; nor can it validate taxes, sustaining capital, closure, uncertainty, or market expectations.

The standardized DCF operator applies the same fractional-final-year and closure-haircut convention used in the generalized Hoskold path. The replacement and throughput comparators are obtained by evaluating that operator at (A, n_{RR}) and (A_K, n_K) , respectively:

$$\mathcal{D}(A, n; i, h) = \sum_{t=1}^{N_c-1} \frac{\kappa(n, h)A}{(1+i)^t} + \frac{\kappa(n, h)A\alpha(1-h)}{(1+i)^{N_c}}. \quad (37)$$

$$V_{DCF}^{RR} = \mathcal{D}(A, n_{RR}; i, h), \quad V_{DCF}^K = \mathcal{D}(A_K, n_K; i, h). \quad (38)$$

For each project, absolute percentage error (APE) is the absolute difference between the formula value and the relevant benchmark divided by the absolute benchmark value. Mean APE (MAPE) is the arithmetic mean of project-level APEs, while median APE is the middle project-level error. Generalized Hoskold is evaluated analytically because its purpose is to preserve timing within dual-rate capitalization: it nests the original rule when flows are flat and becomes DCF when $i = j$. The two empirical benchmarks answer different questions. The disclosed-plan benchmark tests institutional fit to a published reserve-based object; the standardized DCF benchmark tests internal consistency after the object is widened.

4.4 Comparative statistical analysis

The same 50 assets are valued under each formula, so observations are matched rather than independent. Because valuation ratios are skewed and contain ties, the omnibus comparison uses Friedman's rank test (Friedman, 1937). Pairwise differences use two-sided Wilcoxon signed-rank tests (Wilcoxon, 1945), with family-wise error controlled by Holm's sequential correction (Holm, 1979). Matched-pairs rank-biserial correlation is reported as the effect size.

Uncertainty around mean ratios and paired differences is summarized with 20,000 non-parametric project-level bootstrap resamples (Efron and Tibshirani, 1993). Zero differences are omitted from signed-rank statistics, all tests are two-sided, and the significance level is 5%. Because the 50 projects are a purposive public-disclosure sample rather than a probability sample of world mines, p-values describe the consistency of within-sample paired differences; they should not be read as design-based population inference. Economic magnitude, effect size, and benchmark interpretation, therefore, receive more weight than statistical significance alone.

5. Results

5.1 Overall valuation differences across the 50-project sample

Table 3 and Figure 1 report the central cross-sectional distribution. Generalized Hoskold remains tightly clustered around classical Hoskold, with a mean ratio of 0.98 and a median of 0.99. Reserve-replacement Hoskold has a mean of 1.20 and a median of 1.09, while managed-reserve Hoskold has a mean of 1.24 and a median of 1.14. The difference between mean and median shows that the reserve-related distributions are right-skewed by a small number of short-booked-life assets with large identified inventories. Capacity-aware Hoskold has a median of 1.00 and a maximum of 1.08 because the public-data proxy changes only nine projects.

Table 3. Valuation ratios relative to original Hoskold across the 50-project sample.

Formula	Mean	Median	Q1	Q3	Min	Max
Generalized	0.98	0.99	0.98	0.99	0.96	1.00
Reserve-replacement	1.20	1.09	1.05	1.27	1.00	2.20
Managed-reserve	1.24	1.14	1.09	1.31	1.00	2.20
Capacity-aware	1.00	1.00	1.00	1.00	1.00	1.08

The boxplots make the distributional pattern explicit. Generalized Hoskold exceeds the original in only three projects and is lower in 47 because the standardized path includes a partial final year and a closure haircut. Reserve-replacement and managed-reserve Hoskold exceed the original in all 50 projects under the positive-conversion scenario. Managed-reserve equals reserve-replacement Hoskold in 15 assets whose replacement-adjusted life does not exceed the 10-year horizon and exceeds it in the remaining 35 assets with continuation. Capacity-aware Hoskold exceeds the original only in the nine positive-gap observations. The long upper tails in

the reserve-related formulas caution against interpreting the means as representative of the typical project.

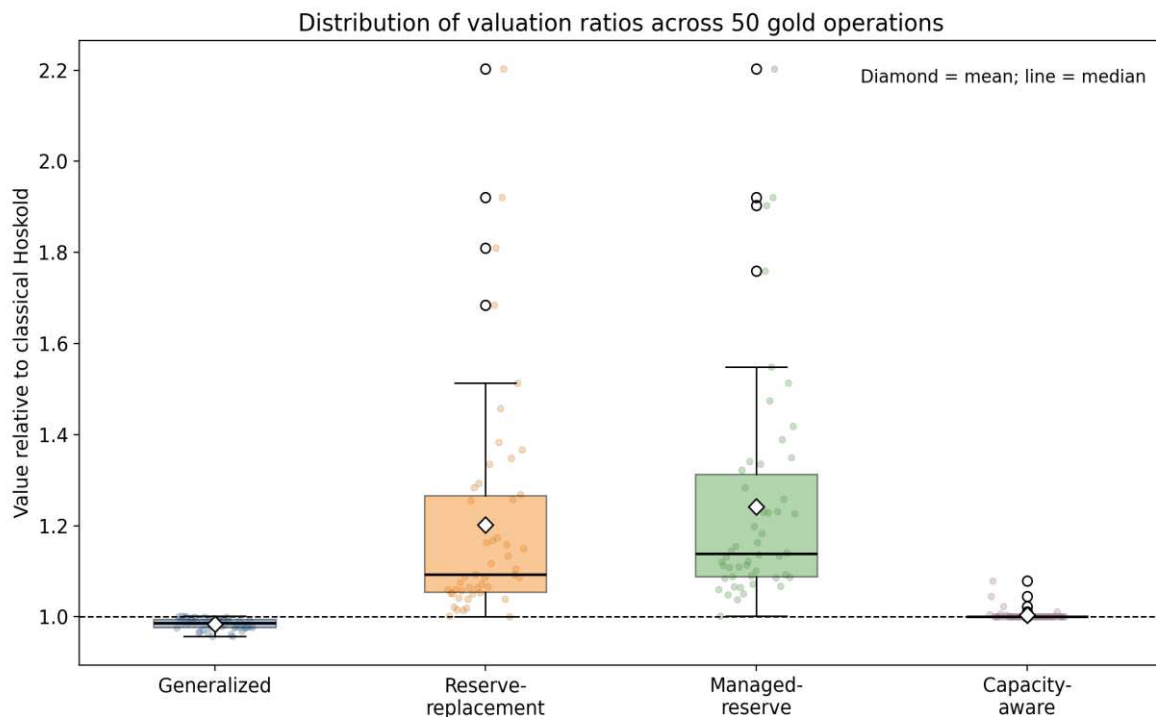


Figure 1. Distribution of valuation ratios relative to classical Hoskold across the 50-project sample.

Within this standardized public-data calibration, the largest valuation adjustments are associated with reserve conversion and continuation beyond the policy horizon. Timing is modest under the deliberately conservative one-year path, and the capacity adjustment appears only where a technical-output gap is observable. This pattern is consistent with a managed-reserve interpretation of modern mines, but it is not a universal ranking of formulas: each adjustment is conditional on the information admitted into the valuation object.

5.2 External mine-plan evidence and construct-consistency benchmarks

The disclosed mine-plan benchmark provides the most direct evidence on when classical Hoskold remains adequate within the observed disclosure regime. Across the 10 Agnico Eagle assets, booked reserve life has a mean absolute error of 2.0 years and a median error of 0.9 years relative to the disclosed plan. Conversion-adjusted life has corresponding errors of 3.4 and 3.0 years. On value, mean absolute percentage error is 10.3% for classical Hoskold, 10.9% for generalized Hoskold, 15.0% for reserve-replacement Hoskold, and 16.5% for exact managed-

reserve Hoskold. Capacity-aware Hoskold equals classical Hoskold in this subset because the empirical throughput proxy does not create a separate adjustment. These figures should be read as single-producer institutional-fit evidence rather than a general validation across mine operators.

Table 4. External institutional-fit benchmark: project lives, closest formula, and summary errors.

Project	Plan end	Plan life (yr)	Reserve life n	Conversion life nRR	Closest formula / value-error summary
Meadowbank	2028	4	3.2	4.1	RRH = MH
Pinos Altos	2028	4	4.9	7.8	GH
Macassa	2031	7	7.4	8.4	GH
Goldex	2032	8	7.1	11.6	Classical = CKH
Meliadine	2032	8	8.9	10.5	GH
LaRonde	2034	10	8.9	10.7	RRH
Fosterville	2036	12	7.3	9.7	RRH = MH
Kittila	2036	12	15.5	18.6	GH
Canadian Malartic	2042	18	11.4	13.2	MH
Detour Lake	2052	28	28.4	36.6	Classical = CKH
Summary: mean absolute error	—	—	2.0 yr	3.4 yr	Value MAPE: H 10.3%; GH 10.9%; RRH 15.0%; MH 16.5%
Summary: median absolute error	—	—	0.9 yr	3.0 yr	Value MAPE: H 9.0%; GH 10.1%; RRH 11.1%; MH 10.3%

The project-level pattern is also conditional. Generalized Hoskold is closest on four assets, reserve-replacement or its identical managed-reserve case on three, classical Hoskold on two, and managed-reserve Hoskold on one. The result is consistent with the article's central distinction: a disclosed mine plan is normally a reserve-disciplined institutional object, not a claim on every identified opportunity or every possible continuation phase. The single-company nature of the benchmark, however, limits the extent to which this pattern can be generalized.

Table 5. Construct-consistency tests against state-augmented standardized DCF comparators.

Comparison	Mean APE	Median APE	Projects improved vs original	Relevant N
Original vs replacement-adjusted DCF	24.3%	20.7%	—	50
Reserve-replacement vs replacement-adjusted DCF	11.7%	12.6%	50	50
Managed-reserve vs replacement-adjusted DCF	8.7%	8.4%	50	50
Original vs capacity-adjusted DCF	12.5%	12.2%	—	9
Capacity-aware vs capacity-adjusted DCF	10.8%	11.7%	9	9

The state-augmented DCF construct test asks a different question and yields a complementary result. Against replacement-adjusted DCF, classical Hoskold has a mean absolute percentage error of 24.3%. Reserve-replacement Hoskold lowers that error to 11.7%, while exact managed-reserve Hoskold lowers it to 8.7% (Figure 2). Both extensions are closer to the constructed comparator for all 50 projects, as expected when the benchmark object contains the same added state variables. Managed-reserve equals reserve-replacement Hoskold in 15 assets without continuation beyond τ and lowers error in the other 35. These results document construct consistency, not independent market-value validation.

The empirical capacity result is narrower. Nine projects have a positive throughput-reconciliation gap under the disclosed tonnes-grade-recovery identity. On that subset, capacity-aware Hoskold lowers mean absolute percentage error against the corresponding DCF comparator from 12.5% to 10.8%, with improvement in all nine observations (Wilcoxon $p = 0.004$). The result is consistent with a capacity margin mattering when a technical-output gap is visible; it is not evidence of unused installed capacity, which would require rated throughput, utilization, product-accounting, and bottleneck data.

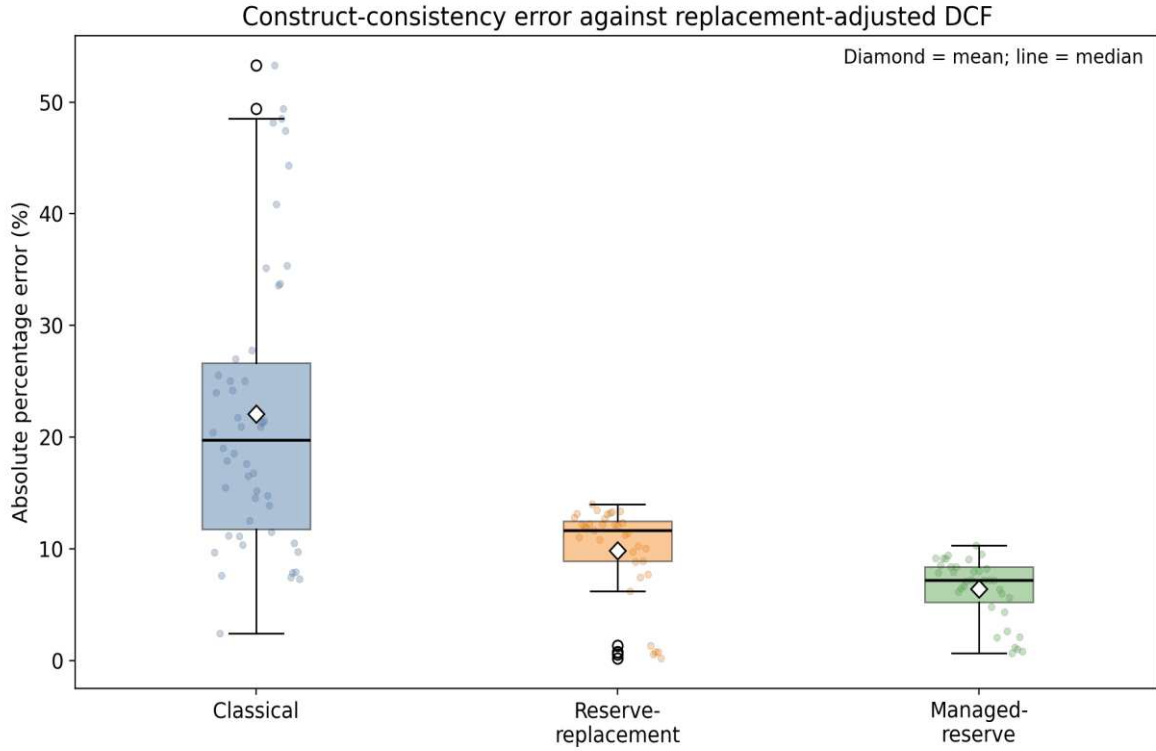


Figure 2. Distribution of absolute percentage errors against the replacement-adjusted standardized DCF comparator.

Three qualifications are important. First, the external plan-life benchmark and the state-augmented DCF comparator test different valuation objects; their different rankings are therefore informative rather than contradictory. Second, generalized Hoskold is not included in Table 5 because its timing property is established analytically by the nesting results in Appendix A. Third, neither benchmark establishes transaction or market value. The construct test shows only that admitting the relevant state variable moves the shortcut toward a DCF comparator built from the same expanded information set.

5.3 Which state variable drives the divergence?

Table 6 documents how each valuation difference relates to its intended driver. Reserve-replacement uplift is strongly related to the conversion-inventory ratio $\theta M^{ex}/R$ (Pearson $r = 0.88$; Spearman $\rho = 0.89$) (Figure 3A). Incremental managed-reserve uplift is related to continuation share (Pearson $r = 0.57$; Spearman $\rho = 0.63$) (Figure 3B). Capacity uplift is nearly one-for-one with the throughput-reconciliation gap $Q^K/Q - 1$ (Pearson $r = 0.97$; Spearman ρ

approximately 1.00), as expected from the construction (Figure 3C). Generalized uplift is related to the fractional final-year term (Pearson $r = 0.74$; Spearman $\rho = 0.75$). The straight line in Figure 3B is shown only as the linear summary associated with Pearson's r . It is not a proposed structural functional form. The visible hump-shaped pattern reflects the bounded continuation-value mechanism: the incremental managed-reserve effect is zero when no continuation remains, rises at intermediate continuation shares, and compresses again as the reserve-replacement and managed-reserve values approach their long-life limits.

Table 6. Diagnostic correlations linking each formula uplift to its theoretical driver.

Relationship	Pearson r	Spearman ρ
Reserve-replacement uplift vs theta M^{es}/R	0.88	0.89
Managed incremental uplift vs continuation share	0.57	0.63
Capacity-aware uplift vs $Q^K/Q - 1$	0.97	1.00
Generalized uplift vs fractional life	0.74	0.75

These relationships show that the extensions are not arbitrary rescalings, but they are primarily construct checks because the drivers enter the formulas directly. The stronger empirical evidence is the contrast between the external plan-life benchmark and the state-augmented DCF comparator. Cross-sectional ranking is, nevertheless, highly stable: all pairwise Spearman correlations among valuation levels are at least 0.990. The formulas alter levels and the definition of the valued asset more than they reorder projects.

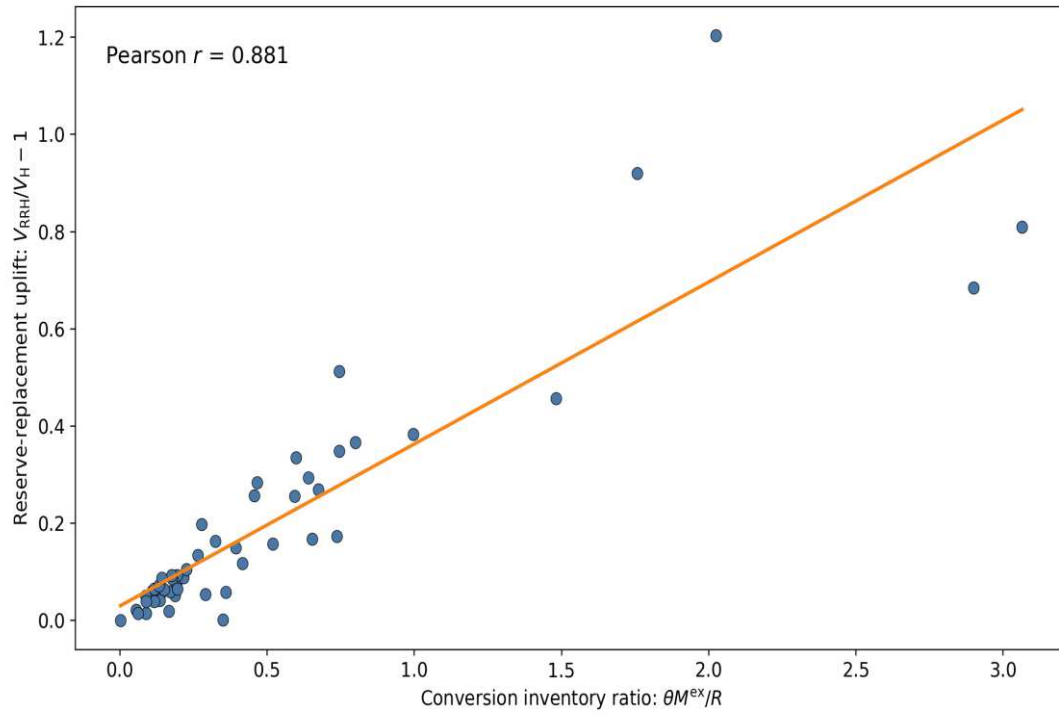


Figure 3A. Reserve-replacement uplift and conversion inventory.

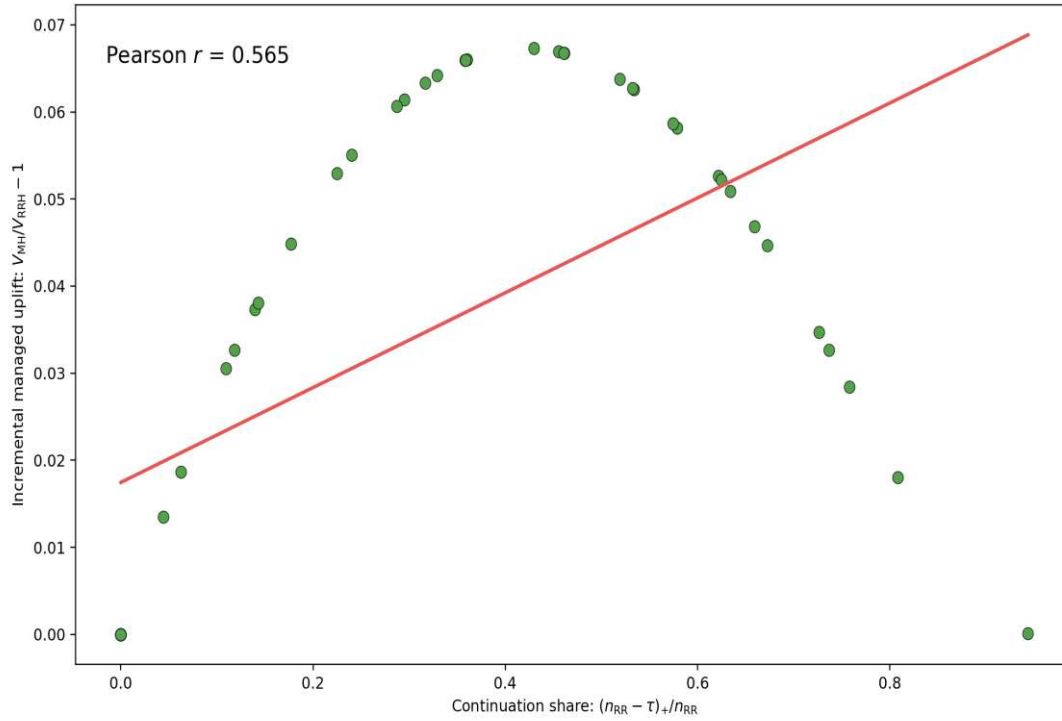


Figure 3B. Incremental managed-reserve uplift and continuation share.

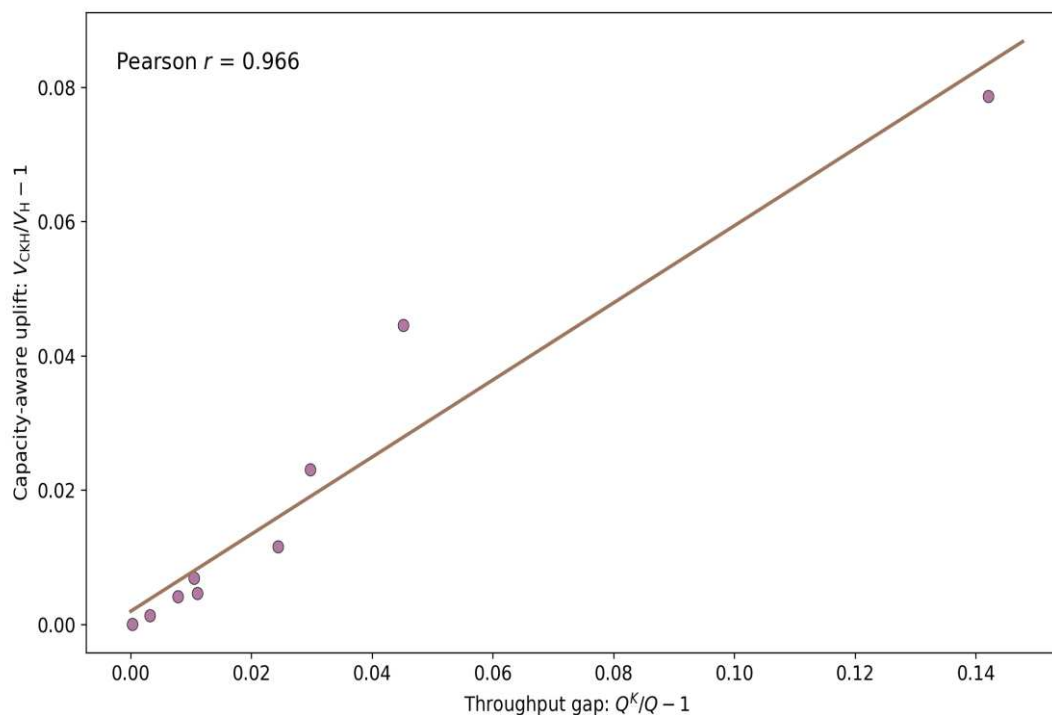


Figure 3C. Capacity-aware uplift and the implied throughput gap.

5.4 Company patterns and project-level heterogeneity

Company medians reveal meaningful portfolio heterogeneity. Harmony has median reserve-replacement and managed-reserve ratios of 1.26 and 1.26, while Kinross medians are 1.19 and 1.25. Newmont is closer to the original, with medians of 1.05 and 1.10, consistent with longer booked lives and more moderate conversion inventory. Median capacity-aware ratios equal 1.00 for every company because only nine projects have a positive throughput-reconciliation gap. Those observations comprise seven Newmont assets and two Kinross assets, with company maximum ratios of 1.08 and 1.01, respectively. Table 7 therefore separates the incidence and maximum of the capacity proxy from the reserve-related company medians.

Table 7. Company median valuation ratios and incidence of the capacity proxy.

Company	Median GH / H	Median RRH / H	Median MH / H	Capacity proxy: positive-gap assets / max CKH / H
Agnico Eagle	0.99	1.09	1.13	0 / 1.00

Company	Median GH / H	Median RRH / H	Median MH / H	Capacity proxy: positive-gap assets / max CKH / H
Barrick	0.98	1.15	1.23	0 / 1.00
Harmony	0.98	1.26	1.26	0 / 1.00
Kinross	0.98	1.19	1.25	2 / 1.01
Newmont	0.99	1.05	1.10	7 / 1.08

The largest reserve-replacement uplifts occur at Masimong, Kusasaletu, Tshepong South, Tshepong North, and La Coipa. Under the exact terminal-value implementation, the largest managed-reserve uplifts occur at Masimong, Kusasaletu, Tshepong South, Tshepong North, and Target 1. These are short-booked-life assets or assets with large identified inventory relative to reserves. **Table B3** and **Table B4** in **Appendix B** report the detailed rankings.

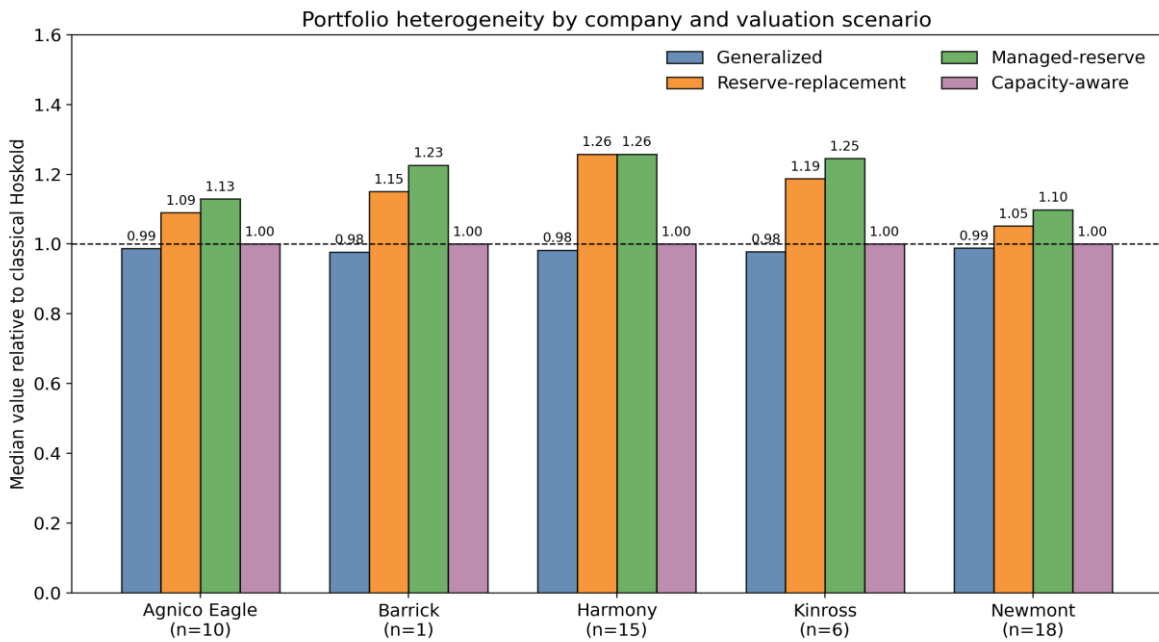


Figure 4. Median valuation ratios by company and formula scenario.

5.5 Sensitivity and robustness

The central ordering is stable across the parameter changes reported in Table 8. The sensitivity exercise varies the risky rate, sinking-fund rate, reserve-conversion factor, and managed-reserve

horizon. Reserve-replacement Hoskold remains above the original in every scenario. Exact managed-reserve Hoskold also remains above reserve-replacement Hoskold on average, although the difference narrows as the horizon lengthens and a smaller share of the asset remains in continuation.

Construct-consistency rankings are stable within the reported sensitivity exercise. Mean error for reserve-replacement Hoskold remains below classical Hoskold in every scenario, and managed-reserve Hoskold remains below reserve-replacement Hoskold. A shorter horizon increases the continuation component and improves fit to the replacement-adjusted DCF comparator in this calibration; 15- and 20-year horizons move managed-reserve Hoskold toward the direct reserve-replacement value. The sensitivity grid exposes, rather than conceals, the horizon dependence of dual-rate capitalization.

Table 8. Sensitivity of average ratios and benchmark errors to alternative parameter choices.

Scenario	GH / Orig	RRH / Orig	MH / Orig	CKH / Orig	Mean APE RRH	Mean APE MH
Base	0.98	1.20	1.24	1.00	11.7%	8.7%
$i = 10\%$	0.99	1.23	1.26	1.00	10.6%	7.8%
$i = 15\%$	0.98	1.18	1.22	1.00	12.6%	9.4%
$j = 3\%$	0.98	1.20	1.25	1.00	13.4%	9.9%
$j = 6\%$	0.99	1.21	1.23	1.00	8.4%	6.4%
$\theta = 15\%$	0.98	1.10	1.14	1.00	11.6%	9.1%
$\theta = 55\%$	0.98	1.28	1.32	1.00	11.5%	8.2%
$\tau = 5$	0.98	1.20	1.27	1.00	11.7%	7.1%
$\tau = 15$	0.98	1.20	1.22	1.00	11.7%	10.1%
$\tau = 20$	0.98	1.20	1.21	1.00	11.7%	10.8%

5.6 Comparative statistical analysis

Because every asset is valued under every formula, the comparison is paired. The ratio distributions are skewed and contain ties, so the inferential analysis relies on rank-based tests and project-level bootstrap intervals. Several signs are partly analytical: with positive conversion inventory, reserve-replacement Hoskold must exceed classical Hoskold; managed-reserve Hoskold equals or exceeds reserve-replacement Hoskold under the chosen terminal-value

construction; and capacity-aware Hoskold changes only on the positive-gap subset. Descriptive means, medians, and bootstrap intervals use the full matched sample unless the comparator exists only for a subset; Wilcoxon tests omit exact zero differences. The tests therefore quantify consistency and magnitude within the sample rather than supply independent causal evidence. Main descriptive tables use two decimal places; formal test tables retain additional precision where necessary to reproduce small paired effects.

Table 9. Formal comparative tests for valuation ratios relative to original Hoskold.

Comparison (descriptive N; Wilcoxon non-zero N)	Mean or mean difference (95% bootstrap CI)	Median	Adjusted p	Rank-biserial / W
Generalized / Original (50; 50)	0.984 [0.981, 0.988]	0.987	<0.001	-0.973
Reserve- replacement / Original (50; 50)	1.202 [1.141, 1.275]	1.093	<0.001	1.000
Managed-reserve / Original (50; 50)	1.242 [1.179, 1.316]	1.139	<0.001	1.000
Capacity-aware / Original (50; 9)	1.004 [1.001, 1.008]	1.000	0.004	1.000
Friedman omnibus across four ratios (N = 50)	chi-square = 138.080	—	<0.001	W = 0.921
Generalized - Reserve- replacement (50; 50)	-0.218 [-0.292, - 0.154]	-0.109	<0.001	-1.000
Generalized - Managed-reserve (50; 50)	-0.258 [-0.333, - 0.193]	-0.154	<0.001	-1.000
Generalized - Capacity-aware (50; 50)	-0.019 [-0.024, - 0.015]	-0.017	<0.001	-0.978
Reserve- replacement - Managed-reserve (50; 35)	-0.040 [-0.049, - 0.031]	-0.047	<0.001	-1.000
Reserve- replacement - Capacity-aware (50; 50)	0.199 [0.136, 0.273]	0.092	<0.001	0.973

Comparison (descriptive N; Wilcoxon non-zero N)	Mean or mean difference (95% bootstrap CI)	Median	Adjusted p	Rank-biserial / W
Managed-reserve - Capacity-aware (50; 50)	0.239 [0.176, 0.314]	0.136	<0.001	0.995

Table 9 reports the formal comparison. The Friedman test rejects equality across the four extension ratios ($\chi^2(3) = 138.080$, $p < 0.001$; Kendall's $W = 0.921$). Holm-adjusted Wilcoxon tests reject equality for every formula pair. These results document a systematic within-sample hierarchy, but economic interpretation should rest on effect size and valuation object, not on p-values alone. On median, reserve-replacement exceeds generalized and capacity-aware Hoskold by 10.9 and 9.2 percentage points. Managed-reserve exceeds them by 15.4 and 13.6 points. Managed-reserve exceeds reserve-replacement by 4.7 points in the full matched sample and by 6.3 points among the 35 assets with non-zero continuation.

Table 10. Paired tests of benchmark-error reductions against standardized DCF comparators.

Paired benchmark comparison (descriptive N; Wilcoxon non-zero N)	Mean Δ APE, percentage points (95% bootstrap CI)	Median Δ APE (pp)	p-value	Rank-biserial
Original - RRH, replacement DCF (50; 50)	12.6 [9.5, 15.9]	7.4	<0.001	1.000
Original - MH, replacement DCF (50; 50)	15.5 [12.6, 18.8]	11.1	<0.001	1.000
RRH - MH, replacement DCF (50; 35)	3.0 [2.3, 3.6]	3.3	<0.001	1.000
Original - CKH, capacity DCF subset (9; 9)	1.7 [0.5, 3.2]	0.6	0.004	1.000

Table 10 reports paired benchmark-error reductions. Relative to replacement-adjusted DCF, reserve-replacement Hoskold lowers mean absolute percentage error by 12.6 percentage points and managed-reserve Hoskold by 15.5 points versus the original. Averaged across all 50 assets, managed-reserve lowers error by a further 3.0 points relative to reserve-replacement; the gain is

non-zero in 35 assets. On the nine-asset throughput-gap subset, capacity-aware Hoskold lowers error by 1.7 points. The statistical result remains conditional: an extension improves construct consistency when its added state variable is included in the benchmark object.

6. Policy and appraisal implications

The practical implication is that there is no single “resource value” independent of the scarcity model and institutional object embedded in the rule. Classical Hoskold is not wrong. It can be the least misleading shortcut when the object is a published booked-reserve plan and the information set is correspondingly narrow. The 50-asset construct test shows why the same formula can understate a broader object that includes credible conversion inventory or continuation. Policy should therefore define the object first, assess the evidence second, and choose the method third.

For public policy, four use cases stand out. First, reserve-based tax, compensation, or administrative settings can use classical Hoskold as a transparent secondary check when the disclosed plan is the legally relevant object and the available information does not justify a richer model. Second, disputes that expressly include a credible pipeline of convertible inventory should test reserve-replacement Hoskold rather than treating booked reserves as the full asset. Third, public-asset accounting over a finite horizon should recognize continuation only when residual inventory and its economic pathway are documented. Fourth, infrastructure-constrained systems require rated-capacity and bottleneck evidence before applying a capacity-aware formula; the public-data proxy used here is illustrative, not engineering proof. Whenever full annual forecasts exist and the stakes justify the effort, DCF remains the primary method and generalized Hoskold is at most a dual-rate cross-check.

Table 11 translates the results into an information-and-effort decision matrix. It is not a substitute for professional judgment or full DCF where detailed forecasts are available. It indicates which shortcut is least demanding while still representing the state variables that the evidence and the institutional mandate can support.

Table 11. Decision matrix for selecting among Hoskold-type shortcuts and DCF.

Method	Best use	Why it is applicable	Main caveat
Original Hoskold	Low-information check for a fixed disclosed reserve plan; legacy appraisal	Valid limiting case and best mean fit to the single-producer public mine-plan benchmark	Misses broader conversion inventory, continuation, and capacity scarcity

Method	Best use	Why it is applicable	Main caveat
Generalized Hoskold	Intermediate-information setting with annual forecasts but dual-rate institutional practice	Preserves timing and fractional years	Timing path is stylized in the present cross-section. DCF remains primary
Reserve-replacement Hoskold	Valuation object expressly includes technically and economically supported conversion inventory	Endogenizes life through an auditable inventory-conversion assumption	Conversion is not automatic. Requires technical and economic support
Managed-reserve Hoskold	Finite policy horizon with documented residual inventory and a credible continuation pathway	Applies the terminal-value identity explicitly	Dual-rate value is horizon-sensitive unless $i = j$
Capacity-aware Hoskold	Documented plant, infrastructure, haulage, power, water, or logistics constraint	Separates throughput scarcity from reserve scarcity	Requires rated-capacity/bottleneck evidence; current proxy is illustrative
Full DCF	High-stakes bankable valuation, transactions, and investment approval with full forecasts	Models full cash-flow timing, taxes, capital, closure, and uncertainty	Data- and assumption-intensive, but necessary when the decision requires complete cash-flow detail

A broader policy implication concerns reserve statistics themselves. Reserve levels are endogenous economic inventories, but published mine plans are also conservative governance objects constrained by reporting standards, permitting, engineering, and capital commitments. Governments can, therefore, err in both directions: they may overread a short reserve life as geological exhaustion, or over-capitalize identified resources as though conversion were automatic. The formula ladder is useful only when evidence supports the state variable being added.

7. Discussion and limitations

The empirical claim is deliberately narrower than feasibility-study valuation. The exercise uses a common benchmark price, heterogeneous but disclosed site operating-cost proxies, a common scenario conversion factor, and a stylized final-year path. Cost boundaries and by-product treatment are not identical across companies, although the within-asset formula ratios are algebraically less sensitive to this heterogeneity than absolute values. Taxes, sustaining capital, closure liabilities, grade scheduling, co-product allocation, uncertainty, and real-option value are

not modeled. The external mine-plan test evaluates institutional fit to a public planning object, not market value; the standardized DCF test is construct validation using the same expanded inputs, not independent out-of-sample validation. For investment approval or transaction pricing, full project DCF and, where material, option analysis remain necessary.

The exact managed-reserve formula corrects the earlier two-stage approximation by applying the terminal-value identity directly. It also reveals an important theoretical limitation: dual-rate Hoskold capitalization is not recursively time-consistent unless the risky and sinking-fund rates coincide. Hence the managed value can depend on the selected policy horizon even when the underlying cash-flow stream is unchanged. The appropriate response is explicit horizon sensitivity and disclosure, not concealment of that dependence.

External validity is bounded in five ways. First, the 50 projects are a purposive sample from five large gold producers, so statistical inference does not represent the universe of mines. Second, the 10-operation mine-plan benchmark is drawn from one producer and may reflect company-specific planning, technology, governance, and disclosure conventions. Third, the capacity illustration uses disclosed processed tonnes, grade, and recovery rather than rated capacity, utilization curves, product-accounting reconciliations, or expansion costs. Fourth, the cost proxies follow different company definitions and by-product conventions. Fifth, gold reporting is richer and more comparable than reporting for many industrial minerals, coal, or hydrocarbons. Sector- and company-specific testing is therefore required before transferring the numerical results beyond large gold operations.

Two natural extensions follow from these limitations. The first is a multi-company and eventually multi-commodity external benchmark of disclosed mine-plan lives. The second is a consistent site-level panel, ideally covering about a decade, that measures actual reserve additions, depletion, resource-to-reserve conversion, production, and capacity utilization through time. Such a panel would replace the common theta scenario and point-in-time capacity proxy with observed dynamics and would allow out-of-sample tests. Building it requires a new data architecture and is left for future research rather than being folded into the present controlled cross-section.

Finally, the generalized Hoskold result is a stylized timing diagnostic because the cross-section does not contain annual life-of-mine cash-flow schedules. Its modest average effect should not

be interpreted as evidence that timing is generally unimportant. With actual annual forecasts, generalized Hoskold provides a clean bridge from historical dual-rate appraisal to explicit cash-flow analysis, although ordinary DCF remains the natural benchmark.

8. Conclusion

This article did not set out to show that classical Hoskold is wrong. It asked when the formula is an adequate representation of the asset and when the available information supports a richer state space. The analytical result is a nested family and an information-and-effort ladder: generalized Hoskold restores timing, reserve-replacement Hoskold admits finite conversion inventory, managed-reserve Hoskold prices continuation at a policy horizon, and capacity-aware Hoskold separates throughput scarcity from reserve scarcity when credible capacity evidence exists.

The two benchmarks deliver a conditional empirical result. Relative to publicly disclosed mine-plan lives in the single-producer benchmark, classical Hoskold has the lowest mean error at 10.3%, closely followed by generalized Hoskold at 10.9%: The broader reserve-replacement and managed-reserve formulas are less accurate because the published object is reserve-disciplined. Once the object is deliberately widened in the 50-operation construct test, the ordering changes: against replacement-adjusted DCF, mean error falls from 24.3% under classical Hoskold to 11.7% under reserve-replacement and 8.7% under managed-reserve Hoskold. Across the sample, mean value ratios are 0.98, 1.20, 1.24, and 1.00 for generalized, reserve-replacement, managed-reserve, and capacity-aware Hoskold. These figures are specific to the public-data sample, parameter scenarios, and test design.

For resources policy, valuation shortcuts are not innocuous administrative conveniences: they encode a theory of scarcity, a definition of the asset, and an implicit information requirement. Classical Hoskold remains defensible for a fixed disclosed reserve plan. Reserve-replacement and managed-reserve Hoskold become applicable only when technically and economically supported conversion inventory or continuation beyond that plan is part of the mandate. Capacity-aware valuation requires actual bottleneck or rated-capacity evidence. The disciplined rule is to define the valuation object, document the available state variables, select the least demanding method that represents them faithfully, and use full DCF whenever the information and stakes justify complete cash-flow modeling.

Data availability

Data available at request to authors.

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Appendix A. Selected derivations and nesting relations

A1. Exact reduction of generalized Hoskold to classical Hoskold

Starting from

$$V_{GH} = \frac{\sum_{t=1}^N \Pi_t (1+j)^{N-t}}{1+i\Phi_N(j)}. \quad (39)$$

set $\Pi_t = A$ for all t .

Then

$$\sum_{t=1}^N \Pi_t (1+j)^{N-t} = A \sum_{t=1}^N (1+j)^{N-t} = A\Phi_N(j). \quad (40)$$

Hence

$$V_{GH} = \frac{A\Phi_N(j)}{1+i\Phi_N(j)} = \frac{A}{i+\Phi_N(j)^{-1}} = \frac{A}{i+\frac{j}{(1+j)^{N-1}}}. \quad (41)$$

A2. Exact reduction of generalized Hoskold to DCF

Start again from

$$V_{GH} = \frac{\sum_{t=1}^N \Pi_t (1+j)^{N-t}}{1+i\Phi_N(j)}. \quad (42)$$

Set $j = i$. Since

$$\Phi_N(i) = \frac{(1+i)^N - 1}{i}, \quad (43)$$

we have

$$1 + i\Phi_N(i) = 1 + (1+i)^N - 1 = (1+i)^N. \quad (44)$$

Therefore

$$V_{GH} = \frac{\sum_{t=1}^N \Pi_t (1+i)^{N-t}}{(1+i)^N} = \sum_{t=1}^N \frac{\Pi_t}{(1+i)^t}. \quad (45)$$

Thus generalized Hoskold and DCF are identical under a common rate.

A3. Exact reduction of managed-reserve Hoskold to terminal-value DCF

Start from

$$V_{MH}(\tau) = \frac{L_\tau + \sum_{t=1}^\tau \Pi_t (1+j)^{\tau-t}}{1+i\Phi_\tau(j)}. \quad (46)$$

Setting $j = i$ yields denominator $(1 + i)^\tau$, so

$$V_{MH}(\tau) = \frac{L_\tau}{(1+i)^\tau} + \sum_{t=1}^{\tau} \frac{\Pi_t}{(1+i)^t} \quad \text{when } i = j. \quad (47)$$

This is precisely terminal-value DCF.

A4. Endogenous life under reserve replacement

Let

$$S_{t+1} = S_t + z - q. \quad (48)$$

with constant z and q . Iterating forward gives

$$S_t = S_0 - t(q - z). \quad (49)$$

The exact first non-positive reserve period is therefore

$$N_d = \text{ceil}\left(\frac{S_0}{q-z}\right), \quad q > z. \quad (50)$$

The associated fractional capitalization life, using the replacement ratio $\rho = z/q$, is

$$n^e = \frac{S_0}{q-z} = \frac{S_0/q}{1-\rho}, \quad \rho = \frac{z}{q}, \quad 0 \leq \rho < 1. \quad (51)$$

This expression reveals the exact relation between classical reserve coverage and the replacement-adjusted economic life.

Appendix B. Supplementary empirical tables

This appendix collects supporting empirical tables referenced in the main text. All values are calculated from the supplementary workbook under the common assumptions in Table 2 and the exact managed-reserve identity in Eq. (35).

B1. Additional benchmark and sensitivity tables

Table B1. Sensitivity scenarios for mean valuation ratios and benchmark errors.

Scenario	Gen / Orig	RRH / Orig	MH / Orig	CKH / Orig	Mean APE RRH	Mean APE MH
Base	0.984	1.202	1.242	1.004	0.117	0.087
i=10%	0.987	1.227	1.264	1.003	0.106	0.078
i=15%	0.981	1.175	1.216	1.004	0.126	0.094
j=3%	0.982	1.199	1.247	1.004	0.134	0.099
j=6%	0.989	1.208	1.234	1.003	0.084	0.064
$\theta=15\%$	0.984	1.104	1.136	1.004	0.116	0.091
$\theta=55\%$	0.984	1.276	1.322	1.004	0.115	0.082
$\tau=5$	0.984	1.202	1.265	1.004	0.117	0.071
$\tau=15$	0.984	1.202	1.223	1.004	0.117	0.101
$\tau = 20$	0.984	1.202	1.214	1.004	0.117	0.108

Table B2. Pairwise Spearman rank correlations among valuation levels.

Formula	Original	Generalized	Reserve-replacement	Managed-reserve	Capacity-aware
Original	1.000	1.000	0.992	0.991	1.000
Generalized	1.000	1.000	0.992	0.990	1.000
Reserve-replacement	0.992	0.992	1.000	0.999	0.992
Managed-reserve	0.991	0.990	0.999	1.000	0.991
Capacity-aware	1.000	1.000	0.992	0.991	1.000

B2. Largest project-level uplifts

Table B3. Largest reserve-replacement uplifts in the 50-project sample.

Company	Project	RRH / Original
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Company	Project	RRH / Original
Harmony	Masimong	2.203
Harmony	Kusasaletu	1.921
Harmony	Tshepong South	1.809
Harmony	Tshepong North	1.684
Kinross	La Coipa	1.513
Harmony	Target 1	1.457
Harmony	Joel	1.383
Kinross	Bald Mountain	1.367
Harmony	Savuka	1.348
Agnico Eagle	Pinos Altos	1.336

Table B4. Largest managed-reserve uplifts in the 50-project sample.

Company	Project	MH / Original
Harmony	Masimong	2.203
Harmony	Kusasaletu	1.921
Harmony	Tshepong South	1.904
Harmony	Tshepong North	1.759
Harmony	Target 1	1.549
Kinross	La Coipa	1.513
Harmony	Joel	1.474
Kinross	Bald Mountain	1.419
Harmony	Savuka	1.390
Kinross	Round Mountain	1.350

Table B5. Throughput-gap subset and capacity-aware uplifts.

Company	Project	CKH / Original	Throughput gap
Newmont	Peñasquito	1.079	0.142
Newmont	Red Chris	1.045	0.045
Newmont	Cadia	1.023	0.03
Kinross	Paracatu	1.012	0.024
Newmont	Boddington	1.007	0.011
Newmont	Brucejack	1.005	0.011
Newmont	Ahafo	1.004	0.008

Company	Project	CKH / Original	Throughput gap
Kinross	Tasiast	1.001	0.003
Newmont	Éléonore	1.0	0.0

B3. Primary source documents

Table B6. Primary public documents used in the cross-sectional workbook; direct URLs are retained in the supplementary workbook.

Company	Document	Report ing year	Primary use
Newmont	2024 Annual Report	2024	Production, throughput, grade, recovery, cost proxies, reserves, resources, and ownership notes.
Newmont	2024 Reserves and Resources Release	2024	Reserve and resource cross-check.
Agnico Eagle	2024 Annual Report	2024	Production, total cash costs, reserve disclosures, and operating statistics.
Kinross	2024 Annual Report	2024	Production, throughput, grade, recovery, and cost proxies.
Kinross	2024 Annual Mineral Reserve and Resource Statement	2024	Reserves and measured and indicated resources.
Harmony	FY24 Operational Report	FY2024	Production, mill tonnage, head grade, and cash operating cost.
Harmony	FY24 Mineral Resources and Mineral Reserves Report	FY2024	Reserve and resource totals (inclusive of reserves).
Barrick	2024 Annual Report	2024	Hemlo reserve/resource and cost data; Pueblo Viejo operating-cost proxy.

B4. Project-level sample tables

The following tables summarize the 50-project sample. “Prod koz” is attributable 2024 gold production in thousand ounces, “Res koz” is attributable reserves, “MIex koz” is the exclusive additional measured and indicated inventory proxy, “Life yrs” is booked reserve life, and the last two columns report reserve-replacement and exact managed-reserve values relative to original Hoskold.

B4.1. Newmont assets

Table B7. Newmont projects in the 50-asset sample.

Project	Prod koz	Res koz	MIex koz	Life yrs	RRH / Orig	MH / Orig
Brucejack	258	1,900	600	7.4	1.061	1.061
Red Chris	28	3,700	3,700	132.1	1.002	1.002
Peñasquito	299	4,100	1,600	13.7	1.052	1.121
Merian	205	4,100	2,200	20.0	1.052	1.113
Cerro Negro	238	3,200	500	13.4	1.022	1.085
Yanacocha	354	5,300	2,600	15.0	1.06	1.132
Pueblo Viejo	235	8,200	2,100	34.9	1.015	1.049
Boddington	590	10,800	4,200	18.3	1.042	1.108
Tanami	408	5,100	2,800	12.5	1.075	1.144
Cadia	464	14,100	14,500	30.4	1.058	1.088
Lihir	614	15,800	2,800	25.7	1.015	1.067
Ahafo	798	9,200	5,700	11.5	1.088	1.155
Nevada Gold Mines	400	17,900	8,500	44.7	1.019	1.038
Cripple Creek & Victor	146	2,400	800	16.4	1.039	1.109
Musselwhite	212	1,500	500	7.1	1.065	1.065
Porcupine	284	2,300	3,900	8.1	1.256	1.323
Éléonore	240	1,600	400	6.7	1.051	1.051
Akyem	204	900	1,200	4.4	1.284	1.284

B4.2. Agnico Eagle assets

Table B8. Agnico Eagle projects in the 50-asset sample.

Project	Prod koz	Res koz	MIex koz	Life yrs	RRH / Orig	MH / Orig
LaRonde	307	2,740	1,522	8.9	1.093	1.114
Canadian Malartic	656	7,497	3,232	11.4	1.064	1.123
Goldex	131	927	1,694	7.1	1.293	1.342
Detour Lake	672	19,051	15,793	28.4	1.054	1.090
Macassa	279	2,074	788	7.4	1.072	1.072
Meadowbank	505	1,609	1,277	3.2	1.198	1.198
Meliadine	379	3,365	1,714	8.9	1.086	1.101
Fosterville	225	1,650	1,527	7.3	1.164	1.164
Kittila	219	3,400	1,899	15.5	1.066	1.137

Project	Prod koz	Res koz	Mlex koz	Life yrs	RRH / Orig	MH / Orig
Pinos Altos	88	433	741	4.9	1.336	1.336

B4.3. Harmony assets

Table B9. Harmony projects in the 50-asset sample.

Project	Prod koz	Res koz	Mlex koz	Life yrs	RRH / Orig	MH / Orig
Moab Khotsong	212	3,521	4,188	16.6	1.117	1.183
Mponeng	281	4,503	8,402	16.0	1.168	1.230
Tshepong North	104	818	6,775	7.8	1.684	1.759
Tshepong South	101	660	5,779	6.6	1.809	1.904
Doornkop	112	1,887	3,971	16.9	1.173	1.228
Joel	56	436	1,242	7.8	1.383	1.474
Target 1	60	517	2,188	8.6	1.457	1.549
Kusasaletu	124	407	2,043	3.3	1.921	1.921
Masimong	57	130	752	2.3	2.203	2.203
Mine Waste Solutions	121	1,352	344	11.2	1.04	1.086
Kalgold	46	645	957	14.1	1.158	1.231
Phoenix	30	224	169	7.5	1.134	1.134
CPR	20	366	2	18.5	1.001	1.067
Savuka	20	126	268	6.4	1.348	1.390
Hidden Valley	164	869	1,135	5.3	1.258	1.258

B4.4. Kinross assets

Table B10. Kinross projects in the 50-asset sample.

Project	Prod koz	Res koz	Mlex koz	Life yrs	RRH / Orig	MH / Orig
Tasiast	622	4,705	2,365	7.6	1.093	1.093
Paracatu	529	4,887	3,165	9.2	1.105	1.141
La Coipa	246	642	1,366	2.6	1.513	1.513
Fort Knox + Manh Choh	377	2,073	843	5.5	1.087	1.087
Round Mountain	215	1,883	3,625	8.7	1.269	1.350
Bald Mountain	181	1,173	2,683	6.5	1.367	1.419

B4.5. Barrick assets

Table B11. Barrick projects in the 50-asset sample.

Project	Prod koz	Res koz	Mlex koz	Life yrs	RRH / Orig	MH / Orig
Hemlo	143	1,600	1,800	11.2	1.15	1.226