Lecture Notes on Technical Change

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Questions

- Will resource scarcity and/or climate change force us to reduce consumption?
- Will scarcity lead to increasing shares of income going to pay for energy and other natural resources?
- Will technical change save us?
- Can we use data to inform us about these questions?
- Need to endogenize technical change to answer these questions.

Scarcity and directed technical change

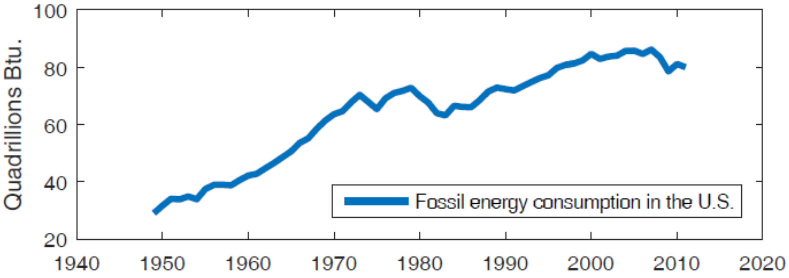
- We start with HKO (JPE, 2021).
- The paper is about the implications of resource depletion in general (no climate externalities).
- HKO analyses what our dependence on natural resources in finite supply implies for prices, quantities and technical change.
- Postwar U.S. data on fossil energy use informs the model producing quantitative predictions.

Mad Max

Will energy scarcity lead to a Mad Max scenario? The answer requires a quantitative model.

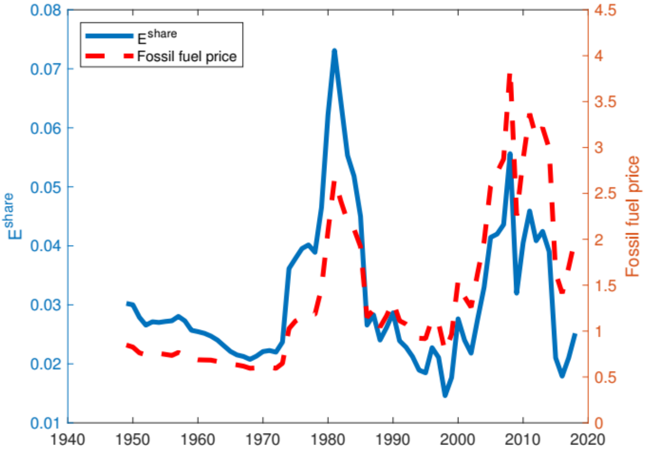
Data: fuel use

- Fossil fuel use has increased for a long time (but must fall eventually). Contradicts standard macro models with fuel in limited long-run supply



Data: expenditure share of fuel

- Expenditure share of fossil fuel (energy) highly variable in short and medium run and correlated with price. Implies elasticity of substitution $\varepsilon << 1$.



The HKO Model

- Preferences

$$\sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\sigma} - 1}{1-\sigma}$$

- Production

$$F(k_t, l_t, e_t, A_t, A_{e,t}) \equiv y_t = \left[\left(A_t k_t^{\alpha} l_t^{1-\alpha} \right)^{\frac{\varepsilon-1}{\varepsilon}} + \left(A_{e,t} e_t \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

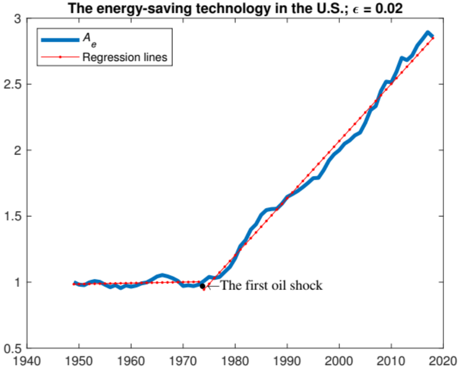
Resource constraint

$$c_t + k_{t+1} = \left[\left(A_t k_t^{\alpha} l_t^{1-\alpha} \right)^{\frac{\varepsilon-1}{\varepsilon}} + \left(A_{e,t} e_t \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} + (1-\delta) k_t$$

$$\sum_{t=0}^{\infty} e_t \leq R_0$$

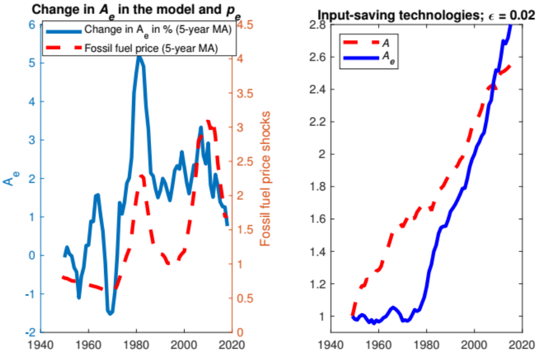
Energy augmenting technology

- Straightforward to back-out the two technology trends A_t and $A_{e,t}$ from data trends as two Solow-residuals.



- The mean growth rate in A^E: 1.52% per year (Std: 2.13%).
- Kink around oil crisis. 0.13% and 3.6% growth rate before and afterwards.

Prices and technology



- Two observations: i) Fuel price and growth rate of energy augmenting tech positively correlated and ii) the two tech trends have growth rates that are negatively correlated.
- Suggests ETC where R&D can be directed between different uses. Related to old *Putty-Clay* literature

Technology trade-off

- Technology frontier, trade-off between capital/labor augmenting (A_t) vs. energy augmenting ($A_{e,t}$) technical change

$$G\left(A_{t+1}/A_t, A_{e,t+1}/A_{e,t}\right) = M.$$

- The idea is that we have a given measure of scientists that can be allocated to improve the growth rate of either A or A_e. Can be easily decentralized if their is a spill-over after one period.
- Given that elasticity of substitution in (short-run) production function is below 1. Choice s interior.
- The economy reach a balanced growth path with constant expenditure shares.
- Thus: in the short run the economy is close to Leontief. In the long run, it is Cobb-Douglas-ish.

Expenditure shares in the long-run

- Intuitively: the easier it is (relatively) to increase $A_{e,t}$, the lower the expenditure share of energy.
- More specifically: how many percent increase in the growth rate of energy augmenting technology do we get for a reduction in capital/labor augmenting technology growth rate? I.e., how high is the elasticity

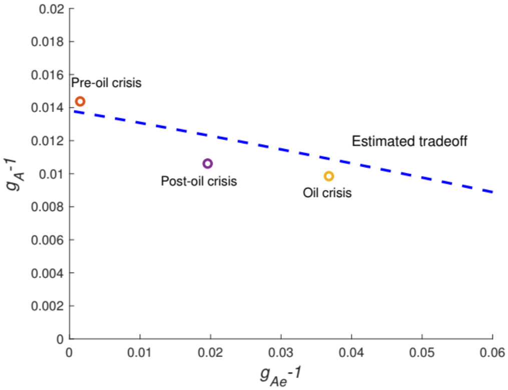
$$\frac{dg_{A_e}}{dg_A}\frac{g_A}{g_{A_e}}.$$

- Formal result in HKO:

$$\frac{1-e^{share}}{e^{share}} = -\frac{dg_{A_e}}{dg_A}\frac{g_A}{g_{A_e}}.$$

- This elasticity can be estimated.

Technology trade-off



- Our estimate: $-\frac{dg_{A_e}}{dg_A}\frac{g_A}{g_{A_e}} = 13.7 \Rightarrow e^{share} = \frac{1}{13.7+1} = 0.068.$
- Historic relation implies that we don't need to worry about the return of Max Max.

Convergence and increasing energy use.

- In a balanced growth path, the use of a natural resource in finite supply must necessarily fall over time.
- However: convergence is slow – it may take many decades for to substantially change the relative level of the two technologies.
- Then, due to the low short-run elasticity between capital/labor and fuel. The latter and GDP may grow together for a long time although eventually fuel growth must become negative.

Green vs Brown energy

- A similar approach can also be used to model green vs. brown technology advances. Production is

$$Y_t = A_t L^{1-\alpha-\nu} K_t^{\alpha} E_t^{\nu}$$

$$E_t = \left[\left(A_t^g e_g \right)^{\frac{\varepsilon-1}{\varepsilon}} + \left(A_t^b e_b \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

- Energy service provider sells E_t competitively. Decides the fuel mix $\frac{e_g}{e_b}$ and chooses the green and brown energy augmenting growth rate A_t^g and A_t^b subject to

$$G\left(\frac{A_t^g}{\bar{A}_{t-1}^g}, \frac{A_t^b}{\bar{A}_{t-1}^b} \right) = M.$$

- FOC for choice of A_t^g and A_t^b implies

$$e_g^* = \Lambda G_{A^g}\left(.,.\right) \text{ and } e_b^* = \Lambda G_{A^b}\left(.,.\right)$$

- LHS's are values of increasing A_t^g and A_t^b. A tax on brown energy increases e_g and reduces e_b which increases A_t^g and reduces A_t^b.

Path dependence

- Interior choice of R&D direction along balanced growth path if $\varepsilon < 1$.
- If the short run elasticity of substitution between green and brown is larger than unity, $\varepsilon > 1$, the technology choice is never interior. Only brown or only green innovation, also along growth path.
- Basis for Acemoglu et al. (2012)—AABH but with a slightly different model structure regarding R&D.
- Brown energy eventually leads to disaster.
- If brown for a long time has been the competitive energy source, $\frac{\bar{A}_t^b}{\bar{A}_t^g} >> 1$.Then little value of doing green R&D.
- A temporary R&D subsidy is necessary to push A^g high enough. After that, no policy is needed. Reasonable? Quantitative predictions?

Some conclusions

- Energy and capital/labor are complementary in the short run.
- Much less so in the longer run. Income shares of energy not trending. Likely due to endogenous technical change.
- Evidence that R&D direction responds to prices (and taxes).
- Similar mechanism likely to apply to green vs brown technologies. Elasticity of substitution lower in short than in long run. Arguably due to ETC.
- Not different from how we think of capital vs labor augmenting technical change.