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Research Brief

Addressing Uncertainty in the Joint Production of Energy Transition Metals

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An efficient and resilient supply of critical raw materials such as copper, cobalt, and nickel is essential to ensure supply chain stability and advance energy transition goals. Drawing on data from 114 mining projects worldwide and employing an economic model of joint metal production, this study uses Monte Carlo simulations to assess how cost, technology, and policy factors drive fluctuations in marginal cost of metal production, ore demand, and waste management.

The global shift towards clean energy and decarbonization has led to a significant increase in demand for critical raw materials such as copper, cobalt, and nickel. These metals are essential components of energy transition technologies, including batteries, electric vehicles, and renewable energy infrastructure. However, their production is subject to significant uncertainties related to costs, market demand, regulatory policies, and technological developments, that make planning and investment decisions more complex. Unexpected cost increases can affect how companies allocate resources, while shifting environmental policies can influence decisions about waste management and sustainability efforts[1]. In addition, metal prices can be highly volatile, with fluctuations leading to significant increases in the cost of producing clean energy technologies. Some estimates suggest that metal price changes alone could raise the costs of renewable energy production by 13% to 41%, making it more difficult to meet sustainability goals[2]. These price shifts often stem from uncertainties in mining and supply chains, which can delay investments as companies struggle to predict future profitability. Moreover, the rapid pace of technological change in mineral extraction and processing adds another layer of uncertainty. Environmental regulations further complicate the picture, as governments introduce new policies on waste management and ecological restoration that affect mining operations.

While recent studies[3] have explored how market uncertainties affect green investments, there is still limited understanding of what drives fluctuations in metal production costs, ore extraction, and waste management. These challenges become even more complex when multiple metals are extracted from the same ore at a single mining site. When two or more metals are produced together, changes in the market conditions, costs, or regulatory policies for one metal can have ripple effects on the production and cost structure of all co-produced metals. These interdependencies introduce operational complexities and amplify uncertainties in investment and production decisions. This is particularly true for critical minerals such as cobalt, which face greater technological uncertainties compared to base metals like copper.

Although there is increasing research on the demand for energy transition metals, few studies have examined how technical, economic, and policy factors interact to shape production costs and environmental outcomes, particularly in cases where multiple metals are produced from a single ore. In addition, the relationships between primary and secondary metals in joint production remain poorly understood. This study aims to fill that gap by introducing an economic model that accounts for multiple sources of uncertainty in joint metal production, i.e., cost parameters, total factor productivity, output elasticity, waste intensity, and regulatory fees.

To understand the dynamics behind the variations of costs and ore processed, we analyze data from 114 mining projects worldwide. These empirical insights are then used to develop an economic optimization model of joint metal production, which is described graphically in Figure 1. The model analyzes the effects of key parameters, i.e., cost, technical (technology, output elasticity, waste intensity) and policy parameters (waste regulation fees), on the marginal costs of metal production, the volume of ore processed, and the percentage of waste managed. Finally, we apply Monte Carlo simulations to visualize the variation in model outputs and identify key factors contributing to this variability. Through this comprehensive approach, our work aims to clarify the complex dynamics that affect joint metal production, offering valuable insights for stakeholders in the mining sector.

The analysis reveals several critical insights regarding the cost dynamics of joint metal production.

- First, marginal production costs are most sensitive to output elasticity rather than waste intensities or fees. This suggests that improving production efficiency through technological advancements can significantly reduce costs.

- Second, ore demand is driven primarily by output elasticity, waste fees, and processing costs, rather than total factor productivity alone. This highlights the importance of regulatory policies and technological innovations in shaping ore extraction decisions.

- Third, the proportion of waste managed is more responsive to waste fees and abatement costs than to production parameters, underscoring the role of regulatory frameworks in driving environmental outcomes.

These results suggest that improving production parameters can significantly enhance the economic viability of joint metal production by lowering marginal costs. This also emphasizes the need for mining firms to prioritize investments in technology and innovations to better navigate

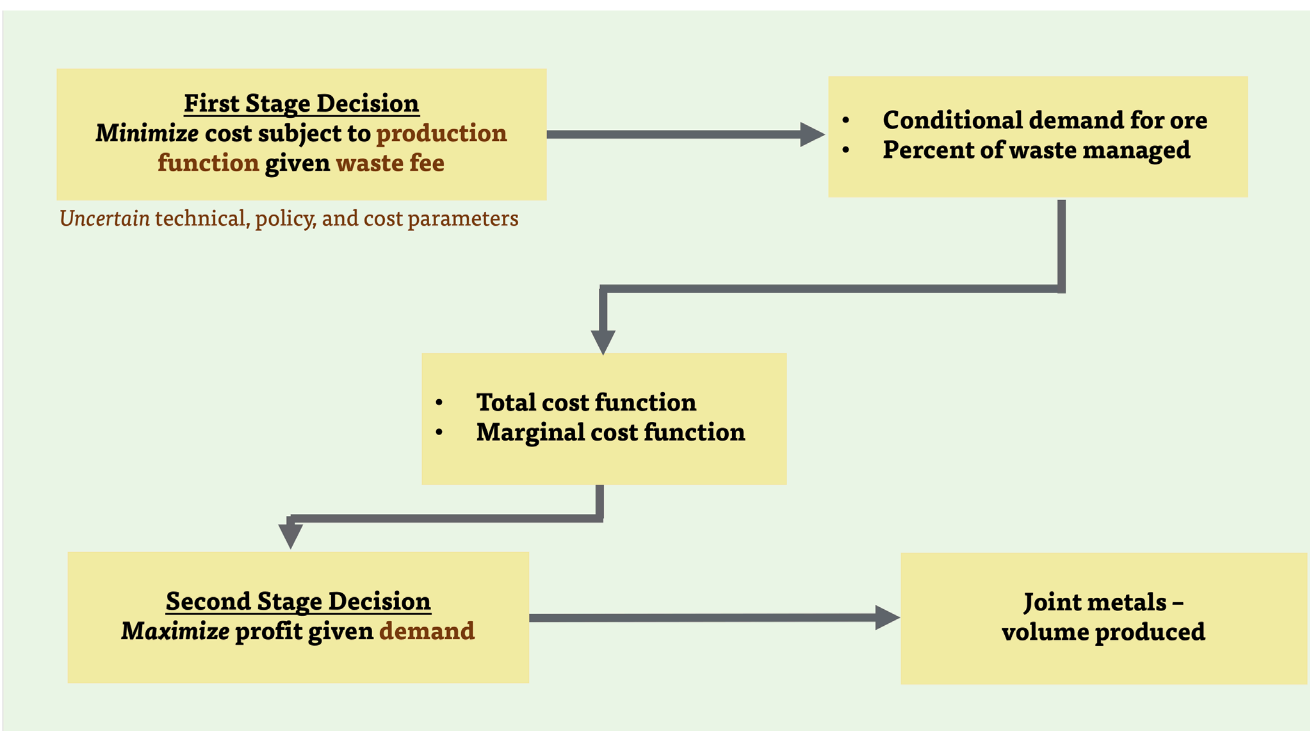

Figure 1: Double optimization framework used in the working paper.

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uncertainties and improve overall production outcomes in the rapidly evolving landscape of energy transition metals. Finally, the fact that the percentage of waste managed is more sensitive to the waste fee than to cost and production parameters underscores the need for ongoing investment in technological advancements and robust environmental policy frameworks to optimize production while minimizing environmental impacts.

References

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Link to the full working paper discussed in this brief:

Fikru, M.G., Ohler A., and Romani I.G. (2025), "Addressing Uncertainty in the Joint Production of Energy Transition Metals," MIT CEEPR Working Paper 2025-07, April 2025.

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