***Switch from fossil fuels to renewables requires battery metals – How should government intervention be designed?***

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## Overview

Increasing demand for materials required in the low-carbon technologies and infrastructure may signal significant changes for the minerals and metals market. A major concern is that extraction of key materials may exacerbate the social and environmental risks associated with the mining industry. This is pronounced in the case of government regulation of mining companies, which often operate in remote, sparsely populated areas where policy makers are keen on spurring development and employment opportunities. Here, we investigate resource policy intervention and regulation needed in the new operating environment where the impacts of commodity price volatility, the adoption of new technologies and environmental risks affecting the profitability of mines must be considered.

Our concern is that environmental regulation is not fully integrated with regards the expected growth of mining sector. When mitigating the risks, government may consider intervention to prevent the mining firm from a bankruptcy and, ultimately, avoiding abandonment of the mine without responsibility of cleanup. Policies such as royalties to compensate for extraction of nonrenewable natural resources and fines to prevent and compensate for environmental hazards are equally important to consider. From a social point of view, a fully financed strategy for mine closure in an environmentally sound way and post-closure monitoring is essential part of regulation of mines.

Our contribution is to carry out simulations where uncertainty and policy instruments to correct for externalities and optimal pricing of the resource are considered. First, as technology adoption is learning by doing, we take into account a learning period when the new technology is still tested by initiating the mining operations at full scale. Uncertainty about technology and learning prolong the time required for reaching the planned, stable production level. Hence, learning curve is captured by the amount of ore extracted and development of salable output. Second, we take explicitly into account the price development which may initially trigger adoption of uncertain technology. Price uncertainty, or the volatility of the world market commodity prices, affects the profitability of the mine during the whole time span of the mine from opening to closure. There are several reasons for price fluctuations, e.g., shocks to production and technology (supply) and unexpected changes in business cycle and expectations about future shortfalls of supply and inventories (demand). Since metals and minerals industries are capital intensive, adjusting extractive capacity and production to prevailing prices may be inelastic, and changes in demand will be resolved with price changes rather than quantity changes. Third, because of environmental accidents, government has to obtain knowledge on whether to intervene with available policy instruments to pursue targets for sustainable mining or whether to close the mine permanently because of financial or environmental concerns.

## Methods

We elaborate a profit-maximization problem of a prototype mine affected by risks and ucertainties. Our modelling tackles not only the uncertainty of prices but also technology and environmental risks as they affect the profitability of a metal mine during its very long lifespan from opening to closure. Specifically, we model price volatility and distinguish in our simulations that both jumps and regime shifts occur regularly in metal prices, as has been observed in the past. Furthermore, adoption of new technology is learning by doing, and learning prolongs the time required for reaching a mine’s planned, stable production level. We also incorporate in the model random variation in discharges of effluents into the environment and probabilities of environmental accidents, and investigate the impact of these considerations on a firm’s and government’s decisions.

The parameters underlying our simulations reflect stylized features of a multi-metal mine extracting nickel and zinc. These metals are important in the switch from fossil fuels to renewable inputs in generation of electricity as the changing energy system requires storage capacity. One of the issues is whether the key base metals, including nickel and zinc, contribute to a low carbon energy shift or constraint the growth of clean technology over the century. For illustration of challenges in learning a new mining technology, we use quantities having been extracted in a representative mine that adopts heap leaching technology with biological activation. The process produces both leached ore residue and chemical precipitates from the recovery plant. Exceptionally high precipitation or other unfavorable weather conditions can lead to a major leakage. Both constant flows of effluents and sudden environmental accidents are included and parameterized in our model calibration. Depending on the magnitude of leakage, the production is interrupted or suspended.

## Results

Given our parameter values based on the prototype mine, metal markets and experiences with an unconventional (heap leaching) technology we show that metal (nickel and zinc) extraction is unprofitable. Only when operating costs are rather low or metal prices are initially higher than the historical average prices does it pay off to continue mining activities.

Furthermore, we investigate alternative government resource policy interventions by introducing an ad valorem tax on output, a mining-industry-specific excess corporate tax rate and a royalty on the amount of ore extracted. Comparison of the instruments show that an excess corporate tax rate on mining (i.e., in addition to a normal corporate tax rate) generates the highest profits for the firm. The difference compared to the other two resource policy instruments, an ad valorem tax and royalty, becomes slightly more pronounced when production increases. This is the most favorable policy instrument for the mining firm as it is taxed only when it makes a profit. However, as the corporate income tax rate is subject to international tax competition, it may not be the most favorable instrument from the point of view of the government or policy makers. This may also explain why royalties are favored by governments. They generate tax revenues from resource firms as soon as production begins.

What is an appropriate rent from a nonrenewable resource stock is, of course, a political decision per se, but given the revenue to be collected for the government, our results are helpful in determining the levels for alternative resource policy instruments. On the other hand, when the goal is to generate a sum of money that compensates the government for the environmental damages caused by a mine, the revenue target can be used as a constraint when simulating the levels of alternative environmental policy instruments, these being a Pigou tax on effluents, fines for environmental accidents, a mandatory up-front payment to an environmental liability fund and a financial surety to cover closure and reclamation costs.

Most interestingly, the Pigou tax generates the highest expected compensation in terms of net present value. In addition, as it is proportional to the amount of the resource extracted, the revenue is similarly distributed to that from the royalty. Hence, environmental and resource policy instruments (here: Pigou tax and royalty) may resemble each other because of the same tax base and expected revenues while initially designed to address different types of market failures. In contrast, the fine is paid only when an accident occurs, and a low probability generates the lowest expected revenues for the government. However, the most serious concern with ex post fines is that firms can declare bankruptcy and escape their liabilities. Moreover, the up-front liability payment emphasizes a collective liability of the industry when the probability of accident is exogenous whereas a surety bond can be tailored for an individual mine to achieve social efficiency.

## Conclusions

Adopting a new technology to bring nonrenewable resources with relatively poor ore content into production is challenging and may turn out to be unprofitable. Because of the potentially extensive social costs generated by mining, governments should carefully consider the soundness of policies that support mining operations for reasons related solely to regional development or employment. In situ value and externalities play an important role from a social point of view and they should be considered in policy design globally as well. Climate policy – with a focus on greenhouse gases – should be aligned with resource policies to avoid the problem that regulating one pollutant induces technological change that may transform pollution to another form of waste that is not regulated. When considering fiscal reforms and intervention through resource and environmental policy instruments, holistic assessments should be carried out making use of mine fiscal models. This is particularly important for resource-rich, developing economies building up institutions for taxation and environmental regulation.

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