Energy and Economic Growth: Many Questions, Some Answers

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1 Introduction

Two sets of questions that we really need to understand concerning energy:

1. What is the outlook for **energy availability**?

2. What are the implications of energy availability for **GDP**?

1.1 The Outlook for Energy Availability

- Question 1: What is the outlook for gross energy production?
  - There are two camps: Optimists and “peakists”.
  - Important question, but separate from today’s topic.

- Question 2: What is the outlook for net energy availability (EROEI)?
  - Drop in global EROEI from 20 to 10 over 10 years:
    - Equivalent to a ≈5% gross production loss (see Question 1).
    - Equivalent to a ≈0.5% p.a. lower production growth.
  - It gets much worse as EROEI declines to the renewables range < 10.
  - With low price elasticities of demand, this would be serious: Next page.

1.2 The Implications of Energy Availability for GDP

- Question 1: How would gross energy scarcity affect well-being and GDP?
  - Very high energy prices?
  - Very high demand destruction (GDP)?
- Question 2: How would net energy scarcity affect well-being and GDP?
  - Same as for gross energy scarcity?
  - Plus: More work for less consumption?
- Empirical Answers: Inconclusive (Pablo-Romero & Sanchez-Braza (2015)).
- Theoretical Answers: Depends on key aspects of the production function:
  1. What is the substitution elasticity between energy and other factors?
  2. What is the output contribution of energy?
  3. What is the connection between energy and technology?
- Theoretical specifications critically affect empirical investigations!

2 The Substitution Elasticity of Energy

2.1 Mainstream Economics

- Low elasticity in short run, much higher elasticity in long run.
- Reason: **High prices** stimulate substitution.

2.2 Alternative: Entropy

- Low elasticity in short run, even lower elasticity in the very long run.
- Reason: **Low quantities** eventually make further substitution impossible.
- Story: After extreme cuts in energy use, entropy starts to degrade capital.
- Implication: From then on, energy and labour/capital in fixed proportions.
- The lower the elasticity, the less the output share of energy matters.

3 The Output Contribution of Energy

3.1 Mainstream Economics

- Finds low output contribution, equal to the cost share (5%-10%).
- This means there is not too much to worry about from energy scarcity.
- The typical production function (if it features energy at all):

$$y_t = (Labour_t)^{\alpha} (Capital_t)^{\beta} (Energy_t)^{1-\alpha-\beta}$$

- Problem:
  - Implies labour and capital can function without energy.
  - Very high energy prices make you use capital instead.
  - This is grossly inconsistent with physics.
  - This is the production function of the shopkeeper.
  - It is not the production function of the engineer or physicist.

3.2 Non-Mainstream Literature

- Biophysical economics.

- Attempts to come up with production functions of the engineer/physicist.

- Finds much higher output contribution, sometimes up to 50%.

- But the production function specifications are open to critique.

- Today I will discuss two alternative specifications:
  - Kumhof and Muir (2014): Technology Externality.
  - Domingos, Keen and Kumhof (ongoing): L and K harness energy.

3.3 Alternative 1: Technology Externality

- Energy is a critical enabler of key technologies (Bob Ayres).
- In other words, technology is only possible because of energy.
- Energy's benefits are partly external and not reflected in cost shares.
- The proposed production function ($E_t =$ energy):

$$y_t = \left((1-\eta)^{\frac{1}{\epsilon}} \left((L_t)^{\alpha} (K_t)^{1-\alpha} \right)^{\frac{\epsilon-1}{\epsilon}} + (\eta)^{\frac{1}{\epsilon}} \left(\left(\frac{E_t^{technology}}{E_{baseline}} \right)^{\xi} E_t \right)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$$

  - E_t is priced like a regular factor, and accounts for low cost share.
  - $E_t^{technology}$ is not priced, and accounts for high output contribution:
    - If this is important: Low gross energy production $=$ big problem.
    - If this is important: Low EROEI $=$ big problem.

3.4 Alternative 2: L and K Are Means to Harness Energy

- GDP is useful work.
- Capital and labour harness energy to produce useful work.
- Labour can only harness a close to constant amount of energy κ.
- But capital can in principle harness unbounded amounts of energy.
- Capital per se does not matter, only harnessed energy matters.
- The proposed production function:

$$y_t = (Labour_t * \kappa)^{\alpha} (Energy_t * x_t * e_t)^{1-\alpha}$$

  - $x_t < 1 =$ exergy to energy ratio (available energy).
  - $e_t < 1 =$ efficiency of use of energy.

3.5 Implications of Alternative 2 for Many Areas of Economics

- Natural sciences:
  - This does bring physics/entropy/ecology into production theory.
  - Can we think of even better ways of bringing in physics?
- Productivity:
  - "Solow residual" is output contribution from harnessed energy.
  - Can we show that this accounts much better for output growth?
- Inequality:
  - Factor rewards have little connection with "marginal productivity".
  - Instead, rewards to L and K must be determined in other ways.
  - Is it bargaining power?
  - What is the "efficient" distribution of bargaining power?

4 Conclusion: No complacency, please!

- The Problems:
  1. Continued growth of gross energy production may be difficult.
  2. Decline of EROEI (net-to-gross energy ratio) seems certain.
  3. Substitutability between energy and K/L may have physical limits.
  4. Our vaunted "technological progress" may have been energy all along.
  5. Our cherished "capital" may only matter because it harnesses energy.

- The Implications:
  - These problems are of first-order macroeconomic importance.
  - There is not nearly enough research in this field.
  - Especially research that reaches the mainstream.
  - Especially outside-the-box and interdisciplinary research.
  - Let's get started!