Discussion of "Non-renewable resources, extraction technology, and endogenous growth" by Martin Stuermer and Gregor Schwerhoff

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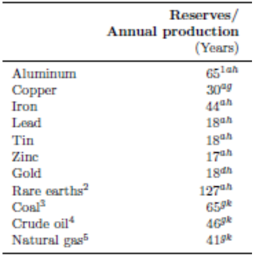
A few predictions

- In 1885, the US Geological Survey announced that there was “little or no chance” of oil being discovered in California. In 1891, it said the same thing about Kansas and Texas.
- In 1939 the US Department of the Interior said that American oil supplies would last only another 13 years.
- 1944 federal government review predicted that by now the US would have exhausted its reserves of 21 of 41 commodities it examined. Among them were tin, nickel, zinc, lead and manganese.
- In 1949 the Secretary of the Interior announced that the end of US oil was in sight.
- In 1974, the US Geological Survey announced “at 1974 technology and 1974 price” the US had only a 10-year supply of natural gas.

Context

- Although these predictions look silly now, the reasoning behind these fears is at first glance compelling:
  - Economic activity uses resources, we are growing exponentially and the Earth is finite

→ We are going to hit a wall (this dates back at least to the club of Rome's report in the 1972 arguing for degrowth).



	Reserves/ Annual production (Years)
Aluminum	65[1ah]
Copper	30[ag]
Iron	44[ah]
Lead	18[ah]
Tin	18[ah]
Zinc	17[ah]
Gold	18[dh]
Rare earths[2]	127[ah]
Coal[3]	65[gk]
Crude oil[4]	46[gk]
Natural gas[5]	41[gk]

Stuermer and Schwerhoff (2016)

1. This paper first shows some stylized facts regarding resource price, consumption and reserves.
    1. There are no clear trend in resource price.
    2. Resource use seems to increase with GDP
    3. Reserves increase (!) over time:
        - Copper reserves have increased 7-fold since 1950.
        - Oil reserves have increased 3-fold since 1980.
2. It develops a simple model which emphasizes the role of extraction technology to explain them

A model of extraction technology

- The typical solution in the economics literature:
  - resource scarcity → Hotelling rents → development of resource saving technology (or development of substitutes).
  - See for instance Krusell, Hassler and Olovsson (2016) for a recent treatment.
  - But in the data, resource price is constant and resource use increases.

→ This motivates a model where technological progress in extraction technology allows to keep the price low and increase resource consumption.

  - Justification: there are a lot of resources in less pure deposits, so that in effect resources are currently finite but with the right technology very abundant.

The model (1)

- Final good produced with intermediate goods Z and resources R

$$Y = \left(\gamma Z^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma) R^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

- Intermediate goods sector is as in Romer.
  - Innovators can use the final good to create new intermediates on which they obtain a permanent monopoly.
- Resources are extracted from deposits in the ground.
  - Deposits are indexed by their grade $d \in (0,1)$.
  - There are more resources in deposits of lower grade $D(d) = -\delta_1 \ln d$.
  - At a given point in time, resources with grade $\geq h(N_R) = \exp(-\delta_2 N_R)$ can be extracted;
  - N_R is the level of technology. Firms can use the final good to increase N_R.

The model (2)

- Market structure is such that if a firm develops the technology to exploit a grade d, it only has a monopoly for that *instant*.
  - → The firm extracts and sells all the resources of that grade in that instant, while taking the price of the resource as given.

$$R = \delta_1 \delta_2 \dot{N}_R = \delta_1 \delta_2 \eta_R M_R,$$

    where M_R is R&D investment in resource technology.
  - If pure extraction costs are 0, then $p_R = 1/\left(\eta_R \delta_1 \delta_2\right)$.

→ We then obtain a BGP where:

  - Resource price is constant.
  - Resource use grows like GDP.

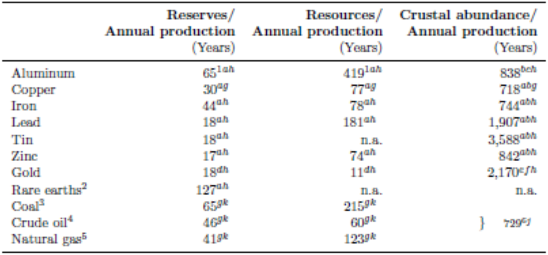
- Growth depends positively on parameters determining resource abundance: $\delta_1 \delta_2 \eta_R$.
  - This increases the relative price of the intermediate and therefore the incentive to undertake labor augmenting research.

A few comments on the stylized facts

- The model prediction is that R/Y is constant: Table 3 should test that instead of testing for trends.
    - Figure 2 suggests that as a resource starts being used, it first experiences fast growth (its use catches up) and then grows at roughly the rate of GDP.
    - Role of recycling for some metals is actually very important (some are nearly entirely recycled).
    - There is evidence of decoupling between resource use and GDP for developed countries (OECD, 2013), is this not true at the world level?
- A key equation in the model is that $R = \delta_1 \delta_2 \dot{N}_R$, some evidence for it would be very nice.
    - Do we see a linear relationship between resource use and R&D in that sector?
    - This would add quite a bit of credibility to the model.
- Extensive literature on resource prices (e.g. Cuddington, Nülle, 2014, for a recent paper) that should be addressed.

Abundant resources?

- Crucial assumption is that resources are "effectively" in infinite supply. Is this realistic?



	Reserves/ Annual production (Years)	Resources/ Annual production (Years)	Crustal abundance/ Annual production (Years)
Aluminum	65^{1ah}	419^{1ah}	838^{bch}
Copper	30^{ag}	77^{ag}	718^{abg}
Iron	44^{ah}	78^{ah}	744^{abh}
Lead	18^{ah}	181^{ah}	$1,907^{abh}$
Tin	18^{ah}	n.a.	$3,588^{abh}$
Zinc	17^{ah}	74^{ah}	842^{abh}
Gold	18^{dh}	11^{dh}	$2,170^{cfh}$
Rare earths[2]	127^{ah}	n.a.	n.a.
Coal[3]	65^{gk}	215^{gk}	729^{cj}
Crude oil[4]	46^{gk}	60^{gk}	
Natural gas[5]	41^{gk}	123^{gk}	

Abundant resources?

- If crustal abundance is the metric, then indeed there is no need to worry at all.
- But what if it is resources? Exploiting deposits which are less and less pure is one thing, exploiting the full crust is another.
  - The paper does not clearly defined what this “resources” measure is.
  - Fossil fuels are not an issue but oil?
  - For some metals (Zinc, Copper) recycling seems necessary to integrate.
  - $>$200 years is essentially infinite.

Resources and energy

- As ores of a lower grade are exploited, energy requirements increase (at least with current technologies).
  - "Currently, 10% of world energy consumption [I found lower numbers] is used for extraction and processing of mineral resources. Without extraordinary advances in mining and refining technology, this fraction is set to rise as poorer and more remote deposits are tapped."
  - Citation here and below from Vidal, Goffé and Arndt (Nature Geoscience, 2013)
- At the same time, need to move towards renewable energy which requires a lot of metals!
  - Consider an increase of energy production from wind turbines and solar energy from 400 TWh (2013 at the world level—total energy consumption was around 105000) to 12000 TWh in 2035 and 25000 TWh in 2050 (projections by the WWF).
  - This would require "a 5 to 18% annual increase in the global production of these metals for the next 40 years" in addition to the rise in demand for other reasons.

Comments on the model

- 2 small mathematical issues:
  - There is a necessary condition on parameters $(1-\gamma)^{\varepsilon}(\eta_R\delta_1\delta_2)^{\varepsilon-1} < 1$ (otherwise there is either infinite or 0 production).
  - Proposition 4 is not correct because the impact of ε on R/Y depends on whether $(1-\gamma)(\eta_R\delta_1\delta_2) \lesseqgtr 1$.
- The asymmetry between the two types of innovation makes the model a bit inelegant.
  - One innovation is embodied in machines but not the other; one never diffuses, the other diffuses immediately.
  - There is more symmetry in the online appendix model, but still difference in IPR.
  - Maybe discrete time would be helpful here: you could get temporary monopoly in both technologies.

Making a better use of the model

- Main issue with the paper: the model can account for the stylized facts but does not do anything else.
    - Now that the model is developed it should be used for something: quantitative analysis, giving additional economic insights, exploring additional predictions, ...
- Old debate around Hotelling pricing of natural resources.
    - Hard to see in the data (and this paper adds some evidence to that claim).
    - But there is a gap between marginal cost of extraction and price (Saudi oil).
        - This is true here as well since the pure extraction cost is 0.
        - Should we think of the R&D in extraction technology as the true source of a "scarcity" rent?

Price signal

- Classic intuition: as a resource gets scarcer, its price increases, which induces more efforts towards research in extraction technology.
- Here in continuous time and in a BGP, this mechanism is harder to see:
  - price is constant, new technologies to extract lower grades of resources are immediately developed and older grades of the resources are all exhausted.
- A model with uncertainty, where older and newer vintages are extracted together would be more realistic and deliver additional insights:
  - Could account for fluctuations in prices and quantities of resource?
  - Could account for commodities price long cycles?
  - (Maybe the most interesting question) Could explain what determines the ratio reserves / annual production?
    - Here it is 1, in reality it is 20 or more depending on resources.

Comparison across resources

- Paper makes implicit comparison between resources yet the model only consider 1. Easy to make this point formally:

$$R = \left({R^c}^{\frac{\sigma-1}{\sigma}} + {R^a}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

  - c for copper and a for aluminium for instance, σ the elasticity of substitution between resources.

- Prices depend solely on geological and technological parameters:

$$p_R^c = \left(\delta_1^c \delta_2^c \eta_R^c\right)^{-1} \text{ and } p_R^a = \left(\delta_1^a \delta_2^a \eta_R^a\right)^{-1}.$$

$$\implies \quad \frac{p_R^c}{p_R^a} = \frac{\delta_1^a \delta_2^a \eta_R^a}{\delta_1^c \delta_2^c \eta_R^c} \text{ and } \frac{R^c}{R^a} = \left(\frac{\delta_1^c \delta_2^c \eta_R^c}{\delta_1^a \delta_2^a \eta_R^a} \right)^{\sigma},$$

$$\frac{p_R^c R^c}{p_R^a R^a} \quad = \quad \left(\frac{\delta_1^c \delta_2^c \eta_R^c}{\delta_1^a \delta_2^a \eta_R^a} \right)^{\sigma-1} \text{ and } \frac{\dot{N}_R^c}{\dot{N}_R^a} = \left(\frac{\delta_1^c \delta_2^c}{\delta_1^a \delta_2^a} \right)^{\sigma-1} \left(\frac{\eta_R^c}{\eta_R^a} \right)^{\sigma}$$

  - Are these predictions supported by the data?

Resource discovery

- We can then investigate what happens when a new resource gets used (e.g. aluminium was not used till the end of the XIXth). Assume $\sigma > 1$.
  - Then the price of the resource aggregate would decline $\left(p_R = \left(\left(\delta_1^c \delta_2^c \eta_R^c\right)^{\sigma-1} + \left(\delta_1^a \delta_2^a \eta_R^a\right)^{\sigma-1}\right)^{\frac{1}{1-\sigma}}\right.$ with both resources and $p_R = \left(\delta_1^c \delta_2^c \eta_R^c\right)^{-1}$ with only copper.
  - This increases the price of the intermediate and therefore growth.
- The new resource is immediately at its steady-state price and growth rate of use.
- Alternatively we could have a progressive increase in aluminium technology:

$$\dot{N}_R^a = \eta_R^a \min\left(N_R^a / \overline{N}, 1\right) M_R^a$$

  - This would generate an initial decline in the real price (as $\eta_R^a \min\left(N_R^a / \overline{N}, 1\right)$ increases) and faster growth in the use of aluminium initially.

Recycling (1)

- An easy way to introduce recycling is to consider the resource as a capital good which gives a flow "resource services" and depreciates at rate Δ.
  - Lower Δ represents progress in recycling.
  - (This is probably not how you should model it in a paper, but just as a first step).
- With $\varepsilon < 1$, to get growth, new resources still have to be constantly extracted (otherwise the available stock shrinks).
  - $p_R = (\delta_1 \delta_2 \eta_R)^{-1}$, the extraction price of a resource is independent of the depreciation rate.
- We obtain that the marginal product of the resource service is:

$$MPR_R = (r + \Delta)\, p_R = \frac{r + \Delta}{\delta_1 \delta_2 \eta_R}.$$

Recycling (2)

- The price of intermediates obey

$$\gamma^{\varepsilon} p_Z^{1-\varepsilon} + (1-\gamma)^{\varepsilon} MPR_R^{1-\varepsilon} = 1$$

- Therefore a better recycling technology (lower Δ) leads to faster aggregate growth:

$$g = \theta^{-1} \left(\beta \eta_Z \left(\gamma^{-\varepsilon} - \left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon} \left(\frac{\rho + \theta g + \Delta}{\delta_1 \delta_2 \eta_R} \right)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon} \frac{1}{\beta}} - \rho \right).$$

Conclusion

- Very nice work which presents important stylized facts.
- The paper convincingly argues that we need to better understand the key role played by extraction technologies.
- A nice model or framework which could be further exploited.