The economic problem as an interplay among desires, matter and energy

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Introduction

- Broad question:

  Can energy be used to understand economic systems?

Introduction

- On the relation between energetic and economic variables
  - Labor (Mountain, 1985) and capital (Tatom, 1979)
  - Market prices (Liu et al., 2008)
  - Income (Asafu-Adjaye, 2000) and GDP (Lee, 2005, 2006)
  - Macro variables (Kilian, 2008; He et al., 2010)
- Remarkable lack of consensus

Introduction

- Within the neoclassical doctrine
  - Energy consumption and growth (Lee, 2006; Stern, 2000)
  - Oil price shocks (Cologni & Manera, 2008; Kilian, 2008)
- Between neoclassics and biophysical economists
  - Energy is fundamental (Podolinski, 1880; Costanza, 1980; Ayres, 1998)
  - ...it is not (Berndt, 1980; Bohi, 1989; Denison, 1985)

Introduction

- What has been done using neoclassical procedures?
  - Energy markets (Atkinson & Halvorsen, 1976; Bhattacharyya, 2011)
  - Energy efficiency (Levinson, 1978; Palmer & Walls, 2015)
  - Greenhouse gas emissions (Murray et al., 2014; Acemoglu et al., 2016)

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  - Greenhouse gas emissions (Murray et al., 2014; Acemoglu et al., 2016)
- What has been done using energy principles?
  - Early work (Podolinsky, 1880; Soddy, 1933; Cottrell, 1955; GR, 1971)
  - Theories of value (Costanza, 1980; Alessio, 1981; Patterson, 1998)
  - Biophysical and ecological economics (Cleveland et al., 1984; Odum, 1996; Ayres, 1998; Gillett, 2006; Hall & Klitgaard, 2012)

Introduction

- What has not been done?
  - Integrate energy principles with neoclassical procedures in a *comprehensive, systematic* way

Basic building blocks

1. Gaps as the necessary condition of the economic problem

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2. Goods as material arrangements that close gaps

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3. Work as energy transfers that produce goods

Energy variables

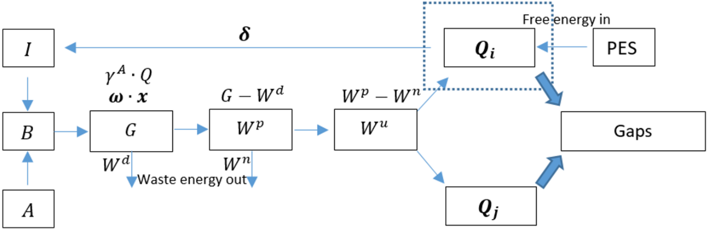

Figure: The process that closes gaps

Energy and prime movers

Figure: Energy goods

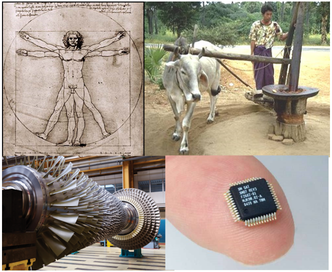

Figure: Prime movers

How to do this?

- Energy and power as the fundamental "scarce means"

"Economics is the science which studies human behaviour as a relationship between ~~ends~~ gaps and scarce ~~means~~ energy and power which have alternative uses."

(Modified) Robins, 1932

Energy expenditure minimization

$$\begin{aligned} \min_{\boldsymbol{x_k}} \quad & G_k = \boldsymbol{\omega_k x_k} \\ \text{s.t.} \quad f(\boldsymbol{x_k}) & \geq \overline{Q_k} \\ x_l & \leq \overline{x_l} \qquad \forall l = 1, \ldots, L \end{aligned}$$

- G_k = Total energy (direct plus indirect) spent on good k
- $\boldsymbol{\omega_k}$ = Energy dissipated at full workload per prime mover
- $\boldsymbol{x_k}$ = Quantity of prime movers used on k
- $f(\boldsymbol{x_k})$ = Production function relating $\boldsymbol{x_k}$ to Q_k

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$$\begin{aligned} \frac{\partial x_1^*}{\partial \omega_1} &= \frac{-f_1^2}{|H|} < 0 \\ \frac{\partial x_2^*}{\partial \omega_1} &= \frac{f_1 f_2}{|H|} > 0 \\ \frac{\partial G_k}{\partial Q_k} &= \gamma_k \end{aligned} \tag{1}$$

Energy surplus maximization

$$\max_{Q_i, x_i} \quad E = I - \boldsymbol{G_i i}$$

$$\begin{array}{rcccc} \boldsymbol{\delta_i Q_i - G_i i}: & \frac{\partial E_i}{\partial Q_i} & \Longrightarrow & \delta_i = \gamma_i & \forall i = 1, \ldots, m \\ \boldsymbol{\delta_i f(x_i)} - \boldsymbol{\omega_i x_i}: & \frac{\partial E_i}{\partial x_l} & \Longrightarrow & \boldsymbol{\delta_i f_l} = m\omega_l & \forall l = 1, \ldots, L \end{array}$$

- $E =$ Total energy surplus
- $I = \boldsymbol{\delta_i Q_i} = \boldsymbol{\delta_i f(x_i)} =$ Energy income
- $\delta_i =$ Energy content of energy good i

Energy surplus maximization

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- More refutable hypothesis
  - Own and crossed substitution effects of prime movers
  - Energy content effect on prime movers and quantity

Utility maximization subject to energy constraints

$$\max_{\boldsymbol{Q_k}} \quad U(\boldsymbol{Q_k})$$
$$\text{s.t.} \quad \gamma_{\boldsymbol{k}}^{\boldsymbol{A}} \boldsymbol{Q_k} \leq I$$

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$$\sum_{j=1}^{n} \gamma_j Q_j + \sum_{i=1}^{m} \int_0^{Q_i} \gamma_i(Q_i) dQ_i \leq \sum_{i=1}^{m} \delta_i Q_i$$

Utility maximization subject to energy constraints

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$$\sum_{j=1}^{n} \gamma_j Q_j \leq E$$

More results

- Tangency conditions
- Marshallian and Hicksian demands
- Engel and Cournot Aggregations

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  - 'Marginal utility of energy' embodied energy effect

Long-run (no power constraints)

Setting production equal to consumption, long-run eq. es characterized by:

- $\delta_i = \gamma_i \qquad \forall i$
- $\delta'_j = \frac{U_j}{\lambda} \qquad \forall j$

Together with tangency conditions, this guarantees Pareto efficiency

Short-run (active power constraints)

Assume $x_1^* > \bar{x}_1$

- $\delta_i = \gamma_i + \phi_1 \cdot f^{-1}(Q_i, x_{i,-1}) \qquad \forall i$

$\rightarrow$ The equimarginal principle no longer holds

Where:

- ϕ_1 = Marginal energy surplus of prime mover 1
- $f^{-1}(\cdot)$ = Marginal technical requirements of production function
- $x_{i,-1}$ = all prime movers used to produce i except 1

Short-run (active power constraints)

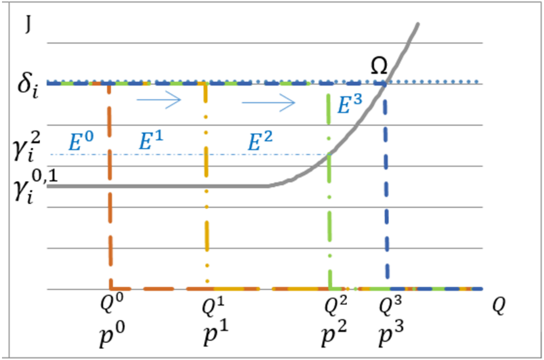
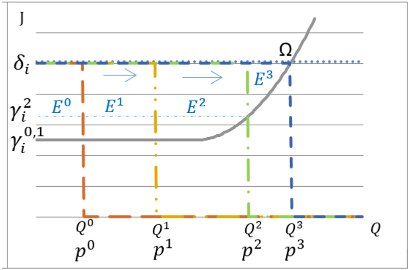


Figure: Evolution from the short to the long-run

Energy transitions

- Agriculture in China
- The steam engine in England



Final remarks

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- Three building blocks
- Energy-based optimization procedures

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    - Test hypotheses

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- Future research
  - Test hypotheses
  - Exchanging agents
  - Multi-period agents

Thank you

$$\omega_l = \frac{1}{K}\sum_{k=1}^{K}\phi_k \cdot f_{l,k} = \frac{1}{m}\sum_{i=1}^{m}\delta_i \cdot f_{l,i} = \frac{1}{n}\sum_{i=1}^{n}\frac{U_j}{\lambda} \cdot f_{l,j}$$