Non-Renewable Resources, Extraction Technology, and Endogenous Growth

Martin Stuermer, Federal Reserve Bank of Dallas
Gregor Schwerhoff, Mercator Institute on Global Commons and Climate Change

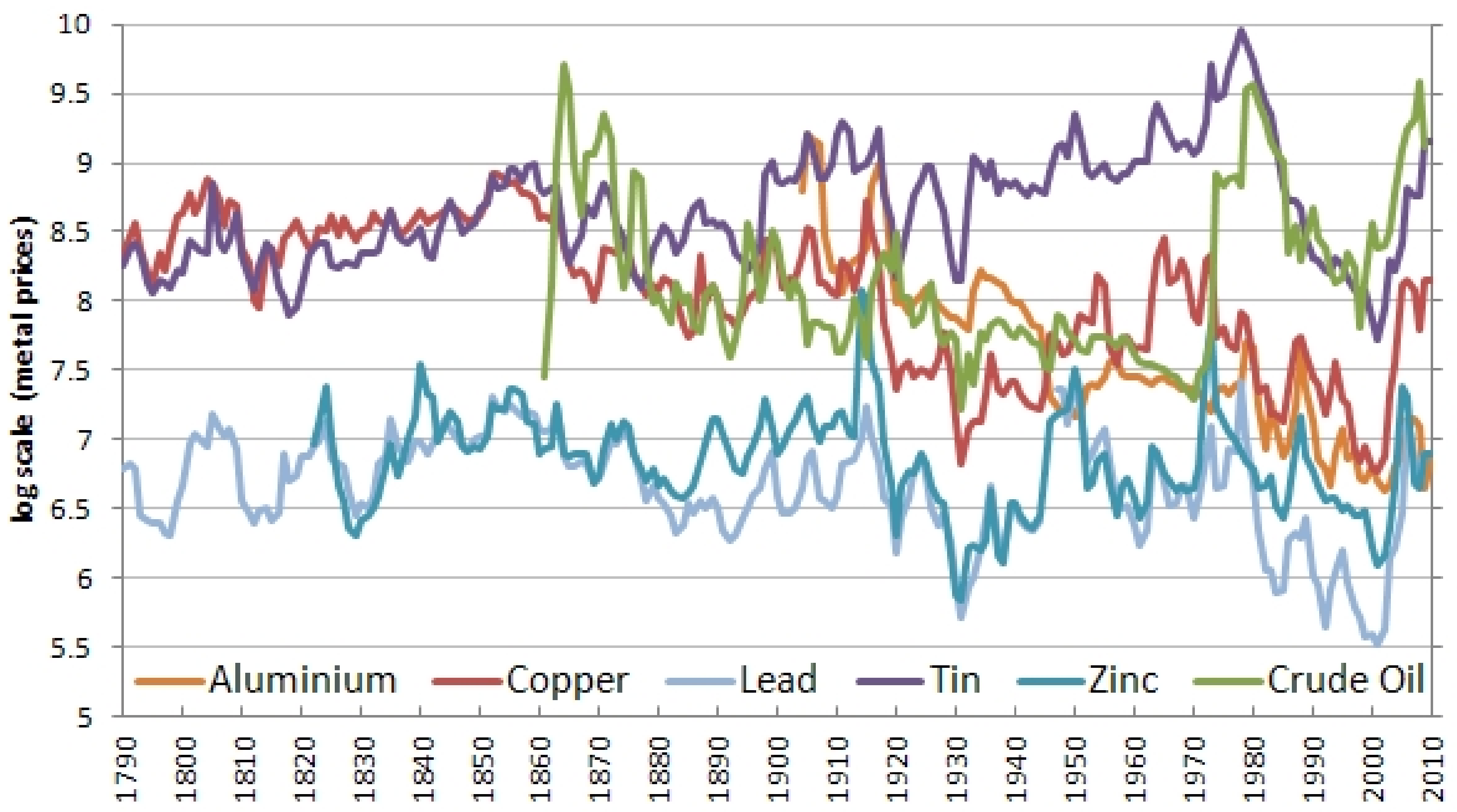
Abstract

We develop a theory of innovation in non-renewable resource extraction and economic growth. Firms increase their economically extractable reserves of non-renewable resources through R&D investment in extraction technology and reduce their reserves through extraction. Our model allows us to study the interaction between geology and technological change, and its effects on prices, total output growth, and the resource intensity of the economy. The model accommodates long-term trends in non-renewable resource markets -- namely stable prices and exponentially increasing extraction -- for which we present data extending back to 1792.

Resource Scarcity and Technical Change

- Traditional growth models overcome resource scarcity by technological change in resource efficiency.
- However, the predictions of these models are not in line with long-run evidence of rising resource production and non-increasing price trends.
- This model: scarcity is overcome by innovation in extraction technology.
- We build an endogenous growth model with R&D investment in extraction technology that accommodates the long-run trends.

Non-Increasing Real Commodities Prices Since 1790 (in logs, U.S. CPI deflated)



Resource Availability of Important Materials (adapted and updated from Nordhaus, 1974)

	Known Reserves/ Annual Extraction (Years)	Crustal Abundance/ Annual extraction (Years)
Aluminium	133	9,400,000,000
Gold	20	27,800,000
Coal	144	1,400,000
Oil	74	
Natural gas	2,100	

A New Perspective on Natural Resources

- Traditional Modeling: Resource stock S decreases due to the use of the non-renewable resource R: $\dot{S}_t = -R_t$.
- Here: firms can invest into new extraction technology $\dot{N}_R$, which leads to new reserves X (reserves = economically recoverable mineral deposits at current technology).
- Firms' reserves evolve according to: $\dot{S}_t = -R_t + X_t$.

Firms Innovate Because Technology is Deposit Specific

- Innovation in extraction technology despite perfect competition.
- Assumptions: Technology is deposit-specific, excludable; extraction cost infinitely high without new technology.
- Innovation driven by non-replicable factor of production (see Desmet & Rossi-Hansberg, 2012).

References: Desmet, K. and Rossi-Hansberg, E. (2014). "Innovation in Space." *AER*, 102(3): 447-452.
Acemoglu, D. (2002). "Directed Technical Change." *RES*, 69(4): 781-809.
Nordhaus, W. (1974). "Resources as a Constraint to Growth," *AER P&P*, 62(2): 22-26.

Offsetting Effects of Geology and Technology

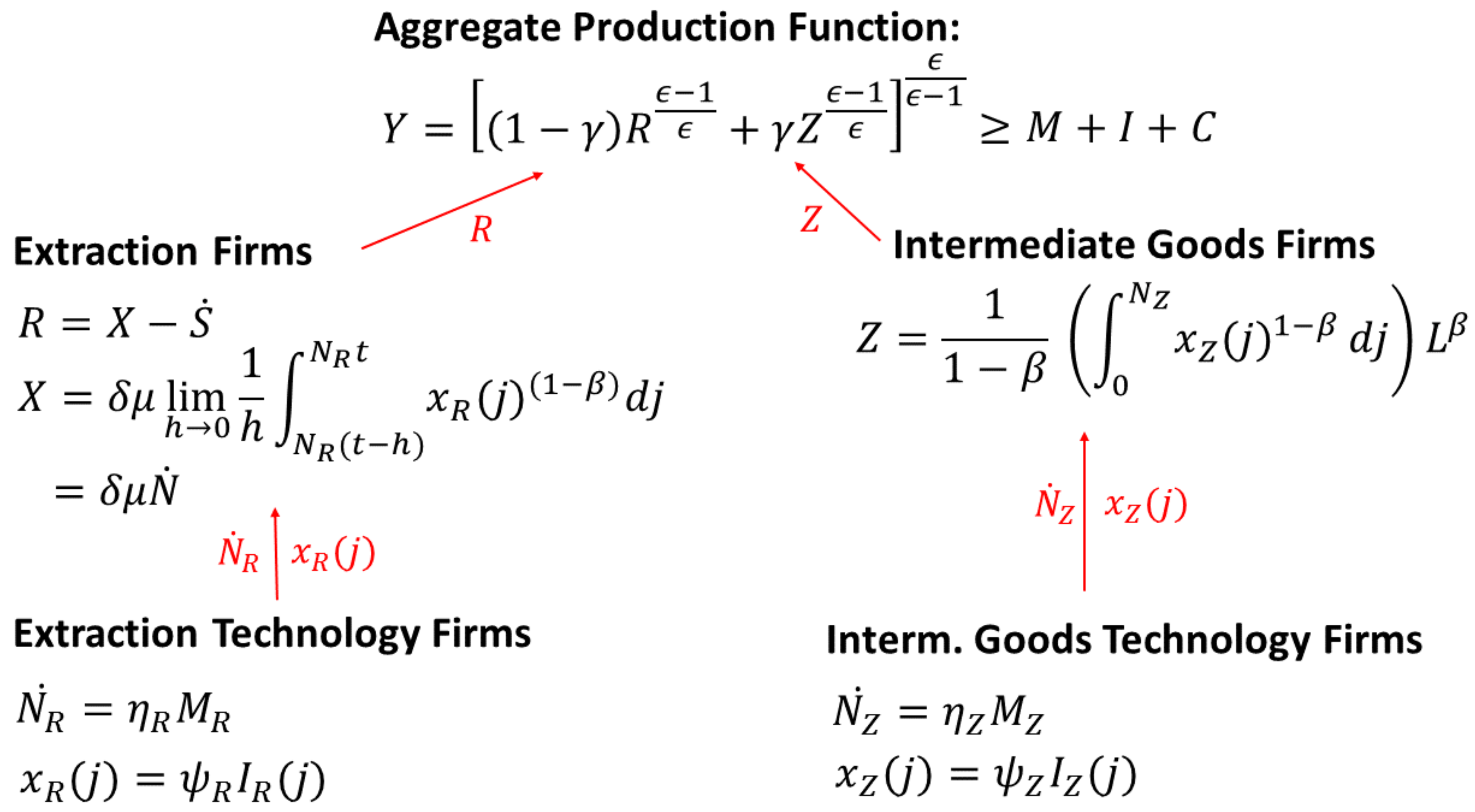
- There is a continuum of deposits of declining ore grades $O \in (0,1)$.
- New reserves result from the interplay of:
  - geological function $Q(O) = -\delta \ln(O)$, $\delta \in \mathbb{R}+, O \epsilon (0,1)$ and
  - extraction technology function $O(N_R) = e^{-\mu N_R}, \mu \in \mathbb{R}+, N_R \in (0,\infty)$.
- Exponentially increasing quantities Q in the geological function are offset by decreasing returns in terms of ore grades O in the technology function.
- The marginal return on extraction technology, $\dot{N}_R$, in terms of new reserves X is constant.

$$X_t = \frac{\partial Q(O(N_R))}{\partial t} = \delta\mu\dot{N}_R$$

- Extraction firms face constant R&D cost in converting one resource unit from a deposit into a new reserve.

Endogenous Growth Model

- We add the extractive sector to a standard endogenous growth model of directed technical change by Acemoglu (2002).



Aggregate Production Function:

$$Y = \left[(1-\gamma)R^{\frac{\epsilon-1}{\epsilon}} + \gamma Z^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} \geq M + I + C$$

R

Z

Extraction Firms

$$R = X - \dot{S}$$
$$X = \delta\mu \lim_{h\to 0}\frac{1}{h}\int_{N_R(t-h)}^{N_R t} x_R(j)^{(1-\beta)}\,dj$$
$$= \delta\mu\dot{N}$$

$\dot{N}_R \mid x_R(j)$

Extraction Technology Firms

$$\dot{N}_R = \eta_R M_R$$
$$x_R(j) = \psi_R I_R(j)$$

Intermediate Goods Firms

$$Z = \frac{1}{1-\beta}\left(\int_0^{N_Z} x_Z(j)^{1-\beta}\,dj\right)L^{\beta}$$

$\dot{N}_Z \mid x_Z(j)$

Interm. Goods Technology Firms

$$\dot{N}_Z = \eta_Z M_Z$$
$$x_Z(j) = \psi_Z I_Z(j)$$

Theoretical Results

- The resource price p_R is negatively affected by the parameters δ and μ, which reflect the concentration of the resource in the Earth's crust and the evolution of technology: $p_R = {}^{1}/_{\delta\mu\eta}$.
- The resource intensity (ratio of resource consumption to aggregate output) is positively affected by δ and μ: $\frac{R}{Y} = [(1-\gamma)\eta_R\delta\mu]^{\epsilon}$.
- A higher resource price leads to a lower growth rate of the economy on the balanced growth path:

$$g = \theta^{-1}\left(\beta\eta_Z L\left[\gamma^{-\epsilon} - \left(\frac{1-\gamma}{\gamma}\right)^{\epsilon}\left(\frac{1}{\eta_R\delta\mu}\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}\frac{1}{\beta}} - \rho\right)$$

- The extraction of the non-renewable resource increases at the same constant rate as the economy.

Conclusion

- Introducing innovation in extraction technology helps accommodating long-run trends in resource markets.
- Offsetting interaction between geology and technology leads to constant marginal cost of resource production in the long run.
- Model reflects empirical observation that very large stocks of all important resources in the earth's crust remain unexploited.
- A higher crustal abundance leads to a lower resource price, a higher resource intensity, and higher aggregate output growth.

Contact: Martin Stuermer
Federal Reserve Bank of Dallas
Research Department

Email: martin.stuermer@dal.frb.org
Website: https://sites.google.com/site/mstuermer1/
Phone: +1 469 682 6524