A theoretical framework to study the economic importance of energy

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An empirical regularity

Costanza & Herendeen (1984)

Fig. 2. Log-log plots of embodied energy inputs vs. dollar output for the 87 sector data, for three years and two alternative direct energy input vectors.
An empirical regularity

Liu et al. (2008)

Fig. 4–Correlation between total energy cost for refinement and the market value of each mole of the elements total energy cost for refinement $\Sigma E$ closely correlate to the market value of the elements (correlation coefficient $r^2=0.80$) when $a/b = 13$ in Eq. (1). The correlation is held through the investigated 40-year period. Prices are in 1992 constant US dollar.
An empirical regularity

Gutowski et al. (2013)

**Figure 6.** Price of various materials plotted against the embodied energy of the materials. The data for embodied energy comes from Ashby (10), for material prices for metals from the Mineral yearbooks (17), plastics from IDES (28) and brick, wood and glass from Ashby (10). Plastic prices are for year 2011, and all others are for 2009.
Why are prices proportional to embodied energy?

- **Energy is absent from the core of neoclassical micro theory**

  (Samuelson & Nordhaus, 2004; Silberberg & Suen, 2001; Mas-Colell et al., 1995;)

- Energy's cost share is low (<10%) (Csereklyei et al., 2016; Ayres et al., 2013; Lindenberger & Kummel, 2011)

- An energy theory of value creates more problems than it solves (Huettner, 1982; Alessio, 1981; Webb & Pearce, 1975)
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- Marginal energy costs are related to average embodied energies
Two key ideas

- Goods are material rearrangements (Ryan & Pearce, 1985; von Mises, 1949)
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- Means are energy transfers (when they further human purpose)

- Only when they further human purpose
Intertemporal utility maximization

The agent’s main objective is

$$\max_{Q_{FT}} U(Q_{F1}, Q_{F2}, \ldots, Q_{FT})$$

s.t. $$\tau_{ft}' Q_{Ft} \leq E_t \quad \forall t \in T$$

with

- **$Q_{ft}$**: Final good $f$ during period $t$
- **$\tau_{ft}'$**: Good $f$’s average energy cost during $t$
- **$E_t$**: Energy surplus during $t$
Intertemporal utility maximization

The FOC to choose optimal quantity of $Q_{ft}$ is

$$\frac{U_{ft}}{\lambda_t} = \tau_{ft} \quad \forall \ f \in F, \ t$$

with

- $\lambda_t$: Marginal utility of energy surplus during $t$
- $\tau_{ft}$: Good $f$’s *marginal* energy cost during $t$
Minimization of direct energy transfers

Given the energy budget constraint, a secondary objective is to minimize direct energy transfers subject to productive and prime mover constraints. The FOC of this problem is

\[ \tau_{kt} = \psi_{kt} + \theta_{kt} \quad \forall \; k, t \]

with

- \( \psi_{kt} = \frac{1}{L} \sum \epsilon_l g'_{-lkt} \): Average direct energy transfers at the margin
- \( \theta_{kt} = \frac{1}{L} \sum \phi_{lt} g'_{-lkt} \): Average indirect energy transfers at the margin
Other secondary objectives

Energy surplus maximization

\[ \tau_{et} = \beta_t 1 \delta_e \quad \forall \ e, t \]

Prime mover accumulation

\[ \tau_{lt} = \sum_{i=1}^{T} \beta_{ti} \phi_{li+1} d_{i}^{i-1} \quad \forall \ l, t \]

Energy surplus assignment

\[ \tau_{ft} = (1 - \rho_t) \Lambda_{ft} \quad \forall \ f, t \]
Gains from trade

- Following conventional ricardian logic, if ‘agent 1’ exchanges $q_B$ units of good $B$ for $q_C$ units of good $C$ with ‘agent 2’, and both consume the same as under autarky, gains from trade are

\[
GT = \int (\tau^2_B - \tau^1_B) dq_B + \int (\tau^1_C - \tau^2_C) dq_C - TC
\]
Gains from trade

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$$GT = \int (\tau_B^2 - \tau_B^1) dq_B + \int (\tau_C^1 - \tau_C^2) dq_C - TC$$

- Under broad conditions $GT > 0$
The commodity price

- Maximizing $GT$ choosing $q_B$ and $q_C$ yields

$$\tau_i = \tau_{iE} + MTC_i$$  \hspace{1cm} (2)

with

- $\tau_i$: Marginal energy cost of good $i = B, C$ of the importing agent
- $MTC$: Marginal transaction cost of good $i = B, C$
The commodity price

- Maximizing $GT$ choosing $q_B$ and $q_C$ yields

$$\tau_i^I = \tau_i^E + MTC_i$$

with

- $\tau_i^I$: Marginal energy cost of good $i = B, C$ of the importing agent
- $MTC$: Marginal transaction cost of good $i = B, C$

- Under (3) and no transaction costs, optimal exchange involves the commodity price

$$\frac{q_B}{q_C} = p^c = \frac{\tau_C}{\tau_B}$$
The real money price

- Barter is very inconvenient
The real money price

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- Define real money $m$ with marginal energy cost $\tau_m$
Barter is very inconvenient

Define real money $m$ with marginal energy cost $\tau_m$

The commodity price between any good $k$ and real money is $k$’s real price

$$p_k = \frac{\tau_k}{\tau_m}$$
The nominal money price

- Real money is also inconvenient
The nominal money price

- Real money is also inconvenient
- Define a representation of real money as $n$. The commodity price between both yields $n$’s purchasing power

\[ \tau_s = \frac{\tau_m Q_m}{Q_n} \]
The nominal money price

- Real money is also inconvenient
- Define a representation of real money as \( n \). The commodity price between both yields \( n \)'s purchasing power

\[
\tau_s = \frac{\tau_m Q_m}{Q_n}
\]

- The commodity price between any good \( k \) and nominal money is \( k \)'s nominal price

\[
P_k = \frac{\tau_k}{\tau_s}
\]
Market prices and average embodied energies

- The relation between marginal energy costs and average embodied energies is

\[ \tau_k = \gamma_k + (\theta_k - \vartheta_k) \]

with

- \( \gamma_k \): Marginal embodied energy of good \( k \)
Market prices and average embodied energies

- The relation between marginal energy costs and average embodied energies is

\[ \tau_k = \gamma_k + (\theta_k - \vartheta_k) \]

with

- \( \gamma_k \): Marginal embodied energy of good \( k \)

- Considering the relation between marginal and average values, nominal prices are

\[ P_k = \frac{\gamma_k^A (1 + \mu_k) + (\theta_k - \vartheta_k)}{\tau_s} \]
Highlights of the model

- Means as energy transfers
Highlights of the model

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- Marginal energy costs as complex variables with economic intuition
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Further implications

- New layer to microeconomic analysis - Price formation, Nonmarket valuation
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- New micro-foundation for macroeconomics - Growth, interest rates, inflation, inequality
Thank you