Investigating the impact of mineral royalty fiscal regime changes on the viability of Zambian copper mines

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Abstract

Zambia's mining industry has undergone various phases of mineral royalty changes since privatisation. Unlike many analyses that relied on subjective probability, this study employs the cut-off grade and mineral royalty model relationship to investigate how changes in mineral royalties impacted the net present value and cut-off grades of Zambian copper mines between 2008 and 2022. The results showed that net present value decreased by 10.39%, 6.13%, 9.69%, and 6.13% for Barrick Lumwana, Kansanshi, Nkana–Mopani Copper Mines, and Mufulira–Mopani Copper Mines, respectively, while First Quantum Minerals Trident's net present value increased by 3.40%. Reductions in NPV correspond to higher government revenue, whereas the increase for FQM Trident reduced government revenue. For cut-off grades, returns increased by 0.42%, 1.20%, and 0.42% for Barrick Lumwana, First Quantum Minerals' Trident, and Kansanshi, respectively, showing how portions of the Zambian copper orebodies accrued to investors, with a corresponding reduction in government revenue. Conversely, reductions of 0.24% and 0.38% for Nkana–Mopani Copper Mines and Mufulira–Mopani Copper Mines indicate that a share of the ore reserves accrued to the government, reducing investor returns. These findings demonstrate that mineral royalty adjustments redistribute economic value between investors and the government, affecting both profit margins and operational decisions. Despite these distributional effects, all projects remained economically viable. The findings underscore the need for an optimal mineral royalty framework that equitably balances the economic value of mineral resources between investors and the state.

Keywords

mineral royalty, cut-off grade, fiscal regime, impact, redistribution of economic value, Zambian copper orebodies

Introduction

Zambia's economy has long been anchored in copper mining (Sikamo, 2016; Unceta, 2021). Since independence, however, the country has struggled to establish a mineral royalty framework that supports both national development and a sustainable mining sector. Initially, mineral rights were held by two private conglomerates, Anglo-American Corporation (AAC) and Rhodesian Selection Trust (RST) Limited (Roan Consolidated Copper Mines Ltd, 1978). These companies controlled mining operations and brought in skilled labour from abroad. As a result, development was concentrated around the mines to sustain and retain the workforce, and the government had limited control over mineral benefits.

In 1971, Zambia acquired a 51% stake in AAC and RST, reorganising them into Nchanga Consolidated Copper Mines (NCCM) and Roan Consolidated Mines (RCM) Limited (Roan Consolidated Copper Mines Ltd, 1978). Later, in 1982, Zambia Consolidated Copper Mines (ZCCM) Limited was established through a merger of NCCM and RCM. This consolidated state control over the mining sector and allowed the country to derive broader benefits from its mineral resources (ZCCM-IH, 2023). Although nationalisation initially accelerated development funded directly from copper revenues, ZCCM became unprofitable during periods of low copper prices and high oil costs, slowing economic growth. After recapitalisation efforts failed, the government commenced the privatisation of ZCCM in 1995. Mineral royalties then became the main source of government revenue from mining.

Driven by public expectations due to rising copper prices, the Zambian citizens demanded a fair share of the country's mineral wealth. This led to multiple revisions of the mineral fiscal regime between 2008 and 2023 (Acheampong, 2019; The Editor, 2016, 2008). The government argued that the royalty adjustments balanced benefits between the state and investors. Investors, however, contended that high royalties reduced returns, making Zambia less attractive compared to other mining countries. Some analysts described the frequent royalty increases as “the tyranny of indecision” (Siwale, Chibuye, 2019).

To keep mining operations afloat, some companies, such as First Quantum Minerals (FQM), threatened to lay off 2,500 employees following the 2019 Mineral Royalty Fiscal Regime change (Diggers Reporter, 2018). The company argued that mineral royalties were no longer deductible for corporate income tax purposes, a policy not applied in other copper mining jurisdictions (Sipindu, 2018). Because increases in royalties often reduce mineral exploration (Castillo, 2021), Glencore Plc, Mopani’s parent company, signalled its intention to divest from Zambia. Additionally, FQM’s Kansanshi delayed its USD1 billion Sulphide Expansion and Life of Mine Extension project. These events have raised concerns that Zambia’s mineral royalty policy changes negatively affect investment.

Beyond Zambia, global debates on mineral royalties have centred on whether regimes should be profit-based or revenue-based. Profit-based systems allow mineral royalties to fluctuate with profitability, which investors view as fairer (Banda, Besa, 2016a, 2016b; Otto et al., 2006), but governments criticise as being vulnerable to tax avoidance through transfer pricing. Moreover, profit-based systems do not necessarily guarantee an optimal balance between state revenue and investor returns, as outcomes depend heavily on cost structures and accounting practices. By contrast, revenue-based systems, like those in Botswana and Australia, guarantee governments an immediate income stream even though these frameworks can reduce investor margins during low-price periods (Calder, 2014). Zambia’s adoption of a revenue-based approach places it closer to the latter model, but questions remain on whether this framework achieves a sustainable balance between state revenue and investor viability.

Notwithstanding these debates, analyses of the Zambian case have often been grounded in assumptions without data-backed assessment. No empirical study has confirmed whether royalty revisions increased government revenue or reduced investor returns. This study, therefore, assesses the impact of mineral royalty fiscal regime changes on the viability of mining the Zambian copper orebodies. The results aim to show that changes in mineral royalty do not often guarantee a stable, optimal framework.

Figure 1 shows the mineral royalty policy revisions, highlighting changes perceived as a threat to the sustainability of the mining sector.

Materials and methods

Data sources

This study utilised secondary data from publicly available Competent Persons’ Reports and financial annual reports prepared by mining companies, as well as government statistical reports on copper production, to analyse the impact of mineral royalty on the viability of mining Zambian copper deposits. The collected data included details on ore reserves, annual copper production, overall recoveries, dilution rates, capital expenditures, discount rates, mine life, operating costs, copper prices, and input parameters for determining the cut-off grades for Barrick Lumwana (Barrick Gold Corporation, 2022, 2021, 2020, 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011, 2010, 2009; Londono, Sanfurgo, 2014; Mining Technology, 2021), Trident Minerals Limited (Gray et al., 2015a), Kansanshi Mining Plc (Gray et al., 2020, 2015b) and the Nkana and Mufulira orebodies of Mopani Copper Mines (Golder Associates Africa (Pty) Ltd, 2011; Goncalves et al., 2018). The collated data are presented in Table 1.

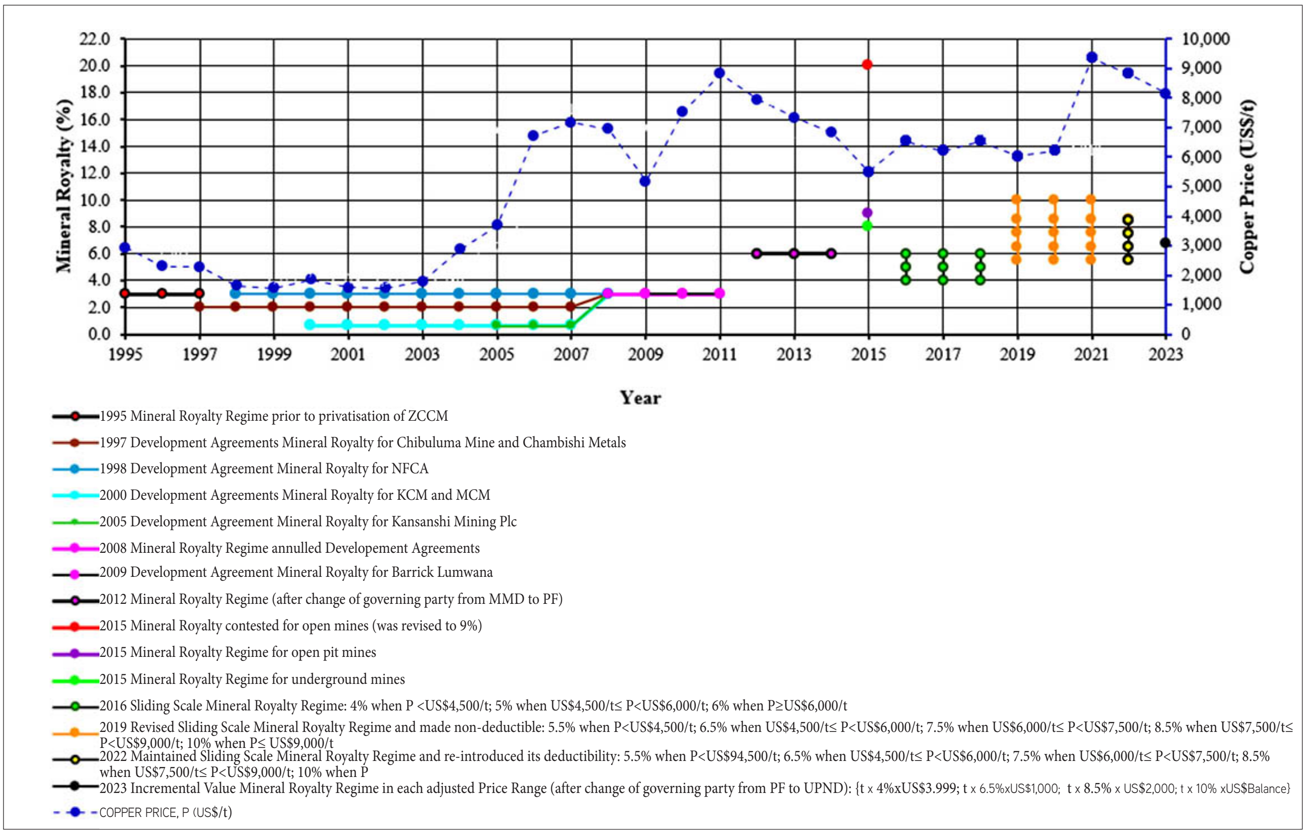

Figure 1—Fluctuating mineral royalty fiscal regime changes

Table 1

Cut-off grade and mining operating parameters

Input parameter	Zambian copper orebody				
	Lumwana	Trident	Kansanshi	Nkana	Mufulira
Mining cost per tonne of ore mined, M_o (USD/t)	3.73	1.97	2.87	28.71	67.55
Processing cost per tonne of ore processed, P_o (USD/t)	9.72	3.98	12.49	36.74	11.13
General & administrative costs per tonne of ore processed, $G\&A_o$ (USD/t)	3.50	4.71	9.15	4.94	3.39
Mining cost per tonne of waste, M_w (US$/t)	2.15	1.87	2.80	0.62	0.43
Processing cost per tonne of waste as necessary to avoid potential water contamination and to satisfy the applicable environmental requirements, P_w (USD/t)	2.75	0.25	6.25	0.15	6.95
G&A costs per tonne of waste processed, $G\&A_w$ (USD/t)	1.95	1.87	3.63	17.49	12.01
Copper price, PC_u for cut-off grade calculation (USD/t)	6,615	6,615	6,615	5,777	5,777
Cost of smelting, refining and freight, and other costs incurred, $COST_{SRF}$ (USD/t)	1,720	816	873	1,279	1,103
Ore reserves (million t)	538.75	960.7	939.6	94.1	29.02
Average ore grade (% TCu)	0.56	0.46	0.68	2.72	3.06
Overall recovery, r (%)	93.42	91	97	63	83
Dilution (%)	5	3	1.3	20	24
Capital expenditure, CAPEX (USDmillion)	833.8	1,900	1,754	1,246.9	380
Weighted average cost of capital, WACC (%)	12	8.5	10	10	10
Life of mine, LOM (years)	25	20	28	21	21

It is important to note that the copper price used in the cut-off grade calculations was based on a fixed benchmark price derived from the reports. In contrast, the discounted cash flow (DCF) analysis included actual and projected copper prices that varied annually throughout the life of each mining project. Similarly, the operating costs (including mining, processing, and general and administrative (G&A) costs) presented in Table 1 were primarily gathered for the cut-off grade estimations as base-case unit costs. These may not reflect the actual annual operating costs, which varied throughout the project life in the cash flow models. Thus, the information presented in this study synthesises data from various reports, ensuring consistency while acknowledging variations in financial assumptions across reporting periods for each Zambian copper deposit studied.

The changes to copper royalties for each mining deposit under exploitation are compiled in Table 2 as the primary variable in the cash flow analysis (Clifford Chance, 1997, 1998a, 1998b, 2000a, 2000b; National Assembly of Zambia, 2022, 2018, 2016, 2015, 2008).

Methods

This study utilised the cut-off grade and mineral royalty model relationship (COGMRMR) (Songolo et al., 2025) to assess the impact of the mineral royalty fiscal regime changes (MRFRC) on the net present value (NPV) and the cut-off grades (COG). The model is an integration of the opportunity cost due to mineral royalty ($OPPCOST_{MR}$) into the cut-off grade model. $OPPCOST_{MR}$ refers to the trade-off in which both the government and investors forego potential economic benefits to balance mineral royalty as compensation to the government with investor returns, thereby ensuring sustainable mining (Songolo et al., 2025). By allowing different MRFRCs to be applied in different years during the life of mine (LOM), the cash flow was discounted to determine the NPV (Equation 1).

$$NPV = \frac{CF_1}{(1+i)^1} + \frac{CF_2}{(1+i)^2} + \frac{CF_3}{(1+i)^3} + \cdots + \frac{CF_{t-1}}{(1+i)^{t-1}} + \frac{CF_t}{(1+i)^t} - \frac{CF_0}{(1+i)^0} \qquad [1]$$

Where, CF_1 to CF_t are the annual cash flows and CF_0 is the capital expenditure at the start of the project; t is the time value of money during the LOM; and i is the weighted average cost of capital (discount rate) applicable to specific Zambian copper orebodies being mined. In the cash flow, the depreciation was calculated using the unit of production method, while the depletion and amortisation were assumed to be zero. The unit-of-production method was preferred because the value of mining assets (such as the mine, processing plant, or equipment) is directly tied to the quantity of ore extracted rather than the passage of time alone. Unlike straight-line depreciation, which assumes assets lose value evenly each year, the unit-of-production method allocates depreciation in proportion to actual production, ensuring costs reflect resource extraction more accurately. Using Equation 1, the NPVs of all studied mines were simulated in Microsoft Excel under different mineral royalty regimes to evaluate the impact of fiscal changes on their financial viability. The simulations incorporated all relevant cash flow inputs, with key parameters including capital expenditures of USD833.8 million, USD1,900 million, USD1,754 million, USD1,246.9 million, and USD380 million; weighted average costs of capital of 12%, 8.5%, 10%, 10%, and 10%; and LOMs of 25, 20, 28, 21, and 21 years for Barrick Lumwana, FQM Trident, Kansanshi, Nkana–MCM, and Mufulira–MCM, respectively. Given the varying mineral royalty, the NPV changes from the initial value (NPV_0) to the new value (NPV_i). Consequently, the $OPPCOST_{MR}$ was in turn simulated as the ore reserve was being depleted by the ore mined each year. The opportunity cost for each year was calculated using the difference between the original and new net present values, divided by the remaining ore reserves, as presented by Equation 2:

$$OPPCOST_{MR} = \frac{(NPV_0 - NPV_i)}{(ore\ reserve - ore\ mined)} \qquad [2]$$

The integration of the $OPPCOST_{MR}$ into the COG model (Equation 3) creates a relationship between the mineral royalty and the COG (Songolo et al., 2025). Thus, the cut-off grade resulting from the mineral royalty policy changes *is given as*,

$$COG_{MR} = \frac{(((M_o + P_o + G\&A_o) + OPPCOST_{MR}) - (M_w + P_w + G\&A_w)) \times D_f}{r(P_{Cu} - COST_{SRF})} \qquad [3]$$

Table 2

Changes in mineral royalty fiscal regime applied to Zambian copper orebodies since commissioning.

YEAR	Nkana, MCM (%)	Mufulira, MCM (%)	FQM Kansanshi (%)	Barrick Lumwana (%)	FQM Trident (%)
2000	0.6	0.6			
2001	0.6	0.6			
2002	0.6	0.6			
2003	0.6	0.6			
2004	0.6	0.6			
2005	0.6	0.6	0.6		
2006	0.6	0.6	0.6		
2007	0.6	0.6	0.6		
2008	3.0	3.0	3.0		
2009	3.0	3.0	3.0	3.0	
2010	3.0	3.0	3.0	3.0	
2011	3.0	3.0	3.0	3.0	
2012	6.0	6.0	6.0	6.0	
2013	6.0	6.0	6.0	6.0	
2014	6.0	6.0	6.0	6.0	
2015	8.0	8.0	9.0	9.0	9.0
2016	5.0	5.0	5.0	5.0	5.0
2017	6.0	6.0	6.0	6.0	6.0
2018	6.0	6.0	6.0	6.0	6.0
2019	7.5	7.5	7.5	7.5	7.5
2020	7.5	7.5	7.5	7.5	7.5
2021	10.0	10.0	10.0	10.0	10.0
2022	8.5	8.5	8.5	8.5	8.5

Where, COG_{MR} is the cut-off grade resulting from the mineral royalty policy changes; M_o is the mining cost per tonne of ore mined; P_o is the processing cost per of tonne of ore processed; and $G\&A_o$ is the general and administrative (overhead) costs per tonne of ore processed; M_w is the mining cost per tonne of waste; P_w is the processing cost per tonne of waste as necessary to avoid potential water contamination and acid generation and to satisfy the applicable environmental requirements; and $G\&A_w$ is the general and administrative costs per tonne of waste processed; D_f is the dilution factor; r is the overall recovery from the ore mined; P_{Cu} is the price of copper per tonne sold; $COST_{SRF}$ is the cost of smelting, refining, freight, and other costs incurred per tonne of copper produced. Based on the data in Table 2, the $OPPCOST_{MR}$ for Barrick Lumwana in 2009 is calculated as:

$$OPPCOST_{MR} = \frac{(NPV_0 - NPV_i)}{(ore\ reserve\ - ore\ mined)}$$

$$\therefore OPPCOST_{2009} = \frac{(US\$1{,}209.9 - US\$1{,}209.9)}{(537.8\,t - 0)} = 0$$

Where $OPPCOST_{2009}$ is the opportunity cost resulting from the 3% mineral royalty in 2009 when copper production was commissioned. The corresponding cut-off grade was calculated using Equation 3:

$$COG_{MR} = \frac{\left[\left(\left((M_o + P_o + G\&A_o) + OPPCOST_{MR}\right) - (M_w + P_w + G\&A_w)\right) \times D_f\right]}{r(P_{Cu} - COST_{RS})}$$

$$\therefore COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + 0\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)}$$

$$\therefore COG_{MR} = 0.22583\%\ Cu$$

For 2012, when MR was adjusted to 6%:

$$OPPCOST_{2012} = \frac{(USD1{,}209.9 - USD1{,}121.0)}{(537.8\,t - 71.3\,t)} = \frac{88.9}{466.4} = USD0.19060/t$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + 0.19060\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)} = 0.23009\%\ Cu$$

For 2015, when MR was adjusted to 9%:

$$OPPCOST_{2015} = \frac{(USD1{,}121.0 - USD1{,}058.7)}{(466.4\,t - 56.6\,t)} = \frac{62.3}{409.8} = USD0.15208/t$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + 0.15208\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)} = 0.22923\%\ Cu$$

For 2016, when MR was adjusted to 5%:

$$OPPCOST_{2016} = \frac{(USD1{,}058.7 - USD1{,}132.7)}{(409.8\,t - 24.9\,t)} = \frac{-74.0}{384.9} = -USD0.19229$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + (-0.19229)\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)} = 0.22153\%\ Cu$$

For 2017, when MR was adjusted to 6%:

$$OPPCOST_{2017} = \frac{(USD1{,}132.7 - USD1{,}115.9)}{(384.9\,t - 23.5\,t)} = \frac{16.8}{361.4} = -USD0.04651/t$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73+9.72+3.50)+(0.04651)\right)-(2.15+2.75+1.95)\right)\times 1.05\right]}{0.93\times(6{,}615-1{,}720)} = 0.22687\%\ Cu$$

For 2019, when MR was adjusted to 9.5%:

$$OPPCOST_{2019} = \frac{(USD1{,}115.9 - USD1{,}095.7)}{(361.4\,t - 41.6\,t)} = \frac{20.2}{319.8} = -USD0.06329/t$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + 0.06329\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)} = 0.22725\%\ Cu$$

For 2021, when MR was adjusted to 10%:

$$OPPCOST_{2021} = \frac{(USD1{,}095.7 - USD1{,}068.7)}{(319.8\,t - 44.5\,t)} = \frac{27.0}{275.3} = -USD0.09796/t$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + 0.09796\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)} = 0.22802\%\ Cu$$

For 2022, when MR was adjusted to 8.5%:

$$OPPCOST_{2022} = \frac{(\text{US\$}1{,}068.7 - \text{US\$}1{,}082.4)}{(275.3\,\text{t} - 20.8\,\text{t})} = \frac{-13.7}{254.5} = -\text{US\$}0.05395/t$$

And therefore,

$$COG_{MR} = \frac{\left[\left(\left((3.73 + 9.72 + 3.50) + (-0.05395)\right) - (2.15 + 2.75 + 1.95)\right) \times 1.05\right]}{0.93 \times (6{,}615 - 1{,}720)} = 0.22462\%\ Cu$$

The calculated NPV, $OPPCOST_{MR}$, and COG for Barrick Lumwana are presented in Table 3.

Similar simulations were performed for the other four copper orebodies using Excel, and the resulting NPVs, $OPPCOST_{MR}$ and corresponding COGs are tabulated in Tables 4 – 7.

The simulated NPV and COG data presented in Tables 3 to 7 were plotted to demonstrate their sensitivity to the changes in mineral royalty policies introduced by the Zambian government (see Figures 2 – 11).

The impact of mineral royalty fiscal regime changes on the NPV and COG was analysed by computing percentage changes in both NPV and COG, using Equations 4 and 5, respectively.

$$\%_{NPV} = \frac{(NPV_{current} - NPV_{new})}{NPV_{current}} \times 100\% = \frac{(NPV_o - NPV_i)}{NPV_o} \times 100\% \qquad [4]$$

The corresponding percentage change in COG is:

$$\%_{COG} = \frac{(COG_{current} - COG_{new})}{COG_{current}} \times 100\% \qquad [5]$$

Considering the data in Table 3, the percentage changes in NPV and COG, arising from adjustments in MR, are determined as follows:

At the commissioning of copper production in 2009, when MR was 3%,

$$\%_{NPV} = \frac{(1{,}209.9 - 1{,}209.9)}{1{,}209.9} \times 100\% = 0\%$$

$$\%_{COG} = \frac{(0.22583 - 0.22583)}{0.22583} \times 100\% = 0\%$$

For 2012, when MR was adjusted to 6%:

$$\%_{NPV} = \frac{(1{,}209.9 - 1{,}121.0)}{1{,}209.9} \times 100\% = 7.35\%$$

$$\%_{COG} = \frac{(0.22583 - 0.23009)}{0.22583} \times 100\% = -1.89\%$$

For 2015, when MR was adjusted to 9%:

$$\%_{NPV} = \frac{(1{,}121.0 - 1{,}058.7)}{1{,}121.0} \times 100\% = 5.56\%$$

$$\%_{COG} = \frac{(0.23009 - 0.22923)}{0.23009} \times 100\% = 0.37\%$$

For 2016, when MR was adjusted to 5%:

$$\%_{NPV} = \frac{(1{,}058.7 - 1{,}132.7)}{1{,}058.7} \times 100\% = -6.99\%$$

$$\%_{COG} = \frac{(0.22923 - 0.22153)}{0.22923} \times 100\% = 3.36\%$$

For 2017, when MR was adjusted to 6%:

$$\%_{NPV} = \frac{(1{,}132.7 - 1{,}115.9)}{1{,}132.7} \times 100\% = 1.48\%$$

$$\%_{COG} = \frac{(0.22153 - 0.22687)}{0.22153} \times 100\% = -2.41\%$$

For 2019, when MR was adjusted to 9.5%:

$$\%_{NPV} = \frac{(1{,}115.9 - 1{,}095.7)}{1{,}115.9} \times 100\% = 1.81\%$$

$$\%_{COG} = \frac{(0.22687 - 0.22725)}{0.22687} \times 100\% = -0.17\%$$

Table 3

Simulated NPVs and cut-off grades resulting from MRFRCs for Lumwana copper orebodies

Year	MR (%)	NPVo (USD million)	NPVi (USD million)	NPVo – NPVi (USD million)	Ore Mined (million t)	Ore Reserve (million t)	$OPPCOST_{MR}$ (USD/t Cu Ore)	COG_{MR} (%)
2009	3.0	1,209.9	1,209.9	0	0	537.8	0.00000	0.22583
2012	6.0	1,209.9	1,121.0	88.9	71.3	466.4	0.19060	0.23009
2015	9.0	1,121.0	1,058.7	62.3	56.6	409.8	0.15208	0.22923
2016	5.0	1,058.7	1,132.7	–74.0	24.9	384.9	–0.19229	0.22153
2017	6.0	1,132.7	1,115.9	16.8	23.5	361.4	0.04651	0.22687
2019	7.5	1,115.9	1,095.7	20.2	41.6	319.8	0.06329	0.22725
2021	10.0	1,095.7	1,068.7	27.0	44.5	275.3	0.09796	0.22802
2022	8.5	1,068.7	1,082.4	–13.7	20.8	254.5	–0.05395	0.22462

Table 4

Simulated NPVs and cut-off grades resulting from MRFRCs for FQM Trident copper orebodies

Year	MR (%)	NPVo (USD million)	NPVi (USD million)	NPVo – NPVi (USD million)	Ore Mined (million t)	Ore Reserve (million t)	$OPPCOST_{MR}$ (USD/t Cu Ore)	COG_{MR} (%)
2015	9.0	3,681.4	3,681.4	0	0	960.7	0.00000	0.13018
2016	5.0	3,681.4	4,087.7	–406.3	14.3	946.4	–0.42934	0.12180
2017	6.0	4,087.7	3,990.2	97.4	36.4	910.0	0.10705	0.13227
2019	7.5	3,990.2	3,865.0	125.3	90.8	819.2	0.15295	0.13317
2021	10.0	3,865.0	3,691.4	173.6	63.2	756.0	0.22961	0.13467
2022	8.50	3,691.4	3,779	–87.6	64.4	691.6	–0.12667	0.12771

Table 5

Simulated NPVs and cut-off grades resulting from MRFRCs for Kansanshi copper orebodies

Year	MR (%)	NPVo (USD million)	NPVi (USD million)	NPVo – NPVi (USD million)	Ore Mined (million t)	Ore Reserve (million t)	OPPCOSTMR (USD/t Cu Ore)	COG_{MR} (%)
2005	3.0	3,964.2	3,964.2	0	0	939.6	0.00000	0.21195
2012	6.0	3,964.2	3,792.9	171.2	117.6	822.0	0.20832	0.21569
2015	9.0	3,792.9	3,675.6	117.3	93.7	728.3	0.16112	0.21484
2016	5.0	3,675.6	3,814.6	−139.0	34.1	694.2	−0.20019	0.20837
2017	6.0	3,814.6	3,782.6	32.0	31.7	662.5	0.04828	0.21282
2019	7.5	3,782.6	3,743.9	38.7	75.1	587.4	0.06588	0.21314
2021	10.0	3,743.9	3,690.5	53.4	70.7	516.7	0.10332	0.21381
2022	8.5	3,690.5	3,719.8	−29.3	35.1	481.5	−0.06081	0.21087

Table 6

Simulated NPVs and cut-off grades resulting from MRFRCs for Nkana copper orebodies, MCM

Year	MR (%)	NPVo (USD million)	NPVi (USD million)	NPVo – NPVi (USD million)	Ore Mined (million t)	Ore Reserve (million t)	OPPCOSTMR (USD/t Cu Ore)	COG_{MR} (%)
2001	0.6	652.5	652.5	0	0	94.1	0.00000	2.20744
2008	3.0	652.5	614.1	38.5	35.7	58.4	0.65810	2.23531
2012	6.0	614.1	593.1	20.9	19.1	39.3	0.53280	2.23000
2015	8.0	593.1	588.5	4.7	12.0	27.4	0.17016	2.21465
2016	5.0	588.5	593.4	−4.9	3.9	23.4	−0.21110	2.19850
2017	6.0	593.4	592.1	1.3	4.2	19.2	0.07013	2.21041
2019	7.5	592.1	591.3	0.8	8.9	10.3	0.07941	2.21080
2021	10.0	591.3	590.8	0.5	6.6	3.7	0.12326	2.21266

Table 7

Simulated NPVs and cut-off grades resulting from MRFRCs for Mufulira copper orebodies, MCM

Year	MR (%)	NPVo (USD million)	NPVi (USD million)	NPVo – NPVi (USD million)	Ore Mined (million t)	Ore Reserve (million t)	OPPCOSTMR (USD/t Cu Ore)	COG_{MR} (%)
2001	0.6	405.5	405.5	0	0	29.0	0.00000	2.00322
2008	3.0	405.5	389.7	15.8	13.0	16.0	0.98790	2.03479
2012	6.0	389.7	382.3	7.4	3.8	12.2	0.60979	2.02271
2015	8.0	382.3	380.4	1.9	2.0	10.2	0.18655	2.00918
2016	5.0	380.4	382.4	−2.1	0.8	9.4	−0.21834	1.99624
2017	6.0	382.4	381.8	0.7	1.3	8.1	0.08081	2.00580
2019	7.5	381.8	381.4	0.4	3.3	4.8	0.08585	2.00596
2021	10.0	381.4	381.1	0.3	3.4	1.4	0.21916	2.01022

For 2021, when MR was adjusted to 10%:

$$\%_{NPV} = \frac{(1{,}095.7 - 1{,}068.7)}{1{,}095.7} \times 100\% = 2.46\%$$

$$\%_{COG} = \frac{(0.22725 - 0.22802)}{0.22725} \times 100\% = -0.34\%$$

For 2022, when MR was adjusted to 8.5%:

$$\%_{NPV} = \frac{(1{,}068.7 - 1{,}082.4)}{1{,}068.7} \times 100\% = -1.28\%$$

$$\%_{COG} = \frac{(0.22802 - 0.22462)}{0.22802} \times 100\% = 1.49\%$$

The calculated percentage changes in NPV and COG for Barrick Lumwana formed a third data set, which was used to generate graphs showing the extent of the impact of different mineral royalty regimes on NPV and COG (Figures 12 and 18). The same procedure was applied to the remaining four mines, and the resulting percentage changes were used to generate graphs illustrating the impact of different mineral royalty regimes on their NPV (Figures 13 – 16) and COG (Figures 17 – 21). The overall impact of the mineral royalty on NPV and COG was evaluated by summing their percentage changes, as shown in Figures 22 and 23, respectively.

Results and discussion

Sensitivity of NPV to mineral royalty fiscal regime changes

Figures 2 – 6, based on data from Tables 3 – 8, illustrate the sensitivity of NPV to MR.

As shown in Figure 2, the net present value for Barrick Lumwana copper orebodies was affected by changes in the mineral

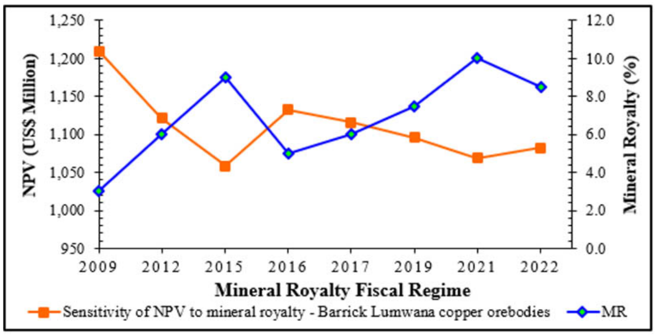

Figure 2—Negative linear relationship between mineral royalty and NPV for Lumwana copper orebodies

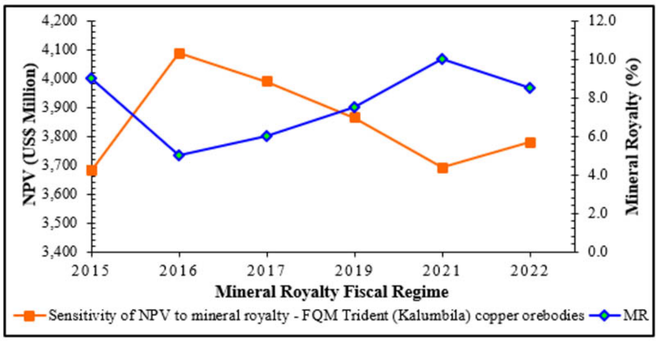

Figure 3—Negative linear relationship between mineral royalty and NPV for FQM Trident copper orebodies

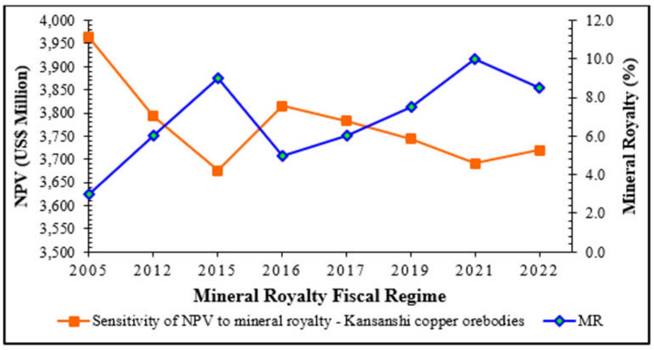

Figure 4—Negative linear relationship between mineral royalty and NPV for Kansanshi copper orebodies

royalty rate. Initially set at 3.0% at the time of commissioning in 2009, the NPV decreased when the mineral royalty was increased to 6.0% in 2012. Three years later, in 2015, the NPV declined further as the copper mineral royalty was raised to 9.0%.

In 2016, the government introduced a sliding scale for the mineral royalty, which reduced the copper mineral royalty to 5.0% when the copper price was USD4,875 per tonne. This change led to an increase in the estimated NPV. However, as copper prices rose to USD6,206 per tonne in 2017, USD6,036 per tonne in 2019, and USD9,359 per tonne in 2021, the mineral royalty also increased to 6%, 7.5%, and 10% in 2021, respectively, reflecting copper prices on the sliding scale. Subsequently, the NPV declined again, as depicted in Figure 2.

In 2022, the NPV increased as the mineral royalty decreased to 8.5% on a sliding scale, corresponding to a copper price of USD8,822 per tonne. Figure 2 illustrates that as MR increases the NPV correspondingly decreases, and vice versa; thus, a negative linear relationship between mineral royalty and NPV is evident. The zig-zag trend in the graphs shown in Figure 2 highlights the

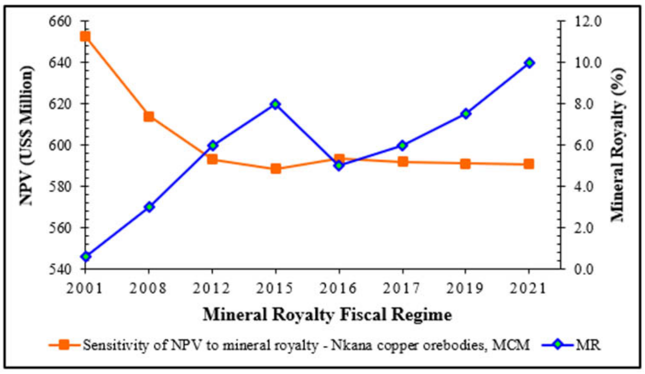

Figure 5—Negative linear relationship between mineral royalty and NPV for Nkana copper orebodies, MCM

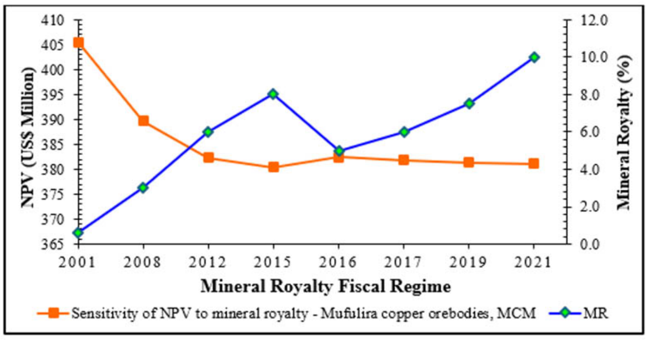

Figure 6—Negative linear relationship between mineral royalty and NPV for Mufulira copper orebodies, MCM

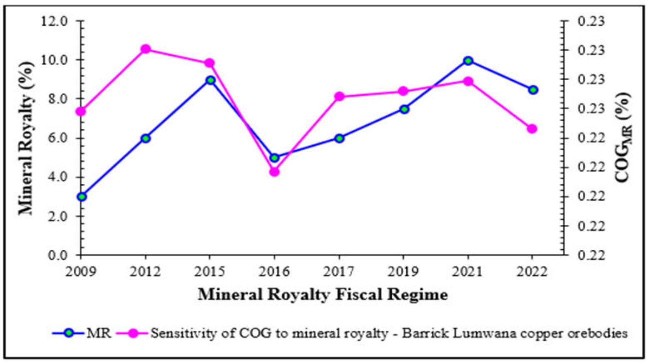

Figure 7—Positive linear relationship between mineral royalty and COG for Lumwana copper orebodies

unpredictability of the mineral royalty fiscal policy, which poses a potential threat to the mining industry in Zambia.

Similar to the Barrick Lumwana copper orebodies, a negative linear relationship between mineral royalty and NPV has been demonstrated again for the open pit deposits in Figures 3 and 4 for the FQM Trident, and Kansanshi copper orebodies, respectively.

This negative relationship between NPV and mineral royalty trends is further illustrated in Figures 5 and 6 for the Nkana and Mufulira underground copper orebodies. However, the slight variation in shape, compared to the open-pit deposits, may be attributed to the inherent ore deposit attributes and differing financial requirements associated with underground mining.

Sensitivity of COG to mineral royalty fiscal regime changes

To evaluate how the COG responds to the same changes in mineral royalty policy, the simulated COG data from Tables 3 to 7 were similarly graphed (Figures 7–11) using the same method applied for the NPV. Figure 7 shows that there is a corresponding increase in COG for Barrick Lumwana copper orebodies as MR increased from 3% in 2009 to 6% in 2012, 5% in 2016 to 6% in 2017, and to 7.5% in 2019 and further to 10% in 2021.

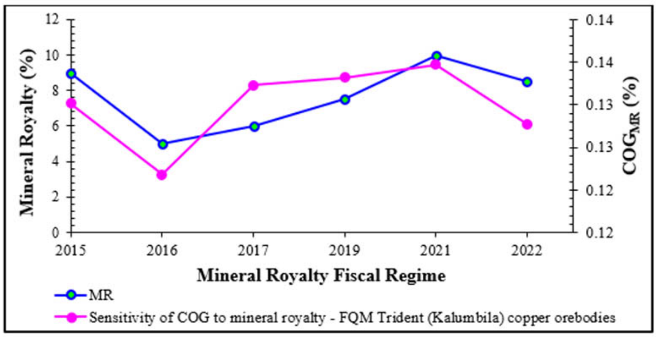

Figure 8—Positive linear relationship between mineral royalty and COG for FQM Trident copper orebodies

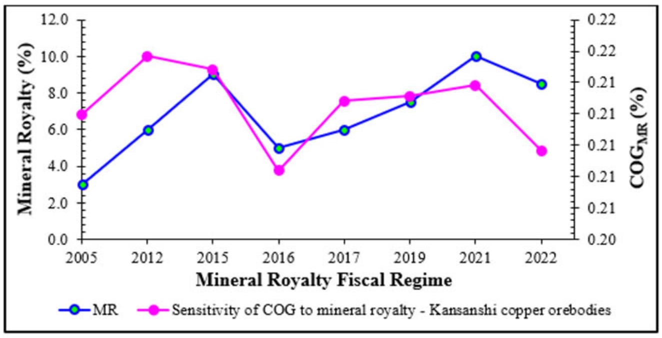

Figure 9—Positive linear relationship between mineral royalty and COG for Kansanshi copper orebodies

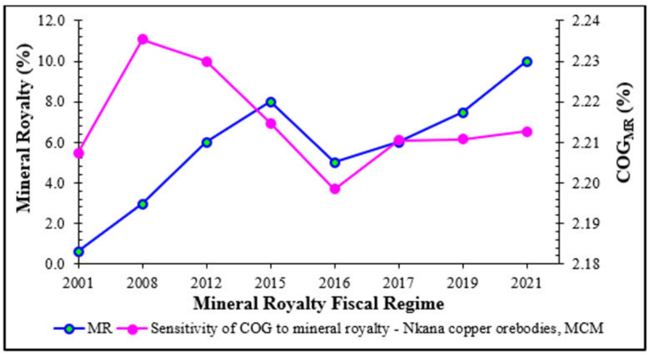

Figure 10—Positive linear relationship between mineral royalty and COG for Nkana copper orebodies, MCM

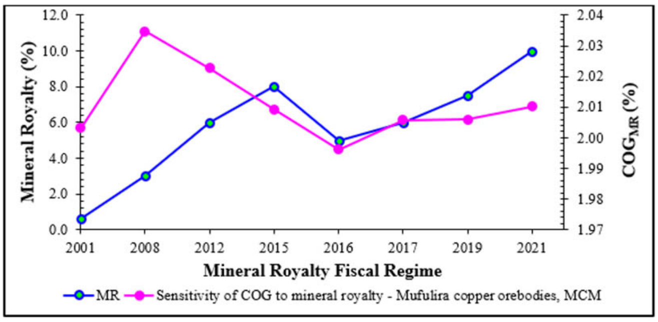

Figure 11—Positive linear relationship between mineral royalty and COG for Mufulira copper orebodies, MCM

The sensitivity of the COG to MR further shows a corresponding decrease in COG as MR reduced from 9% in 2015 to 5% in 2016, and from 10% in 2021 to 8.5% in 2022. This is despite the COG decreasing from 0.23% Cu to 0.22% Cu as the MR increased from 6% to 9% in 2012 and 2015, respectively, due to the price of copper that plummeted from USD7,943/t to USD5,502/t during the same period. The responsiveness of the COG to the MR for FQM Trident copper orebodies (Figure 8), depicted decreasing COG as MR decreased from 9% in 2015 to 5% in 2016, and 10% in 2021 to 8.5% in 2021. Similarly, there was an increase in COG as MR increased consecutively from 5% to 6%, 7.5%. and 10% on the sliding scale from 2016 to 2021.

A similar trend was observed in the FQM Trident copper orebodies (Figure 8), Kansanshi copper orebodies (Figure 9), Nkana copper orebodies (Figure 10), and Mufulira copper orebodies (Figure 11), as was the case with Barrick Lumwana copper orebodies (Figure 7). Interestingly, unlike the relationship between the MR and NPV, there is a positive linear relationship between the COG and the MR, as illustrated in Figures 7 through to 11.

Extent of the impact of mineral royalty fiscal regime changes on NPV

The extent of the impact of the mineral royalty rate on the net present value is reflected by the percentage change in NPV, as shown in Figure 12, for Barrick Lumwana copper orebodies. Following an increase in the mineral royalty rate to 6% in 2012, the NPV reduced significantly by 7.35%. Additionally, the figure indicates that a subsequent increase in the copper mineral royalty to 9% in 2015 resulted in an additional decrease in NPV of 5.56%.

Conversely, a reduction in the copper mineral royalty from 9% in 2015 to 5% in 2016 resulted in a −6.99% change in NPV. This occurred despite the copper price falling from USD5,502/t in 2015 to USD4,875/t in 2016. The positive and negative percentage changes in NPV have important implications for the investor. The positive percentage change indicates a loss to the investor, and a corresponding gain to the mineral resource owner. On the other hand, a negative percentage change in NPV represents a gain to the investor, and a corresponding loss to the mineral resource owner. This is because the sensitivity of the NPV to the mineral royalty reflects a negative linear relationship between the two components. In 2017, a 1.48% loss in NPV was the result of the mineral royalty, which automatically increased to 6% on the sliding scale in response to the copper price of USD6,206/t. Despite the commodity price declining from USD6,206/t in 2017 to USD6,036/t in 2019, a mineral royalty of 7.5% on the sliding scale, yielded a reduction of 1.81% in NPV. Note that the initial (old) sliding scale's lower and

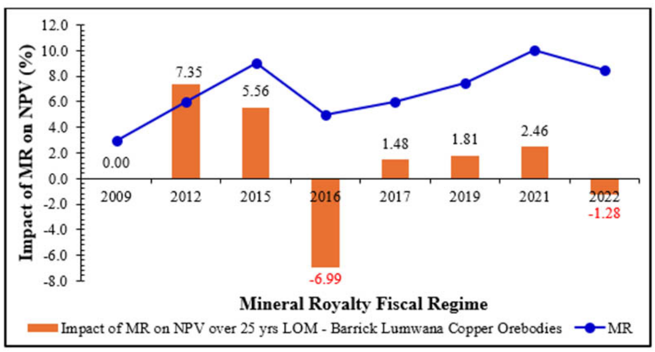

Figure 12—Impact of MRFRCs on NPV for Barrick Lumwana copper orebodies

upper bounds were 4% and 6%, whereas the later (new) sliding scale's lower and upper bounds were 5.5% and 10%, respectively. When the lower and upper mineral royalty bounds were adjusted upwards, the mineral royalty of 7.5% corresponding to the copper price of USD6,036/t further reduced the NPV by 1.81% in 2019. Commensurate with the increase in the price of copper to USD9,359/t, the mineral royalty on the sliding scale increased to 10%, recording a loss of 2.46% in NPV in 2021. The investor recorded a gain of −1.28% in NPV when the mineral royalty was by default reduced to 8.5%, being responsive to the commodity price of USD8,822/t in 2022. The net extent of the impact of the mineral royalty on the NPV was 10.39%. This reduction in NPV, however, did not drive the NPV below zero.

Figure 13 illustrates the degree of impact of the mineral royalty fiscal regime policy changes on the NPV generated from the exploitation of the FQM Trident copper orebodies. While mineral royalty changes of 6%, 7.5%, and 10% impacted the NPV by 2.38%, 3.14%, and 4.49% in 2017, 2019 and 2021, respectively, the mineral royalty changes of 5% and 8.5% in 2016 and 2022, respectively, offset the loss in NPV by −11.04% and −2.37% in 2022, respectively.

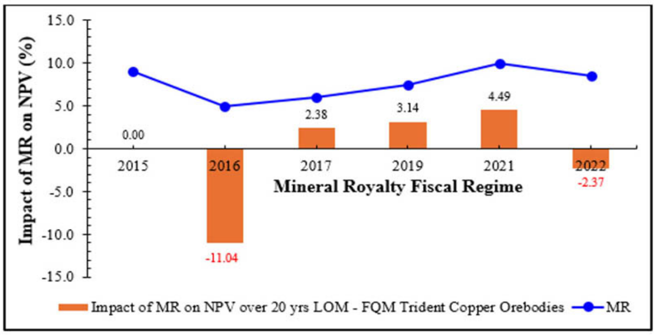

Figure 13—Impact of MRFRCs on NPV for FQM Trident copper orebodies

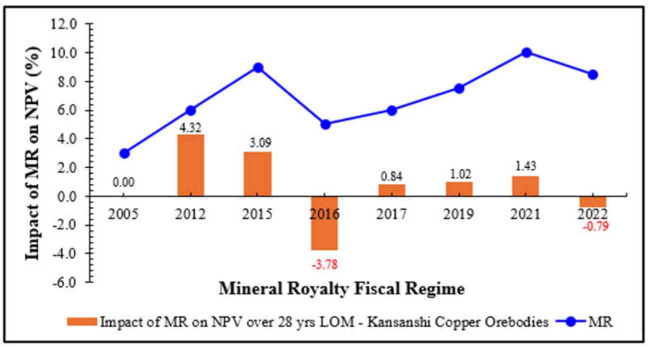

Figure 14—Impact of MRFRCs on NPV for Kansanshi copper orebodies

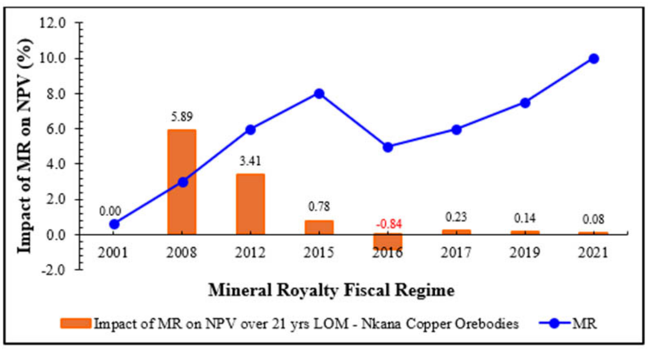

Figure 15—Impact of MRFRCs on NPV for Nkana copper orebodies, MCM

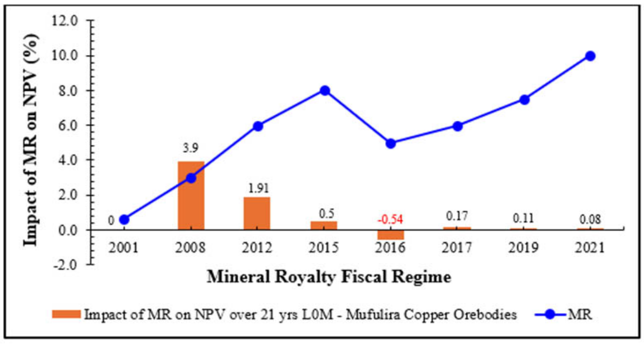

Figure 16—Impact of MRFRCs on NPV for Mufulira copper orebodies, MCM

The net extent of the impact of the mineral royalty on the NPV was, thus, −3.4%. Unlike Barrick Lumwana, where there was a reduction in NPV, FQM Trident benefited from the mineral royalty fiscal regime changes imposed by the government.

Figure 14 depicts the impact of mineral royalty changes on the NPV generated from exploiting the Kansanshi copper orebodies. Like Figures 12 and 13, Figure 14 reflects an increase in NPV by −3.78% and −0.79% in 2016 and 2022, respectively. This pattern has further demonstrated that the mineral royalty policy reviews effected by the Zambian government in 2016 and 2022 benefited the mining sector. The trend across the years 2012, 2015, 2017, 2019, and 2021 was marked by a reduction in NPV by 4.32%, 3.09%, 0.84%, 1.02%, and 1.43%, respectively. The net impact of the mineral royalty was a decline in the project's NPV by 6.13%. The study revealed that, despite the reduction in NPV, the net impact was not severe enough to render the project unviable, as the NPV remained positive.

Considering the individual trends depicted in Figures 12 to 16, the net changes in NPV for the five deposits have been summarised in Figure 17.

Extent of the impact of mineral royalty fiscal regime changes on COG

The analysis of the impact of the mineral royalty on the cut-off grade reveals a positive linear relationship between these two components. The results of this evaluation are illustrated in Figures 18, 19, 20, 21, and 22.

Figure 18 exhibits the COG trend change for Barrick Lumwana copper orebodies, from which a net change of 0.41% was derived. From the trend shown in Figure 19, FQM Trident copper orebodies record a net change of 1.2% in COG.

A net COG change of 0.42% is derived from the trend illustrated in Figure 20 for Kansanshi copper orebodies.

As depicted in Figure 21, Nkana copper orebodies show COG movements that result in a net change of −0.24%.

Similarly, Figure 22 for Mufulira copper orebodies indicate an overall net change of −0.38% in COG.

Figure 23 presents the cumulative net percentage COG changes for the five Zambian copper orebodies.

The positive and negative percentage changes in the cut-off grade have important economic implications for mineral investors and resource owners. A negative percentage change in COG indicates a loss for investors and a corresponding gain for the government. In traditional mining, such changes involve reclassifying materials as ore or waste, affecting reserve sizes. While the traditional perspective associates upward adjustment of mineral royalties with leaving a portion of the reserves unmined, the focus

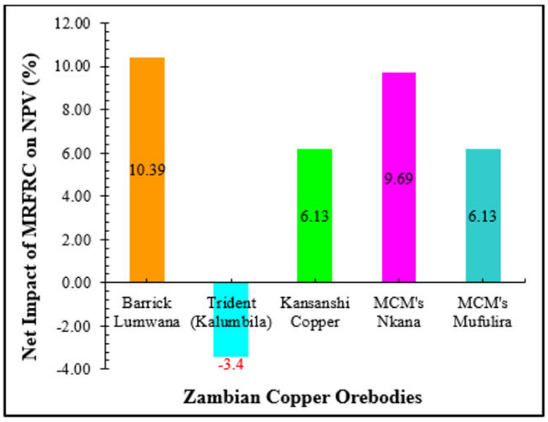

Figure 17 Net impact of MRFRCs on NPV for Zambian copper orebodies

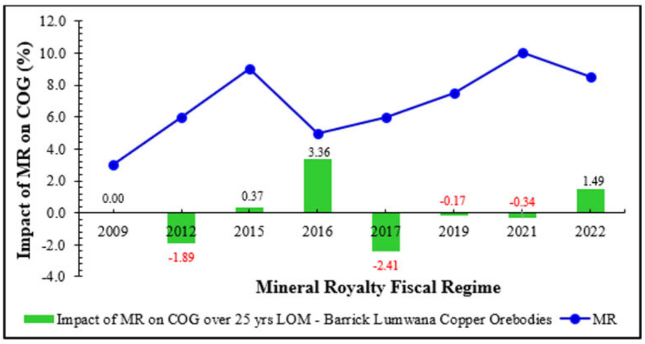

Figure 18—Impact of MRFRCs on COG for Barrick Lumwana copper orebodies

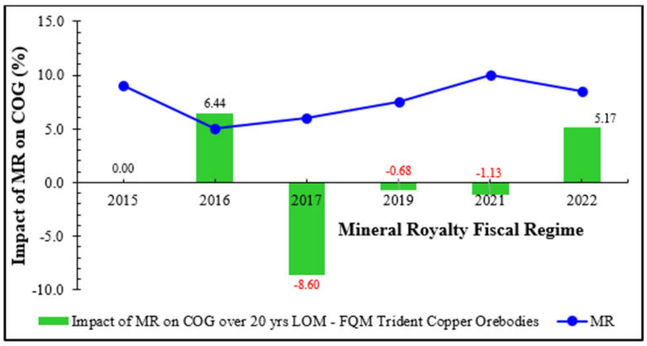

Figure 19—Impact of MRFRCs on COG for FQM Trident copper orebodies

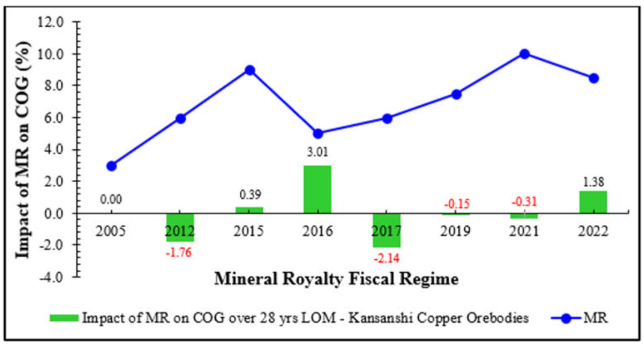

Figure 20—Impact of MRFRCs on COG for Kansanshi copper orebodies

should instead be on ensuring fair economic benefit distribution. Mine planners should view mineral royalties as tools for equitable value distribution between investors and the government. Thus, when the Zambian government increased royalties, the goal was

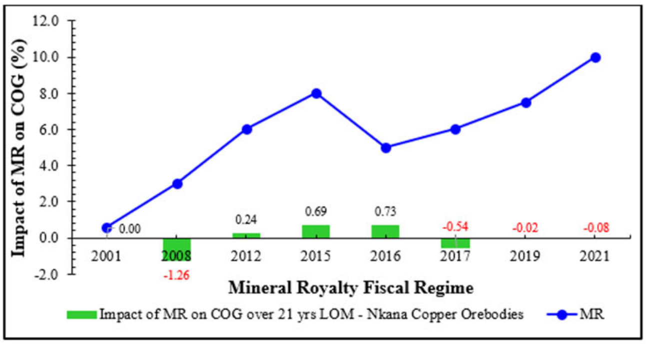

Figure 21—Impact of MRFRCs on COG for Nkana copper orebodies, MCM

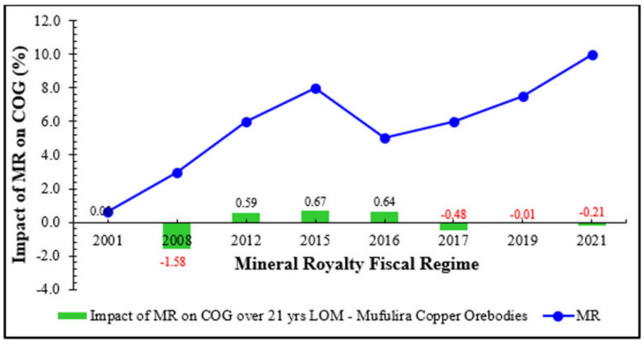

Figure 22—Impact of MRFRCs on COG for Mufulira copper orebodies, MCM

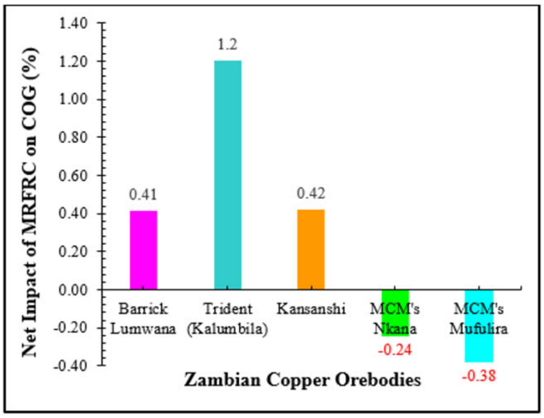

Figure 23—Net impact of MRFRCs on COG for Zambian copper orebodies

not to change physical reserves but to redistribute the economic value from investors to the government. During privatisation, the government prioritised attracting investment and job maintenance over equitable resource distribution. Lowering royalty rates shifts economic returns away from the government to investors. Thus, a positive change in COG suggests a policy favouring investors, while a negative change indicates the government is capturing more value for public development. This relationship highlights the importance of mineral royalties in balancing interests in the mining sector.

Conclusion

This study provides empirical evidence using the COGMRMR to clarify Zambia's royalty policy, moving beyond assumption-driven narratives. The analysis revealed a 10.39% reduction in NPV for Barrick Lumwana, a 3.4% increase for FQM Trident, and reductions of 6.13%, 9.69%, and 6.13% for Kansanshi, Nkana, and Mufulira copper orebodies, respectively. For COG, Barrick Lumwana, FQM Trident, and Kansanshi recorded slight increases of 0.41%, 1.2%, and 0.42%, while Nkana and Mufulira saw small decreases of 0.24% and 0.38%, reflecting the redistribution of investor gains and losses. The COGMRMR results demonstrate how mineral royalty adjustments redistribute economic value between investors and the government, affecting both profit margins and operational decisions. While investor returns reduced in most cases, all projects remain economically viable. This underscores the need for a royalty framework that is evidence-based, balanced, and aligned with the actual economic realities of the Zambian copper sector.

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