Induced Biased Innovation and Exhaustible Resource Prices

John R. Boyce
University of Calgary
Daniel V. Gordon
University of Calgary
Sjak Smulders
Tilburg University

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Professor Rögnvaldur Hannesson
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Problem

- Empirical problem is straightforward: what is the relationship between mineral price growth rates and technical innovation.
- Economists have long been interested in explaining mineral price path
- Barnett and Morse (1963) first to look at U.S. mineral prices to analyze resource scarcity.
- Slade (1982) examined the connection between innovation and exhaustible resource prices. Shows that mineral prices followed a U-shaped price path.

- Popp (2002), Interested in how energy prices affected technical innovation. Shows that both energy prices and state of existing knowledge positive effects on innovation.
- De Cian (2008) data from fifteen OECD countries 1978-2005, postulates that endogenous factor augmenting technological change is driven by R&D expenditures, aggregate imports, imports of machinery and education expenditures.
- None of these papers investigates the empirical connection between innovation and the rate of growth in prices.

- Induced endogenous growth theory Kennedy (1964), Acemoglu (2002, 2007), Smulders and de Nooij (2003)
- Innovation is more likely to occur in markets in which the gains from innovation are large. Tend to be markets for which the size of the market is large.
- If endogenous innovation drives economic growth, commodity prices are more likely to decline when the size of the **world value product** of the commodity is large.
- Build an equation to measure impact of WVP on mineral price growth rates

Motivation

- Hotelling Model 1931 sets the stage for mineral price modelling
- Hotelling prediction on price growth, let λ be the scarcity rental price unit of stock in ground

$$\hat{\lambda} \equiv \dot{\lambda}/\lambda = r$$

$$\hat{P}_c \equiv \dot{P}\Big/P = \frac{r(P-c)}{P} > 0$$

- ***Imperfect Competition***
- Exhaustible resource markets often have few firms Salant (1974), Loury (1986), Polasky (1992)
- Compare growth rate competitive and oligopolistic
- Market power lowers rate of growth of prices

$$\hat{P}_o = \frac{r\left[P(1-\frac{s_i}{|\varepsilon|})-c\right]}{P(1-\frac{s_i}{|\varepsilon|})} < \frac{r(P-c)}{P} \equiv \hat{P}_c$$

Effects of Cumulative Extraction

- Competitive model extended by Schulze (1974), Solow and Wan (1976) and Slade (1982)
- Let *C(Q, X)* be cost of extraction and $c_X \equiv \partial C / \partial X > 0$

$$\dot{P} = \left[1 - \frac{C_{QQ}}{D'(Q)}\right]^{-1} \cdot \left[\frac{C_{QX} Q - C_X}{P} + \left[\frac{r(P - C_Q)}{P}\right]\right]$$

- An effect on price from cumulative extraction implies marginal cost of extraction be increasing in *Q*

Exogenous Technological Change

- With the equilibrium equation for the market price we can find

$$\hat{P} = \left[1 - \frac{C_{QQ}}{D'(Q)}\right]^{-1}\left[\frac{C_{QB}B_Q}{P} + \frac{r(P - C_Q}{P}\right]$$

- Second term is the positive Hotelling effect
- First term is the effect of technological changes

  And $C_{QB} < 0$

- innovation is most valuable when reserves are large, Slade argued that the innovation effect should dominate early in the extraction cycle and that the Hotelling scarcity effect should dominate later in the extraction cycle.
- **Thus, she predicted U-shaped price paths.**

Endogenous Technological Change

- Smulders and de Nooij (2003)

- The rate of technological improvement , $\hat{B}$ is an increasing function of the size of the sector in the economy:

$$\hat{B} = h(v) \quad where \quad h'(v) > 0$$

- Growth in prices

$$\hat{P} = \left[1 - \frac{C_{QQ}}{D'(Q(}\right]^{-1} \left[\frac{C_{QB} B h(v)}{P} + \frac{r(P - C_Q)}{P}\right]$$

- **The Key empirical test is whether the rate of growth of prices is inversely correlated with the size of the sector in the economy**

- From basic theory we have growth in mineral prices should be influenced by interest rate, i, monopoly power, cumulative extraction, and world value product.

$$\hat{P}_g = f(i, monoply\ power, cummulative\ extraction, WVP, control\ variables)$$

Data

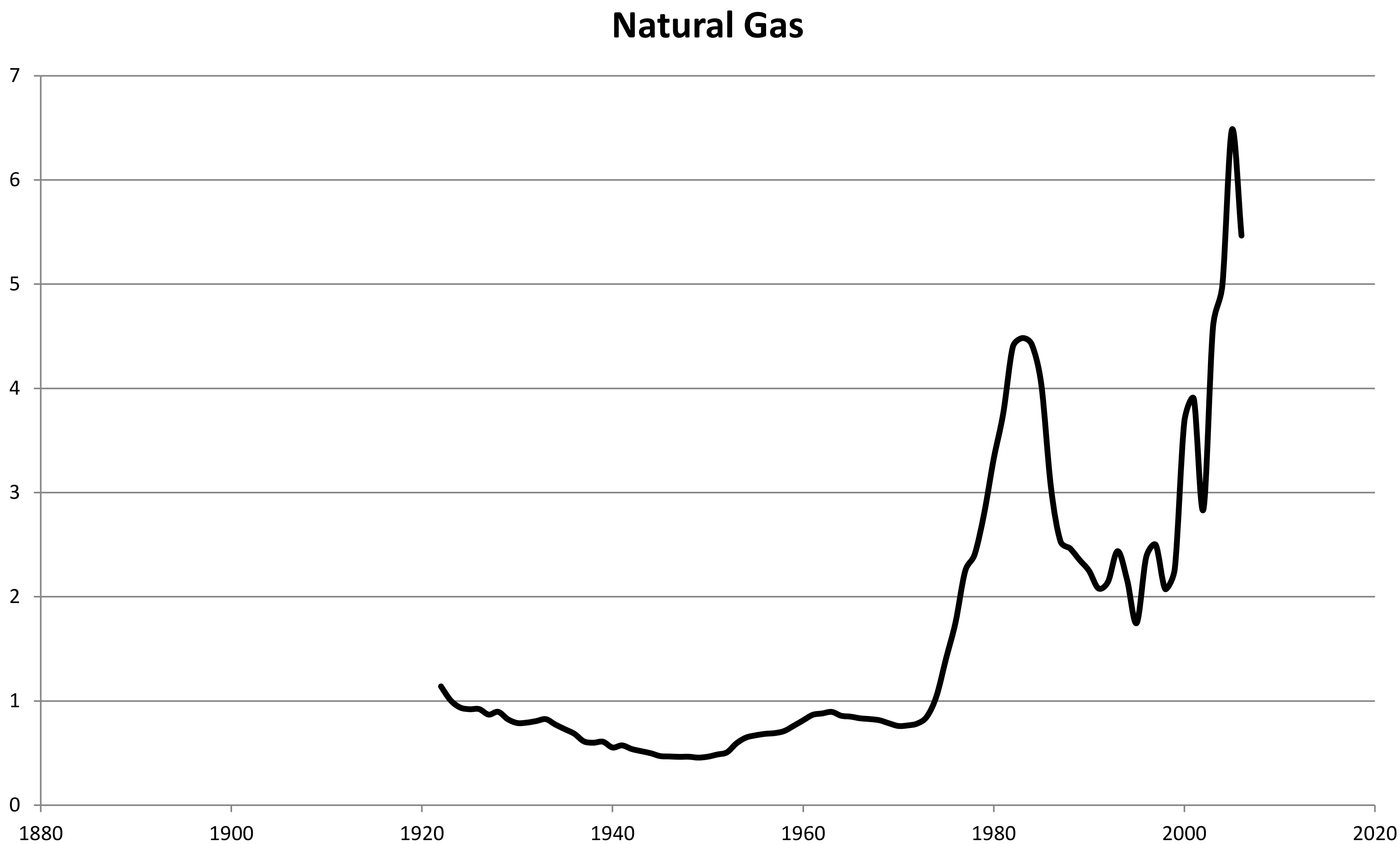
- Price and quantity information on 80 minerals covering period 1900- 2006
- 27 minerals with price and quantity > 100 years
- Two data sets; Main data information on all 80 minerals, Growth rate in mineral price, world value product, cumulative production, world population and the U.S. real bond rate
- Secondary data only a subset of the minerals for a much shorter time period; Includes two proxy variables representing monopoly power on the demand and supply sides of the market

- Data sources, Kelly and Matos 2002, US Geological Survey
- Data on price and quantity information for 76 minerals (2000 US prices per tonne)
- Also collect information on petroleum, coal, natural gas and uranium
- BP Statistical Review and US energy Information Agency

- The growth in mineral price is defined as

$$P_{git} = \ln(P_{it} / P_{it-1})$$

- Gemstones almost 2 billion dollars per tonne Industrial gravel $17 per tonne
- Prices declining at rate -0.008 per year, 3/4 of the minerals experienced declining prices
- While 15 mineral prices declined by more than 2% only two (quartz-crystals and thallium) experience growth rates of more than 2%.


Natural Gas
7
6
5
4
3
2
1
0
1880
1900
1920
1940
1960
1980
2000
2020

- Value of world value product

$$V_{it} = \ln(P_{it} q_{it} / GDP_t^{30})$$

- Maddison: Group of thirty original members of OECD plus Argentina, Brazil, Chile, Columbia, Peru, Uruguay, and Venezuela, India, Indonesia, and Sri Lanka
- Share of minerals in world GDP small, petroleum 2.12% world GDP, coal 1.1%, all other less than 1%, total all minerals 5.63%

- Cumulative production: ratio of current production to cumulative past consumption.
- This measure is without units, and varies between zero and one in value, declining as time progresses.

$$Q_{Xit} = \ln(q_{it} / X_{it-1})$$

- Time Series, probability structure overtime
- Find that growth in prices stationary
- World Value Product not stationary
- Cumulative production stationary.
- Not generally possible to form a proper equation with variables of different orders
- We look at panel data stationarity issues
- Im, Pesearn and Shan (2003) test
- Fisher type test

- IPS test has Ho all panels have unit root with Ha at least one panel stationary.
- Test useful for both T and N approaching infinity.
- Fisher test same null but uses meta analysis on Dickey-Fuller tests reported for time series
- Panel unit root tests suggest stationarity in all three of our important variables

Equation for main data set

$$\ln\left(\frac{P_{it}}{P_{it-1}}\right) = \beta_o + \beta_V \ln\left(\frac{P_{it} q_{it}}{GDP^{30}}\right) + \beta_x \ln\left(\frac{q_{it}}{X_{it}}\right) +$$

$$\beta_n \ln Pop_t^{30} + \beta_{Rb} Rb_t + \eta_i + \varepsilon_{it}$$

Econometric Problems

- First, all variables are integrated of order zero except population and bond rate
- In estimation, the log of the first differences of both population and bond rate are used.
- Use a Fixed Effect estimator for the unobserved heterogeneity within the panels.
- World value product and cumulative production are endogenous

- Herfindahl Supply

$$H_{it}^{s} = \sum_{j=1}^{C} (100 \cdot s_{ij})^2$$

- Sij share of world production of the ith mineral for jth country
- Problem country based not supplier based

- Herfindahl Demand

$$H_{it}^{d} = \sum_{k=1}^{K} (100 \cdot s_{ik})^2$$

- Sik share of the ith mineral consumed by the kth company
- Our Herfindahl demand index cannot measure the number of firms in a sector, but it does measure the number of sectors that are buying the commodity.

Instrumental Variable Panel Results				
	Fixed Effect Regression Estimates			
	1	2	3	4
$\ln((P_{it} \cdot q_{it})/GDP_t^{30})^{a)}$	-0.053 (0.000)	-0.058 (0.000)	-0.045 (0.000)	-0.0753 (0.000)
$\ln(Q_{it}/X_{it})^{b)}$	-	0.014 (0.037)	0.020 (0.226)	0.028 (0.001)
$lnPop_t$ [c)]	-	1.838 (0.003)	1.054 (0.244)	1.821 (0.034)
$lnRb_t$ [d)]	-	0.008 (0.172)	0.011 (0.260)	0.008 (0.321)
Constant	-0.521 (0.000)	-0.554 (0.000)	-0.387 (0.000)	-.718 (0.000)
Panels	80	80	20	60
Max-Min time periods	105-20	105-20	105	101-20
Observations	5865	5865	2099	3766
Wald χ^2	124.52 (0.000)	138.07 (0.000)	44.85 (0.000)	104.63 (0.000)

Elasticity of World Value Product under different lag Specifications of the IV Estimator	
Lags Included in IV	Elasticity of World Value Product
1-4	-0.059 (0.000) [a)]
2-4	-0.61 (0.000)
1-3	-0.061 (0.000)
1-2	-0.058 (0.000)
[a)] p-value in parentheses	

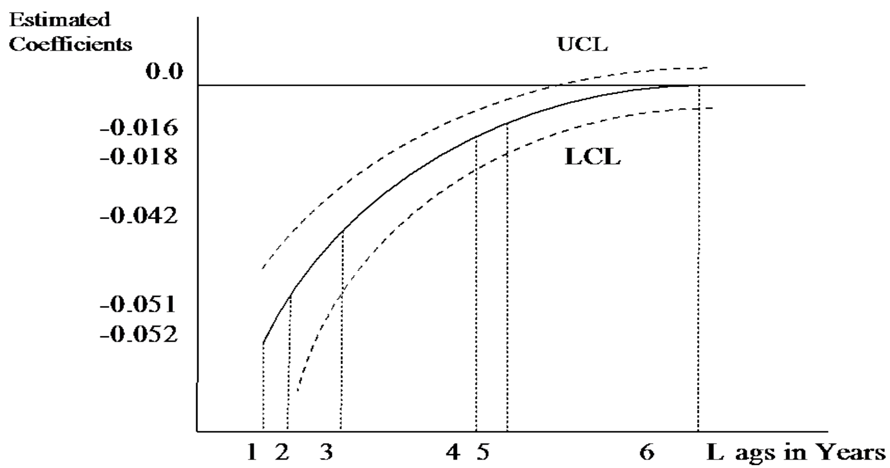


Figure 3: Realization of Innovation on Price Growth Using Different Lag Proxy Variables

Panel Results, Dummy Variables, Alternative IV and Market Power				
	Fixed Effect Regression Estimates			
	1	2	3	4
$\ln\left((P_{it} \cdot q_{it})/GDP_t^{30}\right)$ a)	-0.055 (0.000)	-0.024 (0.028)	-0.023 (0.036)	-0.334 (0.000)
$\ln\left(Q_{it}/X_{it}\right)$ b)	0.005 (0.473)	0.001 (0.946)	0.004 (0.801)	0.026 (0.889)
$lnPop_t$ c)	2.39 (0.000)	-4-26 (0.247)	-5.102 (0.165)	20.25 (0.093)
$lnRb_t$ d)	0.01 (0.101)	0.029 (0.000)	0.032 (0.000)	0.090 (0.006)
lnH_{it}^d e)	-	-	-	-0.007 (0.744)
lnH_{it}^s f)	-	-	-	0.038 (0.422)
DWWI	0.106 (0.000)	-	-	-
DWWII	0.029 (0.088)	-	-	-
DDep	0.016 (0.402)	-	-	-
DRes	-0.043 (0.002)	-	-	-
Constant		-0.177	-0.141	-3.794

Conclusion

- Purpose was to test endogenous innovation of price growth of minerals
- Empirically try to show robustness in the test over different date periods, different IV, proxy variables and alternative specifications
- Main result, is that we find statistical support for a negative relationship between price growth of minerals and endogenous innovation