Investment, Technological Progress and Energy Efficiency

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Table of contents

Introduction

1. Introduction
   - General motivation
   - Energy and the macroeconomy
   - This paper

Issues

Goal:

A theory of energy use: the interaction between technical change and energy-efficiency and its consequences on prices, output and productivity

Key driver: energy price changes

We are silent on:

- the equilibrium price of energy (exogenous)
- the forces behind technological progress (exogenous)

Issues

A simple narrative:

- Machines use energy (that it is embodied somehow)
- There are different efficiencies (at a cost), choice depend upon p^e
- There is also ISTC: new machines are better than old when new (quality improvements or/and cost to produce capital goods)
- Aggregate decision is to install plants (machines) of efficiency v at vintage z ($\equiv$ ISTC), at prevalent both p^e and state of technology.
- As time goes by, the energy requirement and the p^e can make the machine not profitable
  - We start with the Cobb-Douglas case anyhow: important lessons
- Without substitution, scrapping might be an issue.
  However, we may think that energy use is not key for scrapping.

Issues

In perspective

The above story:

"Greenwood, Hercowitz and Krussell (*AER,* 1997) **meets** Atkeson and Kehoe (*AER,* 1999)" – passing by Díaz and Puch (*RED,* 2004)

1. vintage capital (Greenwood-Hercowitz-Krussell)
   1.1 capital heterogeneous by age (quantitative Solow (1960))
   1.2 ISTC a key source of growth and fluctuations (thanks to Gordon (1990))
2. putty-clay (Atkeson-Kehoe)
   2.1 capital with different energy intensity (reduced-form)
   2.2 short & long run elasticity of energy use to prices
3. Short-run elasticity seems to have fallen in recent years

Issues

This paper

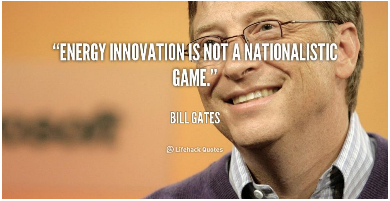
After the “meeting” above, important lessons:

- (Intermediate stop: Solow (1960) with energy) If energy demand is elastic, energy efficiency and use at the macro level only depends on energy prices, not on technical progress.
- Our theory gives us insights about the effects of different margins of ISTC $\Rightarrow$ ISTC at the intensive margin is an energy saving device.

Why important?

Motivation

Motivation: policy



The proposed policy measures are:

1. Increasing energy efficiency in the industry, building and transport sectors.
2. ...

(a) The policy debate

Motivation

Motivation: technical

(...) authors [...some big names...] err in attributing [differences in price indexes for equipment] entirely to quality change, and err even more by equating "quality adjustments" to the concept of "technological change embodied in equipment"

Robert J. Gordon, *NBER Macro Annual,*1996, p. 262

Where does the mistake come from? See our paper
(same tech frontier allows production of inexpensive energy-inefficient and expensive energy-efficient machines)

Motivation

Motivation: data

For data, wait!

Better fix some ideas first, and even introduce some theory:

Energy and the macroeconomy

The response of energy demand to price changes

(Pyndick & Rotemberg, AER, 1983; Killian JEL 2008)

- Aggregate energy demand has a short-run low elasticity; higher in the long run (facts 1&2).
- This elasticity seems to have *fallen* in recent years (fact 3).
- The response of GDP to changes in energy prices has decreased, (Blanchard & Gali, 2007) – smaller impact (fact 4).

Despite the environmentally concerned view about climate change.

[Atkeson and Kehoe (2000) or Díaz and Puch (2004) better response than standard model (reduced form) because different type of capital is in place]

Energy and the macroeconomy

The key issue

How changes in energy prices affect the macroeconomy?

- Financial side of the economy: Precautionary purposes, alternative commodities, role of monetary policy.
- Production of goods:
  - Imperfect competition (prices of intermediate goods affect mark-ups). Further, imperfect competition (the very nature of the energy technology) makes the supply of energy (heavily regulated sector) responsive to changes in aggregate energy demand.
  - technology and changes in energy efficiency.

We need a quantitative model to asses the magnitude of such effects. For the blue part, see Díaz and Puch (2013) – under revision.

Climate change – **Taxes** Marrero et al. '14, [de Castro & Puch '15].

This paper

Key elements

- Capital of vintage z, and age $t - z$ (capital heterogeneous by age). A plant is created by installing one unit of capital.
- Investment-Specfic Technical Change:
  - 1 unit of final good transforms into Θ_t units of capital of vintage $t+1$ (extensive margin of ISTC)
  - Λ_z is the level of embodied technology at time z (quality improvements, intensive margin of ISTC)
- First (Solow '60 with energy), all plants same energy efficiency.

  Our theory: capital can be installed with different energy intensities v ($\equiv$ engine power), $1/v$ is energy efficiency (a choice variable).

  Thus, units of capital of vintage $t+1$ and efficiency v will be produced.

Solow 1960 with energy

2 Solow 1960 with energy
- Technology and Preferences
- Properties of equilibrium
- ISTC and Energy

The environment

The vintage technology with energy

A plant is created installing one unit of capital

$$\pi_t(z) = \max_{\substack{y_t(z)\geq 0,\, h_t(z)\geq 0,\\ e_t(z)\geq 0,\, \kappa(z)\geq 0}} \quad y_t(z) - w_t\, h_t(z) - p^e\, e_t(z)$$

s. t.

$$y_t(z) \leq A_t\, \kappa_t\,(z)^{\alpha}\, h_t\,(z)^{1-\alpha},$$

$$\kappa_t\,(z) \leq {\Lambda_z}^{\frac{\mu-1}{\mu}}\, e_t(z)^{\frac{1}{\mu}}, \quad \mu > 1.$$

The owner of the plant collects the profit
(i.e., the capital rent net of energy expenditures).

standard technology

The environment

The production of capital

- The production of capital uses a linear technology in final good.
- The new capital produced is the new vintage $t+1$, which yields higher services.
- $\pi_t^x = \max_{x_t \geq 0} \left[p_t\,(t+1)\;\Theta_t - 1 \right] x_t$ the profit of the sector.

The environment

The Household problem

$$\max \quad E_0 \sum_{t=0}^{\infty} \beta^t \log(c_t)$$

s. t. $$c_t + \sum_{z=-\infty}^{t+1} p_t(z)\, k_{t+1}(z) + b_{t+1} \leq$$

$$w_t\, \hbar + \left(1 + r_t^b\right) b_t + \sum_{z=-\infty}^{t} \left[(1-\varpi)\, p_t(z) + \pi_t(z)\right] k_t(z) + \pi_t^x,$$

$$k_{t+1}(t+1, v) \geq 0,$$

$$b_{t+1} \geq \underline{b},$$

$k_0(z),\ z \leq 0,\ b_0,$ and energy prices given.

▸ Eq'm def

Properties of eq'm

Allocations of inputs at the plant level

- The demand of energy is linear in vintage $\Rightarrow$

$$\frac{e_t(z_1)}{e_t(z_2)} = \frac{\kappa_t(z_1)}{\kappa_t(z_2)} = \frac{h_t(z_1)}{h_t(z_2)} = \frac{y_t(z_1)}{y_t(z_2)} = \frac{\Lambda_{z_1}}{\Lambda_{z_2}}.$$

- The profit of the plant is the share of capital net of energy expenditure, $\pi_t(z) = \frac{\alpha\,(\mu-1)}{\mu}\, y_t(z)$.
- Value added at the plant level is

$$va_t(z) = \left(\frac{\mu-\alpha}{\mu}\right)\left[\frac{\alpha}{\mu\, p_t^e}\, A_t^{\frac{\mu}{\alpha}}\right]^{\frac{\alpha}{\mu-\alpha}} \Lambda_z^{\widetilde{\alpha}} h_t(z)^{1-\widetilde{\alpha}},\ \widetilde{\alpha} = \frac{\left(1-\frac{1}{\mu}\right)\alpha}{1-\frac{\alpha}{\mu}}.$$

Properties of eq'm

The price of capital (and the aggregation of capital and output)

The price of one unit of capital of vintage z is the present value of all future profits

$$p_t(z) = \sum_{i=1}^{\infty} \frac{(1-\varpi)^{i-1}}{\prod_{j=1}^{i}(1+r_{t+j})} \pi_{t+i}(z),$$

Since $p_t(t+1) = \Theta_t^{-1}$, this implies that

$$p_t(z) = \frac{\Lambda_z}{\Lambda_{t+1}} \Theta_t^{-1}.$$

The distribution of prices across vintages conveys information on both margins of ISTC.

Aggregation of capital | Aggregation of value added | Aggregate value added

The macroeconomics of ISTC and energy

Confronting the facts (I)

- The energy share on value added is constant at the plant level, regardless of the price:

$$\frac{p_t^e\, e_t}{y_t - p_t^e\, e_t} = \frac{\alpha/\mu}{1 - \alpha/\mu}.$$

- Energy use varies in the same magnitude that the price:

$$\frac{E_t}{Y_t - p_t^e\, E_t} = \frac{e_t}{y_t - p_t^e\, e_t} = \frac{\alpha/\mu}{(1 - \alpha/\mu)\, p_t^e}.$$

Facts

The macroeconomics of ISTC and energy

Confronting the facts (II)

- All plants operate with the same energy efficiency, $1/e_t(z)$, which only depends on the energy price.
- The capital to energy ratio is

$$\frac{K_t}{E_t} = \frac{K_t}{VA_t}\frac{VA_t}{E_t} = \frac{\mu - \alpha}{\alpha} p_t^e \frac{K_t}{VA_t}.$$

- K_t/E_t inherits all the price volatility. Look at the 1990s!!!!

Facts

3 Our theory

- Key features
- The environment
- Properties of equilibrium
- The aggregate economy
- ISTC and energy

Our theory

features heterogeneous capital

(To confront the facts) we need heterogeneity in two dimensions

1. ISTC: as before, over time, we produce better machines more efficiently ⇒ investment responds to changes in this (so does capital).
2. **Ex-ante given** energy efficiency: ⇒ to lower energy use, we need to invest in new machines.

   This brings about complementarity in energy: **vintage putty-clay**

Both dimensions interact in a complex way, depending on energy prices.

Remark: Remember efficiency v from the beginning! Now described.

Our theory

delivers

1. Energy efficiency and quality of capital (ISTC) change over time. Investment is needed to change the average efficiency of the economy ⇒ slow response of the economy to price changes.
2. ISTC (Investment specific technical change) interacts with energy efficiency. Higher ISTC is a sort of energy efficiency ⇒ We can give a rational to data patterns during the 1990s.
3. If ISTC is sufficiently high we can afford to be not very efficient (the energy bill is very small) and the economy becomes unresponsive to price changes (the 2000s).
4. The energy bill may be small, but absolute energy consumption may shoot up ⇒ Rebound effect.

▸ Facts

The environment

Miscellanea

- Preferences as before
- Capital indexed by its vintage, $z \in \mathbf{Z}$, and energy intensity $v \in \mathbb{R}_{++}$. Type v determines the amount of energy needed to produce capital services.
- Productivity at the plant level retains aggregate component, A_t, but it features now an idiosyncratic component, s, which is i.i.d. across plants and over time (to deal with complementarity).

  This idiosyncratic shock has a Pareto cumulative distribution function,

$$P(S \leq s) = 1 - \left(\frac{\sigma}{s}\right)^{\varepsilon}, \ \sigma > 0, \varepsilon > 0. \tag{1}$$

The environment

Capital services and energy efficiency

The amount of capital services, $\kappa_t(z,v,s)$, depends now on energy intensity, v, the level of embodied technology at time z, Λ_z (ISTC intensive margin), and the idiosyncratic productivity, s.

$$\kappa_t(z,v,s) = \begin{cases} \Lambda_z\, v^{1-\mu}\, s\, e_t(z,v,s), & \text{if } e_t(z,v,s) < v^{\mu}; \\ \Lambda_z\, v\, s & \text{if } e_t(z,v,s) \geq v^{\mu}. \end{cases}$$

$\mu > 1$. There is an upper bound to the scale of production at the plant.

Irreversibility, physical depreciation and production on newest vintage, the same.

Plants and capital
Irreversibility and new capital

The environment

Differences with Solow 1960

- Capital and energy are complementary at the micro level.
- To change average energy intensity in the economy, we need to invest in new more efficient capital (note $x_t(v)$).
- Intensive and extensive margins of ISTC play different roles.

Properties of eq'm

The plant's problem

▸ The problem of the plant

Profit maximization implies that

1. If $e_t(z,v,s) > 0 \Rightarrow e_t(z,v,s) = v^{\mu} \Rightarrow \kappa_t(z,v,s) = \Lambda_z\, v\, s \Rightarrow$ ISTC at the intensive margin is an energy saving device and

$$\frac{h_t\left(z_1, v_1, s\right)}{h_t\left(z_2, v_2, s'\right)} = \frac{y_t\left(z_1, v_1, s\right)}{y_t\left(z_2, v_2, s'\right)} = \frac{\Lambda_{z_1}}{\Lambda_{z_2}}\frac{v_1}{v_2}\frac{s}{s'}.$$

2. A plant of class (z,v,s) is used for a finite number of periods $T(z,v,s)$ (the wage rises faster than neutral progress) $\Rightarrow$ the utilization rate of capital is endogenous,
but this way it depends on the second moments of productivity.

▸ A lot

Properties of eq'm

The choice of energy efficiency of new capital

⋆

Monotonicity of the profit function implies that investment only takes place, at most, in one type of capital, $v_{t+1} \in I\!R_+$.

$$\Theta_t^{-1} = \sum_{i=1}^{\infty} \frac{(1-\varpi)^{i-1}}{\prod_{j=1}^{i}(1+r_{t+j})} E_{s \geq \underline{s}_{t+i}(t+1,v)} \pi_{t+i}(t+1, v, s), \; v_{t+1} \in I\!R_{++},$$

This simplifies the analysis.

▸ Utilization

Properties of eq'm

The price of capital (and the aggregation of capital and output)

Definition

The cost of one unit of capital of vintage $z \le t+1$, and efficiency type $v_z \in \mathbb{R}_{++}$ in units of gross output at time t is defined as

$$q_t(z, v_z) \equiv \Theta_t^{-1} \frac{\Lambda_z}{\Lambda_{t+1}} \frac{v_z}{v_{t+1}}, \; z \le t+1, \; v \in \mathbb{R}_{++}.$$

- Warning: This is not the market price of capital, which has a more complicated expression. At the BGP both prices are proportional.
- This price (as the market price) varies over time because of ISTC and because of the effect of energy prices in energy efficiency.

Aggregation of capital Aggregation of output

Properties of eq'm

Aggregation: summary results

The aggregate economy

Solving a quasi-SPP's

The evolution of the aggregates is

$$
\begin{aligned}
c_t + x_t &= \left(\frac{\varepsilon\,\sigma}{\varepsilon - 1}\right)^{\alpha} A_t\,\kappa_t^{\alpha}\,h_t^{1-\alpha} - p^e\,e_t,\\
e_{t+1} &= \upsilon_{t+1}^{\mu}\,\Theta_t\,x_t + (1-\varpi)\,e_t,\\
\kappa_{t+1} &= \Lambda_{t+1}\,\upsilon_{t+1}\,\Theta_t\,x_t + (1-\varpi)\,\kappa_t,
\end{aligned}
$$

By parametrizing the exogenous processes for Θ_t and Λ_{t+1} (together with A_t and p_t^e), we can characterize a BGP, and solve for the dynamics of the stationary version of the economy to explore the macroeconomics of ISTC and energy.

▸ Parametrization

The macroeconomics of ISTC and energy

Across steady states

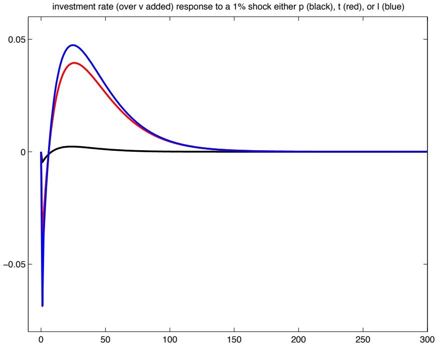
- Efficiency of capital varies across vintages.
- Energy use (per unit of value added) falls with the price but it also falls with ISTC.
- Value added per unit of capital increases more than energy use per unit of capital.
- Long run changes in ISTC change the lifespan of capital.

▸ Parametrization

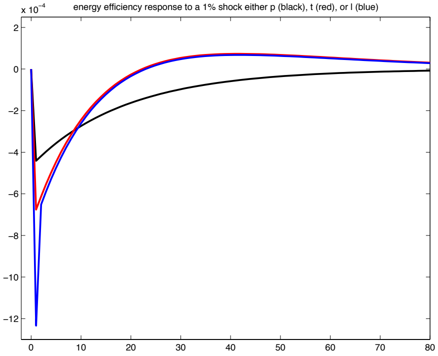
The macroeconomics of ISTC and energy

Impulse response functions: A transitory (with persistence) shock ↑ in p^e, λ, and θ (i)

The shock in p^e affects today, the ISTC shocks affect the return to investment.



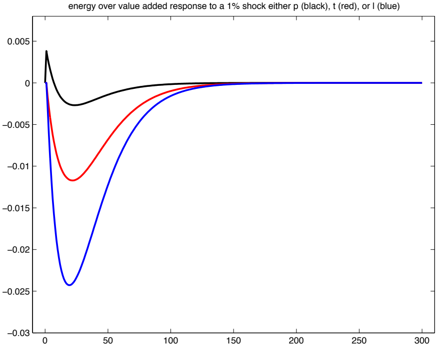
(b) Investment rate



(c) Efficiency of investment

The macroeconomics of ISTC and energy

Impulse response functions: A transitory shock ↑ in p^e, λ, and θ (ii)

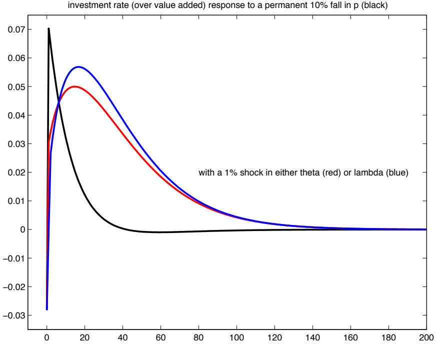


(d) E/VA

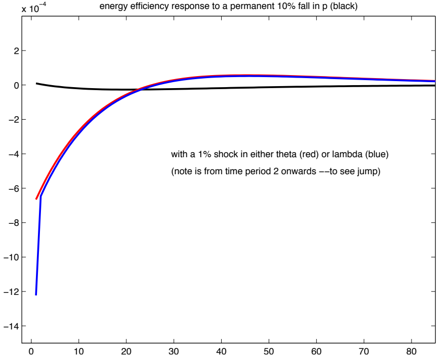
(e) K/E

The macroeconomics of ISTC and energy

Impulse response functions: A permanent ↓ shock in p^e, transitory ↑ in λ, and θ (i)



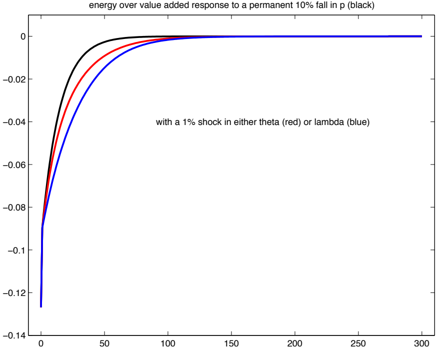
(f) Investment rate



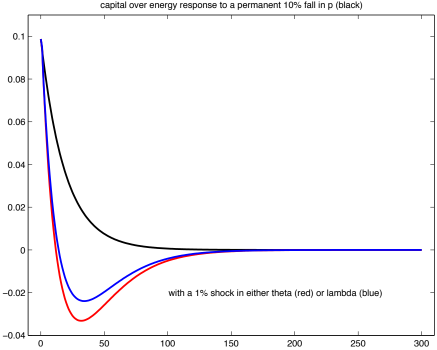
(g) Efficiency of investment

The macroeconomics of ISTC and energy

Impulse response functions: A permanent ↓ shock in p^e, transitory ↑ in λ, and θ (ii)



(h) E/VA



(i) K/E

Conclusion

- We develop a theory of investment and energy use to study the response of macroeconomic aggregates to energy price shocks.
- In particular, we show that the Cobb-Douglas paradigm cannot rationalize the facts.
- The model help to understand:
  - the interaction between the energy efficiency built in capital goods and the growth rate of ISTC
  - the contribution of quality improvements and energy efficiency to the price of capital
- We claim the model is a promising tool to quantitatively asses the magnitude of these effects.
- Important issues will be to identify intensive and extensive margins of ISTC, and the implications of productivity dispersion across plants for the age of capital