“It’s the energy, stupid !”
Energy supply, physical constraints and the end of economic growth

Thomas Bourany

Firms’ dynamics and Growth

March 2020

Introduction – Motivation

- How does energy supply and demand affects growth ?

Introduction – Motivation

- How does energy supply and demand affects growth ?
- Historically production growth largely associated with energy utilization $\Rightarrow$ the best predictor of growth

Introduction – Motivation

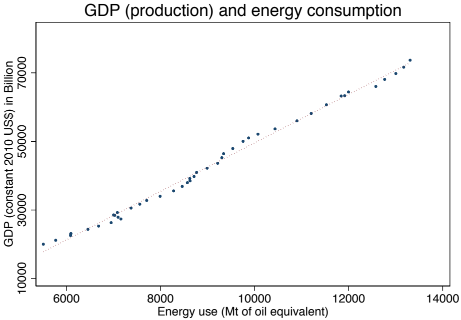
- How does energy supply and demand affects growth ?
- Historically production growth largely associated with energy utilization ⇒ the best predictor of growth
- Scarcity of non-renewable resources
  - Hubbert's peak for Oil : production peaks around 50% of oil reserves
  - Fossil energy production/supply doomed to decrease in this century
- Climate change and desire to reduce CO_2
  - Paris agreement : to stay below $1.5°c/2°c$, we would need to divide by 3 or 4 our carbon emissions
  - Comes through policy-driven reduction in energy demand
  - Technology in efficiency and renewable energy production not available in the next decades

Introduction – Motivation

- This project : provide a Malthusian explanation for secular stagnation and limits to growth
  - Real production growth limited by physical constraints

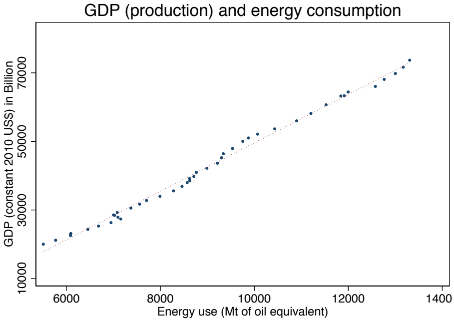
Introduction – Motivation

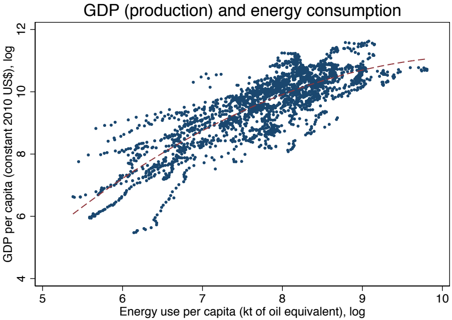
- This project : provide a Malthusian explanation for secular stagnation and limits to growth
  - Real production growth limited by physical constraints
  - Empirical evidence : link between energy use and production/growth



Introduction – Motivation

- This project : provide a Malthusian explanation for secular stagnation and limits to growth
  - Real production growth limited by physical constraints
  - Empirical evidence : link between energy use and production/growth





This project

- This project :
  - ⇒ provide a Malthusian explanation for secular stagnation
  - ⇒ quantify the effect of energy shortage on production growth
  - Secular stagnation : demand vs. supply stories
    - Decreasing trend in interest rates and growth
    - Demand : long-lasting effect of recession, rising inequality, "saving glut" and low consumer spending, demographics (aging pop°)
    - Supply : decline in TFP, innovation, dynamisms
    - ⇒ Alternative explanation : declining growth of energy production

This project

- This project :
  - ⇒ provide a Malthusian explanation for secular stagnation
  - ⇒ quantify the effect of energy shortage on production growth
  - Secular stagnation : demand vs. supply stories
    - Decreasing trend in interest rates and growth
    - Demand : long-lasting effect of recession, rising inequality, "saving glut" and low consumer spending, demographics (aging pop°)
    - Supply : decline in TFP, innovation, dynamisms
    - ⇒ Alternative explanation : declining growth of energy production
  - Theoretical exploration of these facts
    1. Firm response ? Unequal distribution of size/energy consumption across firms and within firm reallocation
    2. Aggregate response ? Reallocation across sector : energy as non-substitutable in production but differential use in different sectors

First line of this project

- Theoretical exploration of energy usage in production
- Firm response ?
  - Unequal distribution of size/energy consumption across firms and within firm reallocation

  $\Rightarrow$ Production function estimation with energy, capital and labor

  (?) Reallocation toward other factors ? or reduction in activity ?
  $\Rightarrow$ Quantitative/structural evaluation

First line of this project

- Theoretical exploration of energy usage in production
- Firm response ?
  - Unequal distribution of size/energy consumption across firms and within firm reallocation

  $\Rightarrow$ Production function estimation with energy, capital and labor

  (?) Reallocation toward other factors ? or reduction in activity ?
  $\Rightarrow$ Quantitative/structural evaluation
  - Model of energy use : Putty-Putty (Pindyck-Rotemberg – 1983) vs. Putty-Clay, c.f. Atkeson and Kehoe (1999)

$$y = G(F(k,e),\ell) \qquad\qquad y = G(z,\ell) - pm$$

$$F(k,e) = \left[\omega_F k^{1-\alpha} + (1-\omega_F)e^{1-\alpha}\right]^{\frac{1}{1-\alpha}} \qquad z = \int_V \min\{k(v)/v\,;e(v)\}f(v)dv$$

$$G(F,\ell) = \left[\omega_G F^{1-\beta} + (1-\omega_G)\ell^{1-\beta}\right]^{\frac{1}{1-\beta}} \qquad \text{s.t. } m = \int_V e(v)f(v)dv$$

Second line of this project

- Theoretical exploration of macroeconomic effect of energy shock
- Aggregate response ? Reallocation across sector : energy as non-substitutable in production
  - Network approach – Farhi & Baqaee (2019)
    - Differential use of energy in different sectors
    - Input-output matrices Ω : direct exposure (expd. share of input on revenue)
    - Leontieff-inverse matrix $\Psi = (I - \Omega)^{-1}$: total indirect exposure
    - Domar Weights $\lambda = b'\Psi$ (share of sale of a producer on agg. revenue)
    - Supply shock (analogous to TFP shock A ?) or reallocation Λ

$$d \log Y = \lambda' d \log A + \Lambda' d \log \Lambda$$

Second line of this project

- Theoretical exploration of macroeconomic effect of energy shock
- Aggregate response ? Reallocation across sector : energy as non-substitutable in production
  - Network approach – Farhi & Baqaee (2019)
    - Differential use of energy in different sectors
    - Input-output matrices Ω : direct exposure (expd. share of input on revenue)
    - Leontieff-inverse matrix $\Psi = (I - \Omega)^{-1}$: total indirect exposure
    - Domar Weights $\lambda = b'\Psi$ (share of sale of a producer on agg. revenue)
    - Supply shock (analogous to TFP shock A ?) or reallocation Λ

$$d \log Y = \lambda' d \log A + \Lambda' d \log \Lambda$$

(?) Reallocation toward other sectors ? What is the (differential) impact on upstream industries ?

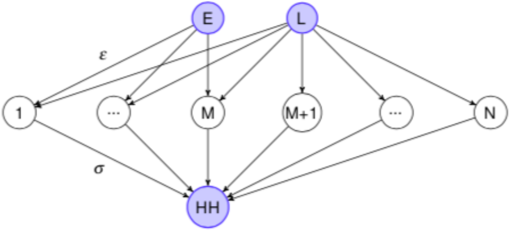
(?) Quantitative assessment of the transmission/amplification effects and mechanisms

Second line of this project

- Network approach – example in Farhi & Baqaee (2019)
  - Energy example : Two factors, electricity E and labor L
  - Downstream sectors use electricity and labor with elasticity $\varepsilon < 1$
  - Final demand uses downstream sectors with elasticity $\sigma \gg \varepsilon$

Second line of this project

- Network approach – example in Farhi & Baqaee (2019)
  - Energy example : Two factors, electricity E and labor L
  - Downstream sectors use electricity and labor with elasticity $\varepsilon < 1$
  - Final demand uses downstream sectors with elasticity $\sigma \gg \varepsilon$



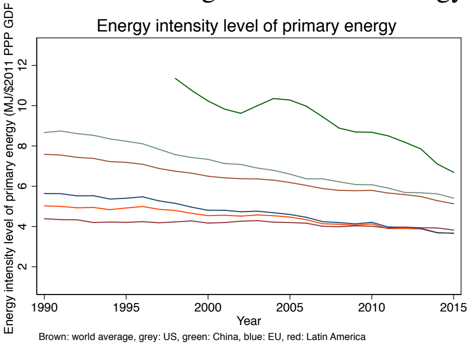
$$\frac{d^2 \log Y}{d \log E^2} = \frac{d\Lambda_E}{d \log E^2}$$

$$= \Lambda_E \frac{(\varepsilon-1)(1-\frac{N}{M}\Lambda_E) + (\sigma-1)\Lambda_E(N-1)}{1+(\sigma-1)\Lambda_E \frac{\frac{N}{M}-1}{1-\Lambda_E} + (\varepsilon-1)\frac{1-\frac{N}{M}\Lambda_E}{1-\Lambda_E}}$$

$$\underset{M=N}{=} \Lambda_E \frac{(\varepsilon-1)(1-\Lambda_E) + (\sigma-1)\Lambda_E(N-1)}{\varepsilon}$$

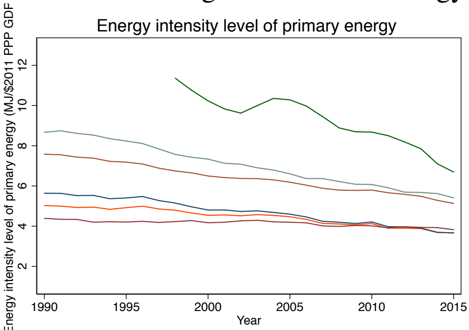
Is green(er) growth possible ?

- Limits to growth without energy and greenhouse gas emission

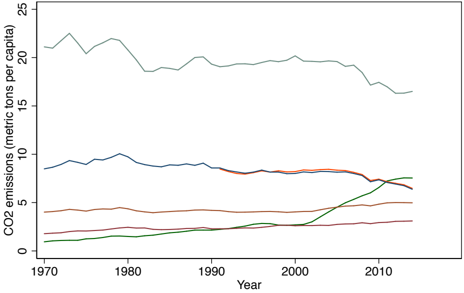


Is green(er) growth possible ?

- Limits to growth without energy and greenhouse gas emission



Brown: world average, grey: US, green: China, blue: EU, red: Latin America



Brown: world average, grey: US, green: China, blue: EU, red: Latin America

- Steady decline in energy production efficiency :
  - Energy returned on energy invested (EROEI) stagnating (increasing for fossil fuels/declining too slowing for renewable)

Is green(er) growth possible ?

- KAYA identity (or $I = PAT$: popul° P, affluence A & technology T)

$$CO_2 = P \times \frac{Y}{P} \times \frac{E}{Y} \times \frac{CO_2}{E}$$

- Controlling CO_2 emissions by leveraging other factors :
- Reduction due to :
  - Reduced emission due to cleaner energy CO_2/E, Efficiency E/Y or... growth Y/P !