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

Anni Huhtala and Olli Ropponen

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VALTION TALOUDELLINEN TUTKIMUSKESKUS
STATENS EKONOMISKA FORSKNINGSCENTRAL
VATT INSTITUTE FOR ECONOMIC RESEARCH

Motivation

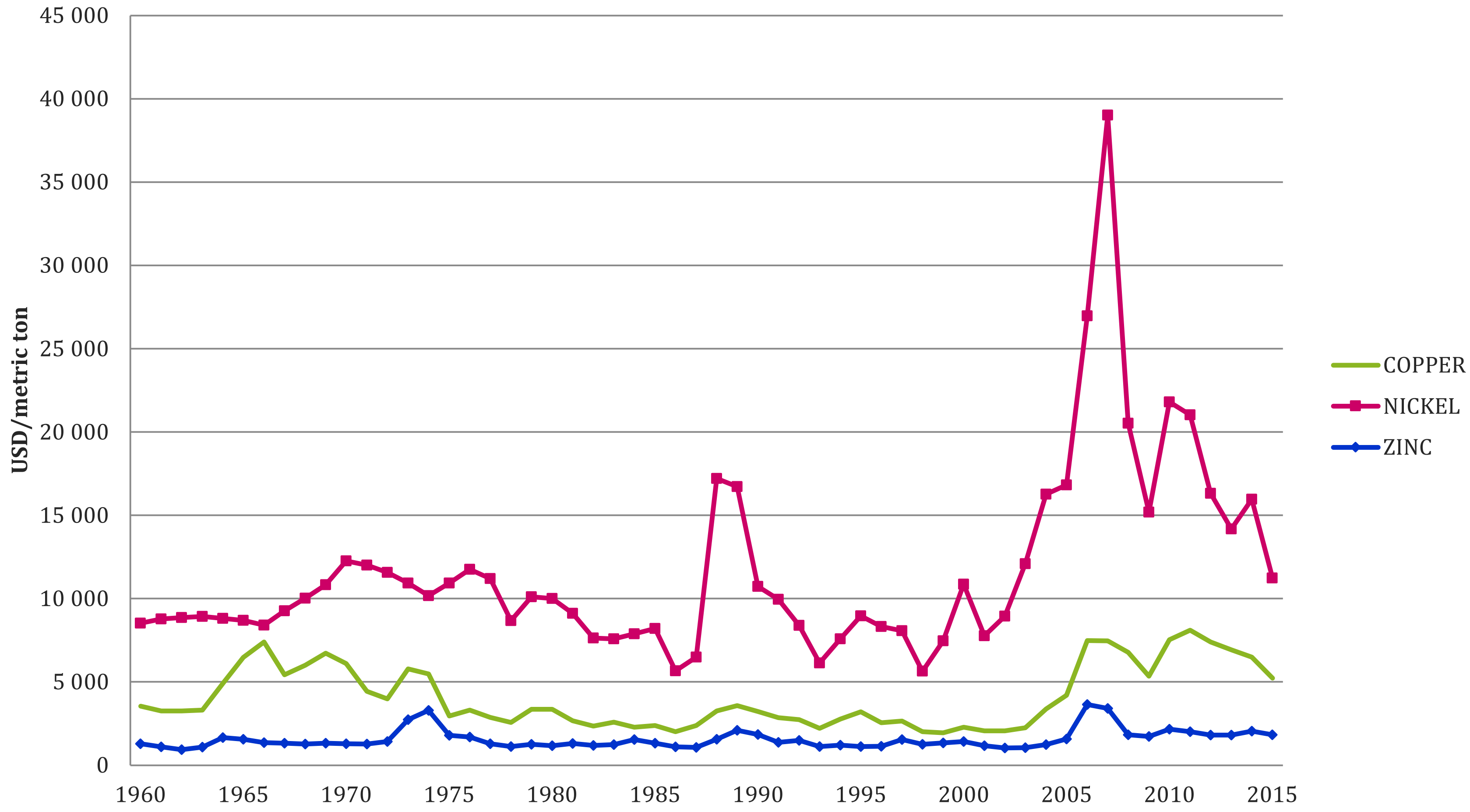
- Growing demand for materials required in the construction of renewable technologies and zero emission infrastructure has potentially significant changes for the minerals and metals market.
- Increasing demand for the key materials may amplify the social and environmental risks associated with the mining industry.

➔ Regulation/policy intervention needed?

1. (New) mining/ extraction technologies

2. with environmental impacts

3. Price volatility: Annual prices (real 2010 USD)



Mining firm and extraction of non-renewable resource

Relevant previous literature

- Deterministic models on extraction; scarcity
  - Hotelling 1931, Kemp and Long 1980
- Stochastic dynamic optimization models; uncertainty
  - Brennan and Schwarz 1985, Mason 2001,
  - Kellogg 2014, Muehlenbachs 2015, Insley 2015
- Taxation of non-renewable resources; resource and environmental policy instruments
  - Hartwick 1977, Dasgupta & Heal 1979, Gaudet and Lasserre 2015, Lund 2009

Our contribution

Profit maximization problem of a mine operating under uncertainty related *simultaneously* to

1) world market prices of metals
2) production technology
3) environmental impacts: water pollution (sulfate) and risk for large-scale environmental accident.

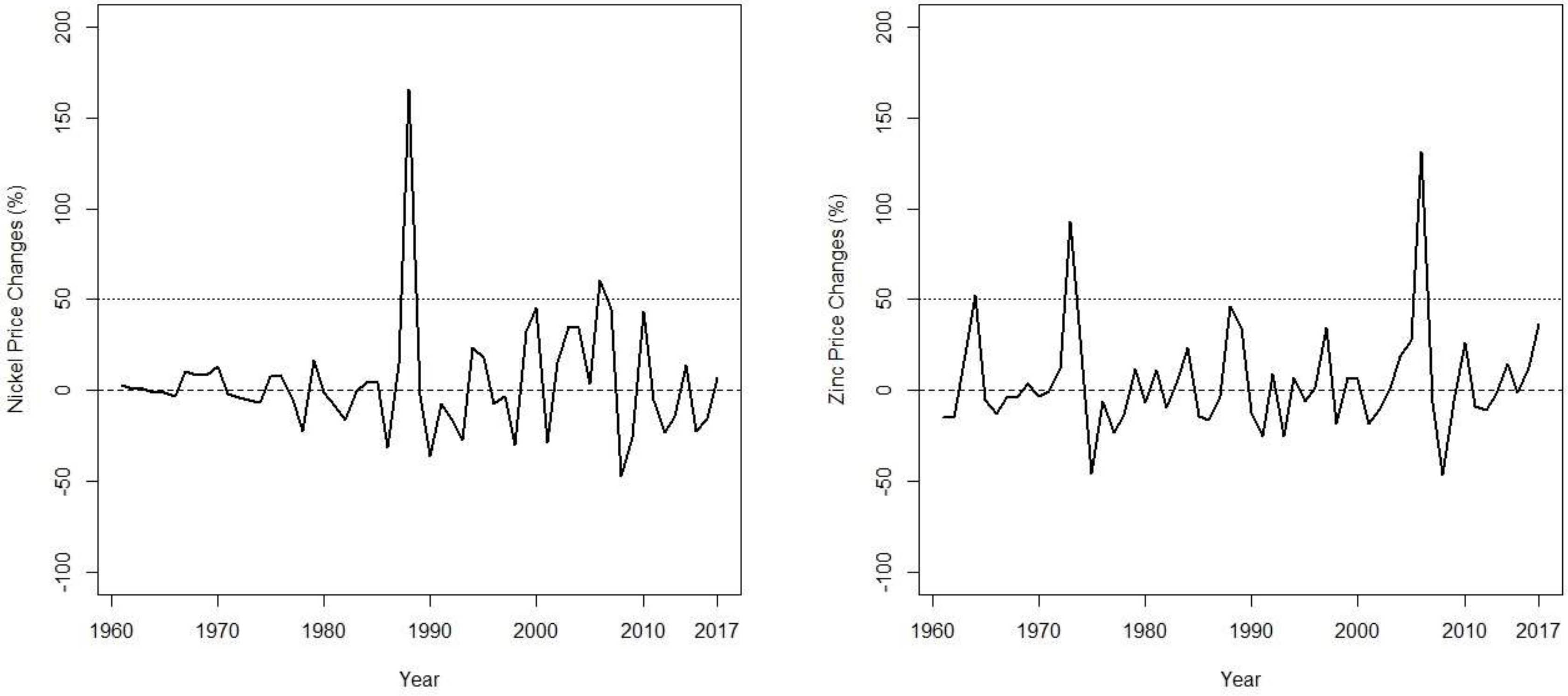
First, should the mine remain open or closed down when closing is costly (including cleaning up of accident)?

Second, how should the alternative policy instruments for internalizing externalities/social costs be set up (levels of instruments etc.)?

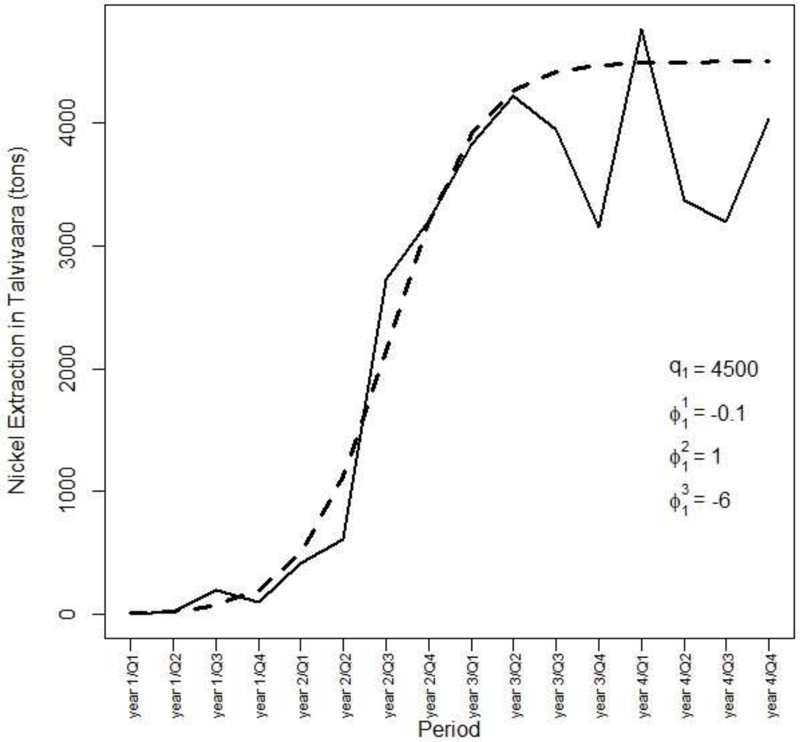
Problem solved by simulations for a prototype mine.

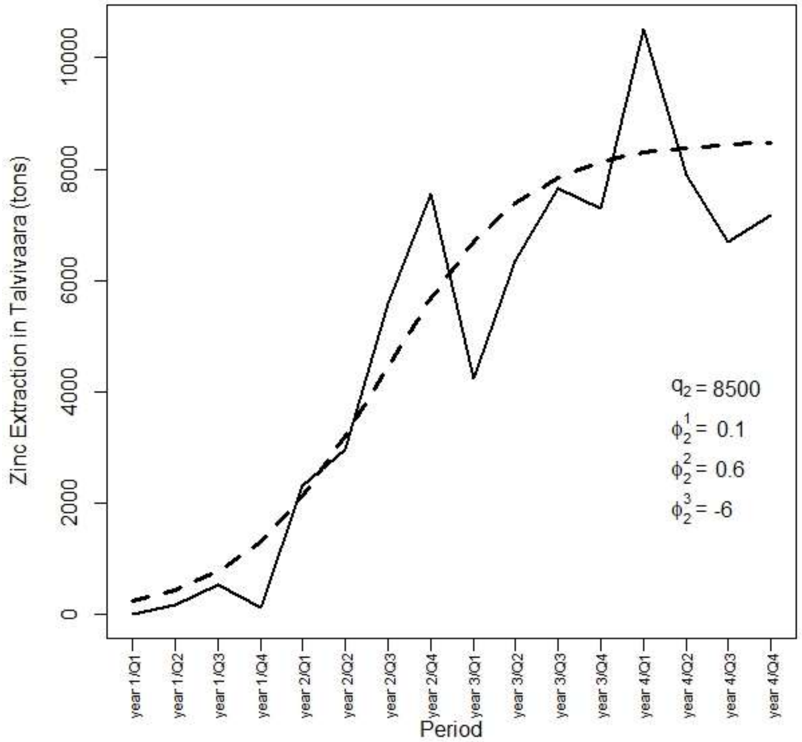
Main features of the prototype mine and its operating environment

Nickel (left) and zinc (right) price changes in 1960-2017

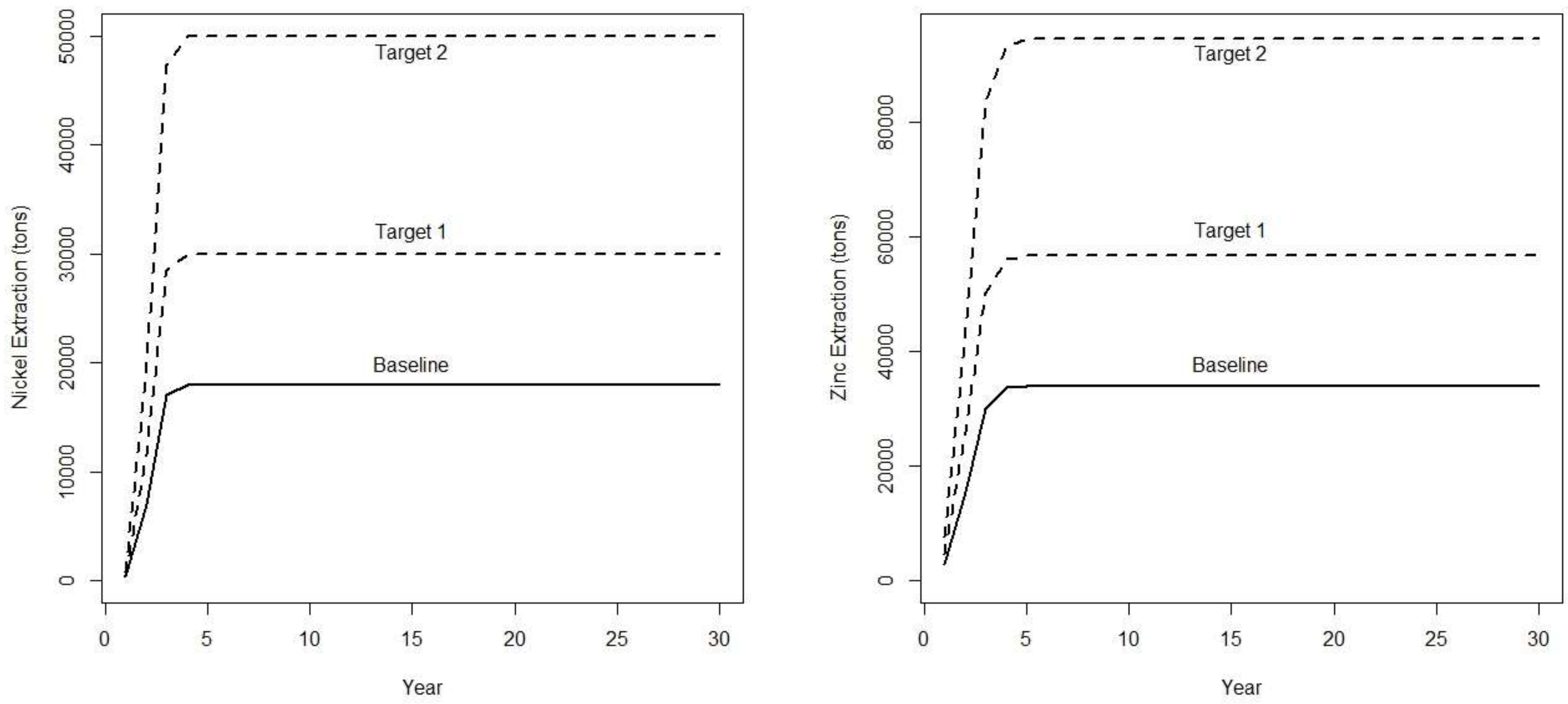


Simulated learning-by-doing in production nickel (left) and zinc (right), dashed lines





Nickel (left) and zinc (right) extraction scenarios



Methods and results

Expected net present value of the income stream (simulated)

From an active mine

$$NPV_{OPEN} = E\left\{\sum_{t=1}^{T} \rho^{t}\left[\sum_{i=1}^{2} \tilde{p}_i^t\, \tilde{q}_i^t(\phi_i, pr^{\psi}) - c_o \tilde{q}_o^t - c_F^t\right]\right\} - \rho^T C_{REC}^T$$

where the reclamation cost paid in the end of time horizon is discounted, $\rho^T C_{REC}^T$.

From a closed mine

$$NPV_{CLOSED} = -C_{CLOSE}$$

where C_{CLOSE} stands for the closing costs of the mine.

➔ EXPECTED price and production quantities and environmental risks

Simulation results under uncertainty

proportion (%) of cases when NPV_{OPEN} > NPV_{CLOSED}

1000 simulations	Benchmark	Sensitivity/Robustness Check		
% of cases when NPV_{OPEN} > NPV_{CLOSED}		Discount Factor 0.97	Price -High Ni : 15000$/t Zn: 3000$/t	Cost – Low 20$/ton of ore
Baseline production	7.3	7.8	44.8	81.8
Target 1	8.6	9.4	49.6	87.0
Target 2	9.5	11.6	51.9	89.9

- **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.**

Alternative Resource Policy Instruments

Royalty, λ, to be paid on the amount of ore

Ad valorem tax, τ^{AD}, on the value of output

Excess corporate tax rate, τ^{CORP}

Alternative Environmental Policy Instruments

Pigou tax, θ, on emissions proportional to amount ore extracted

Mandatory up-front liability payment, P, fixed payment to a liability fund at t=0

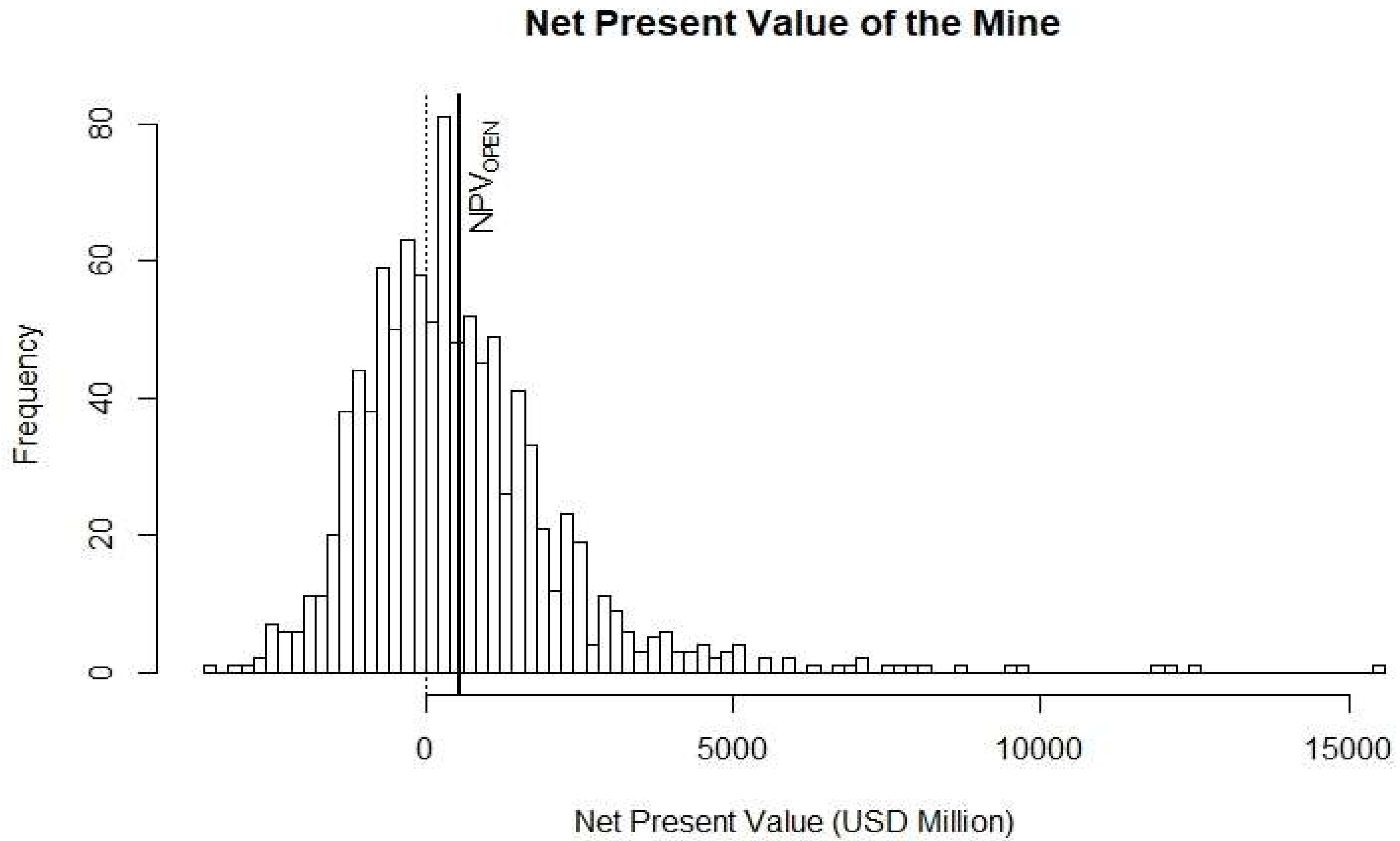
Surety bond, B, made at t=0, returned to the firm, if no accident by t=T

Fine, Ψ, on accident caused by excessive discharges (due to rain) occurring **with a probability** $\boldsymbol{pr^{\psi}}$ during the lifetime of the firm. The fine depends on the damage caused, A.

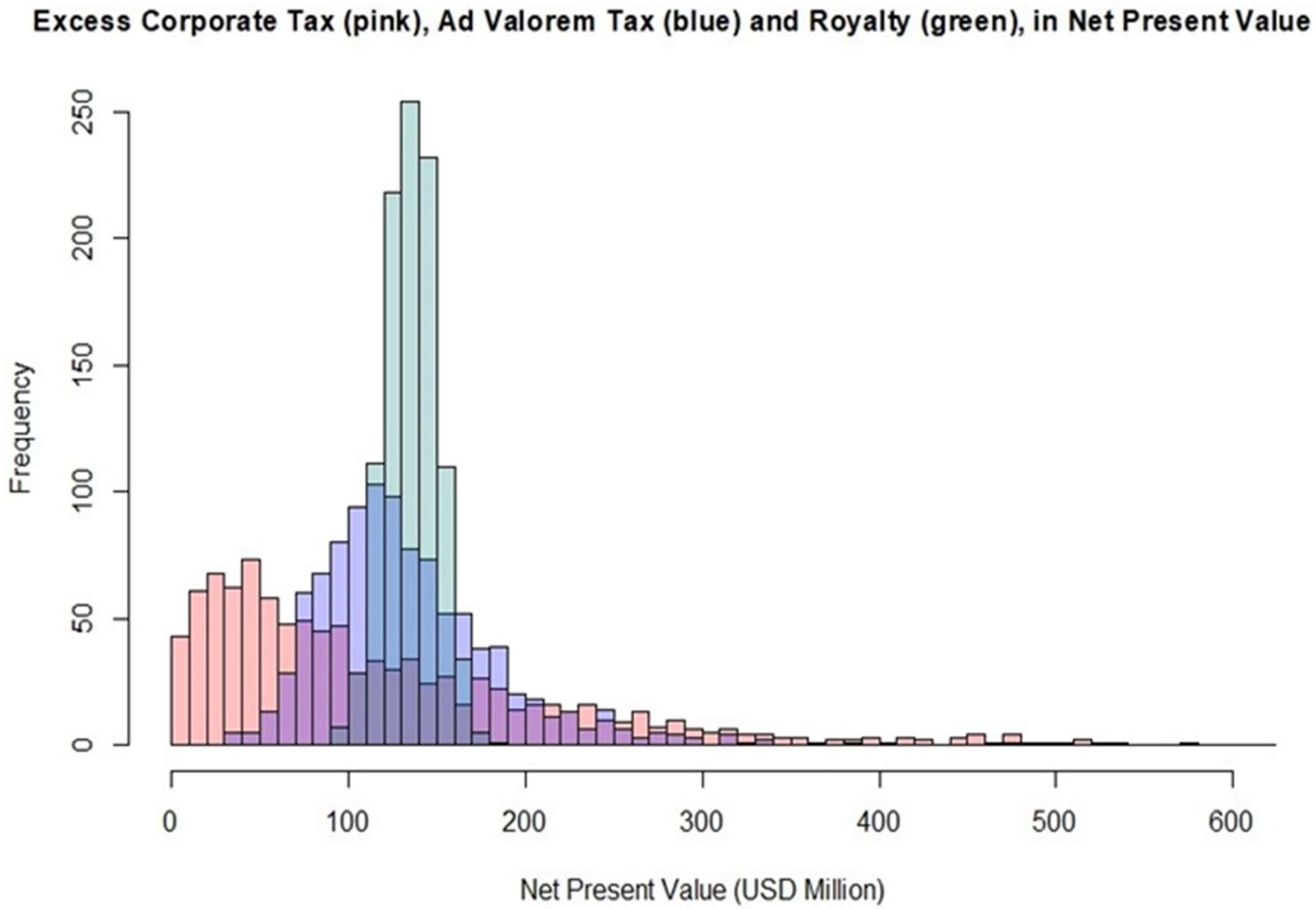
Simulation results for alternative policy insruments to internalize social costs/externalities

Distribution of simulated NPV of firm profits

with ad valorem tax 5%, corporate tax 20% and Pigou tax USD 1,000 per ton of effluent, production level Target 1



Distributions of government revenues



Note: excess corporate tax 14%, ad valorem tax 5%, royalty of USD 1.6 per ton of ore;
In all simulations baseline corporate tax 20% and Pigou tax of USD 1,000 per ton of effluent

Conclusions 1

Given our parameter values based on the prototype mine, metal markets and experiences with an unconventional technology, we show that metal extraction is unprofitable.

Only when operating costs are low or metal prices are initially higher than the historical average prices does it pay off to continue mining activities.

- Our algorithm can be used for design of intervention and/or closing decision
- 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
- Check the relative merits of alternative instruments – what is the main cause of worry

Conclusions 2

- **Excess corporate tax rate** on mining generates the highest profits for the firm; taxed only when makes profit. However, international tax competition may explain why governments favor **royalties** which generate tax revenues from resource firms as soon as production begins.
- **Pigou tax** generates the highest expected compensation for the environmental damages caused by a mine; the revenue is similarly distributed to that from the royalty. **Pigou tax and royalty** resemble each other because of **the same tax base** while designed to address different market failures.
- **Fine** is paid only when an accident occurs; a low probability generates the lowest expected revenues for the government. Moreover, firms can declare bankruptcy and escape their liabilities and ex post fines.
- **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.

Thank you!

For details, see our WP:

https://www.doria.fi/bitstream/handle/10024/180198/vatt-working-papers-137-resource-and-environmental-policies-for-the-mining-industry.pdf

Details of the prototype mine

Project type	Heap leaching	
Production Life Length, T (years)	30	
Discount Factor, ρ^t	0.95	
Operating Costs, c_o ($/ton of ore)	43.7	
Net Financial Costs, c_F^t (M $/year)	39.6	
Closing Cost, C_{CLOSE} (M$)	200	
Reclamation Cost, C_{REC} (M$)	50	
Likelihood of Environmental Accident, pr^{ψ}	1/100	
Price in 1st year ($/ton)	Nickel, p_1^1 10,000	Zinc, p_2^1 2,000
Long-Run Production (ton /year) - Baseline - Target 1 - Target 2	Nickel, q_1^1 18,000 30,000 50,000	Zinc, q_2^1 34,000 57,000 94,000