institute for structural research

Short- vs long-run response of energy demand to price change

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Motivation

$$d\log(emissions) = d\log(emissions/energy) + d\log(energy) =$$

$$= \left(\epsilon_{CI} + \epsilon_{p\tau}\epsilon_E\right) d\log(\tau)$$

where τ is the carbon price,

$$\epsilon_{CI} = \frac{\partial \log(emissions/energy)}{\partial \log(\tau)}$$

$$\epsilon_{p\tau} = \frac{\partial \log(p_E)}{\partial \log(\tau)}$$

$$\epsilon_E = \frac{\partial \log(energy)}{\partial \log(p_E)}$$

Elasticity of demand determines how much energy efficiency can be bought with carbon tax

Le Chatelier principle in Energy Economics

- Two effects of an increase in energy price:
  - Firm substitute energy with other factors of production (usually capital) along the isoquant defined by its current technology
  - In the long-run the firm switch to less energy-intensive and more capital-intensive technology
- Response of energy demand to price change larger in the long-run than in the short-run.
- Impact of the carbon tax larger in the long-run

3 steps of the project

- Investigate the effect of price induced technological adjustment on energy demand
- Investigate the path of energy demand from the moment of change in price until it reaches its new steady state.
- Examine the macroeconomic consequences of the long-run adjustment of energy demand.

Approach

- choice of technology modelled with World Technology Frontier (Caselli and Coleman (2005), Jones (2005) and Growiec (2008, 2013)).
  - Firms choose from the menu of technologies.
- add dynamics by embodying technology into capital stock (Krusell 1998)

Results – theory (focus of this presentation)

Tech choice model:

- Price induced tech adjustment reduced energy consumption (if capital and energy are gross compliments and energy is a small fraction of total cost)

Micro founded dynamic model:

- elasticity of demand larger in the long-run than in the short-run
- as time passes elasticity of demand approaches its long-run level exponentially at the rate that is determined by
  - capital depreciation rate and
  - the growth rate of the economy.

Results - simulations

- DSGE simulations: adjustment of energy demand
  - reduces the negative impact of CO_2 tax on GDP and
  - creates additional negative pressure on the employment in the mining sector.

Tech choice in energy literature

- No study applying tech choice theory to examine substitutability between energy and capital
- Several studies on (closely related) Induced/Directed Technological Change (DTC):
  - Casey (2017), Andree and Smulders (2014), Hassler, Krusell and Olovson (2016), Witajewski-Baltvilks, Verdolini and Tavoni (2017)
  - key difference: Tech Choice: a switch to (existing) energy-saving technologies; DTC: accumulation of energy-saving knowledge

Mickey Mouse model – the setup

- One product, many production methods
- Production method i takes the form

$$F_i = [(A_{iE}E)^\sigma + (A_{iK}K)^\sigma]^{\frac{1}{\sigma}}$$

where E and K stand for energy and capital

- Each production method is characterized by a different pait (A_{iE}, A_{iK})

Available technologies

- The set of available production methods is determined by the global technology paradigm (also known as *World Technology Frontier*)
- described by:

$$\frac{1}{\gamma} {A_E}^{\omega} + {A_K}^{\omega} \leq B$$

Parameters of the tech paradigm: B, γ, ω

Firms optimization

- The firm's maximization problem:

$$\max_{A_E, A_K, E, K} \left\{ \left[(A_E E)^\sigma + (A_K K)^\sigma \right]^{\frac{1}{\sigma}} - K - p_E E \right\}$$

subject to $\frac{1}{\gamma} {A_E}^\omega + {A_K}^\omega \leq B$

where p_E is the price of energy

Optimal choices

$$\log\left(\frac{E}{K}\right) = -\frac{1}{1-\sigma}\log(p_E) - \frac{-\sigma}{1-\sigma}\log\left(\frac{A_E}{A_K}\right)$$

$$\log\left(\frac{A_E}{A_K}\right) = \frac{-\sigma}{1-2\sigma+(\omega-1)(1-\sigma)}\log(p_E)$$

$$+\frac{1}{1-2\sigma+(\omega-1)(1-\sigma)}\log(\gamma)$$

Energy-capital ratio can decline because

- increase in p_E leads to substitution within a production method
- increase in p_E leads to the choice of energy-saving (high $\frac{A_E}{A_K}$) technologies
- change in the global paradigm (change in γ)

Dynamic model – setup

- The production method involves the use of a continuum of machines.

$$Y = \int_{i \in \Omega} (H_i x_i)^\alpha di$$

where Ω is the set of processes available and H_i is the unit productivity of process i

- The growth rate ofH_i, g will determine the growth of the economy
- A machine i uses Leontief technology to combine energy, E_i and capital, K_i and generate the composite x_i:

$$x_i = \min\{A_{Ki} K_i, A_{Ei} E_i\}$$

Machines availability

- At every instance of time the probability that the machine disintegrates is given by $1 - e^{-\delta}$.
- Later δ will determine capital depreciation rate.
- At the same time there is an exogenous inflow of new processes (e.g. due to R&D) at the rate n.

Firms choices

- At every instance the firm chooses
  - energy for every machine installed currently or in the past.
  - capital devoted to each machine installed at that instance of time.
  - technology (A_E and A_K satisfying $\frac{1}{\gamma}{A_E}^{\omega} + {A_K}^{\omega} \leq B$) for machines **installed at that instance of time**.

Model prediction

- Long-run elasticity of demand:

$$\epsilon_{LR} = -\frac{1}{\omega+1} - \frac{\omega+\alpha}{(\omega+1)(1-\alpha)}\frac{d\log m}{d\log p_E}$$

where $m^{\frac{\omega}{\omega+1}} = p_E{}^{\frac{\omega}{\omega+1}} + \gamma^{\frac{1}{\omega+1}}$

- the elasticity of demand for energy at time T after a permanent change of price at t:

$$\epsilon_{T-t} = \left(1 - e^{-(T-t)(\delta+g)}\right)\epsilon_{LR}$$

Implementation in the DSGE model

- Energy services

$$ME_t = A_{Et}E_t + \big(1 - (\delta + g)\big)ME_{t-1}$$

- Capital services

$$MK_t = A_{Kt}K_t + \big(1 - (\delta + g)\big)MK_{t-1}$$

- capital-energy aggregate

$$Y_t = \min\{ME_t, MK_t\}$$

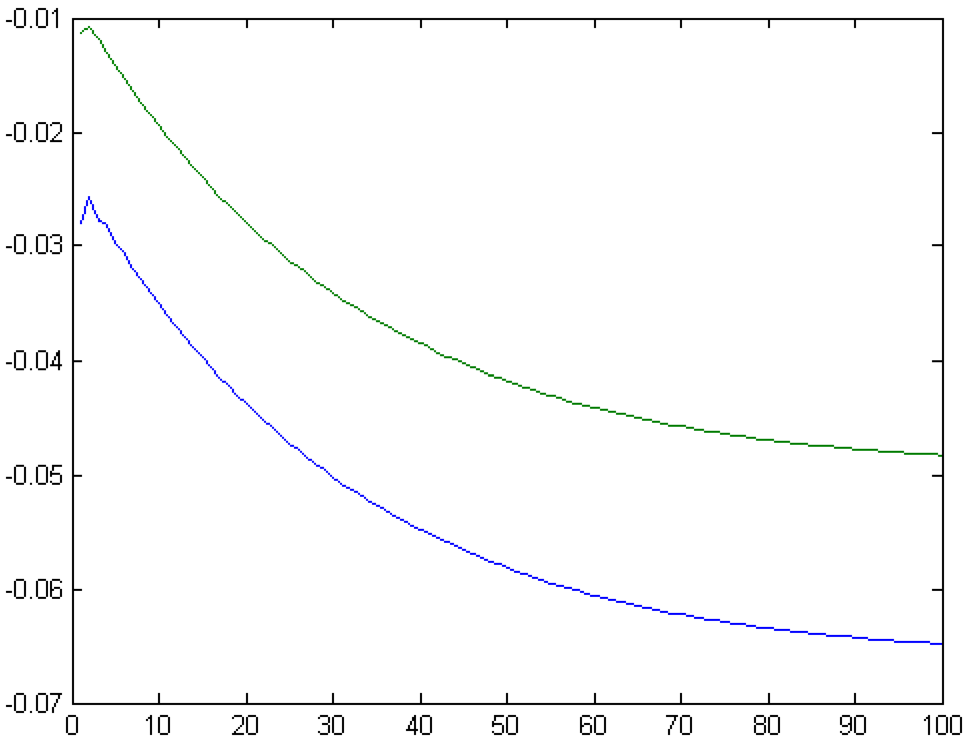
- Technological frontier

$$\frac{1}{\gamma}{A_{Et}}^{\omega} + {A_{Kt}}^{\omega} \leq B$$

Qualitative predictions – Energy demand

Green – without tech choice

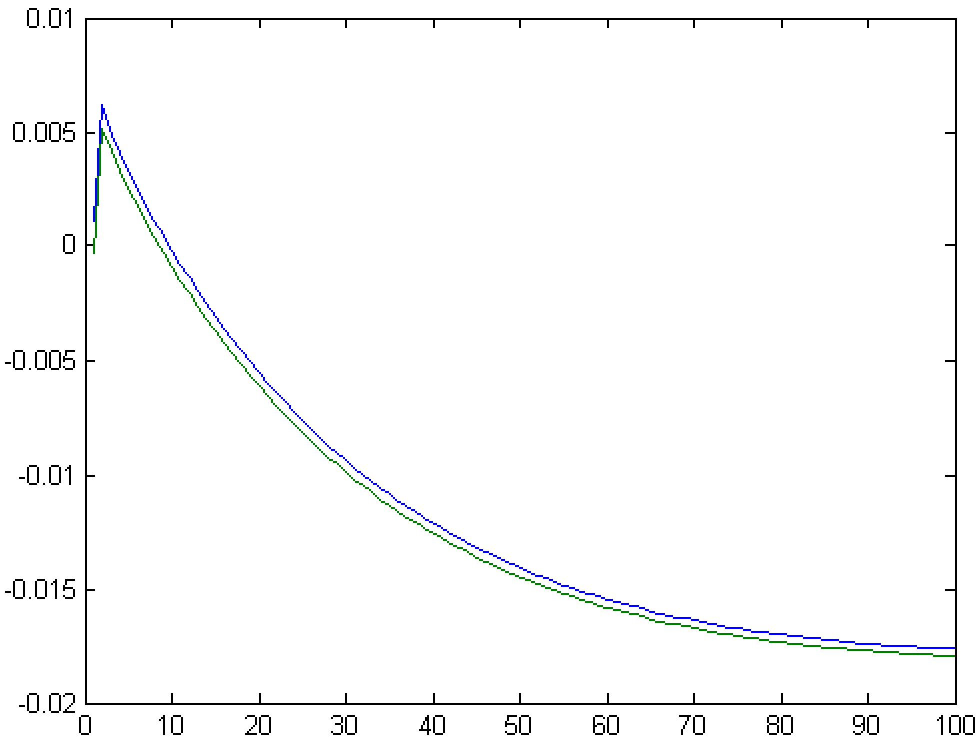
Blue – with tech choice



Qualitative predictions – GDP

Green – without tech choice

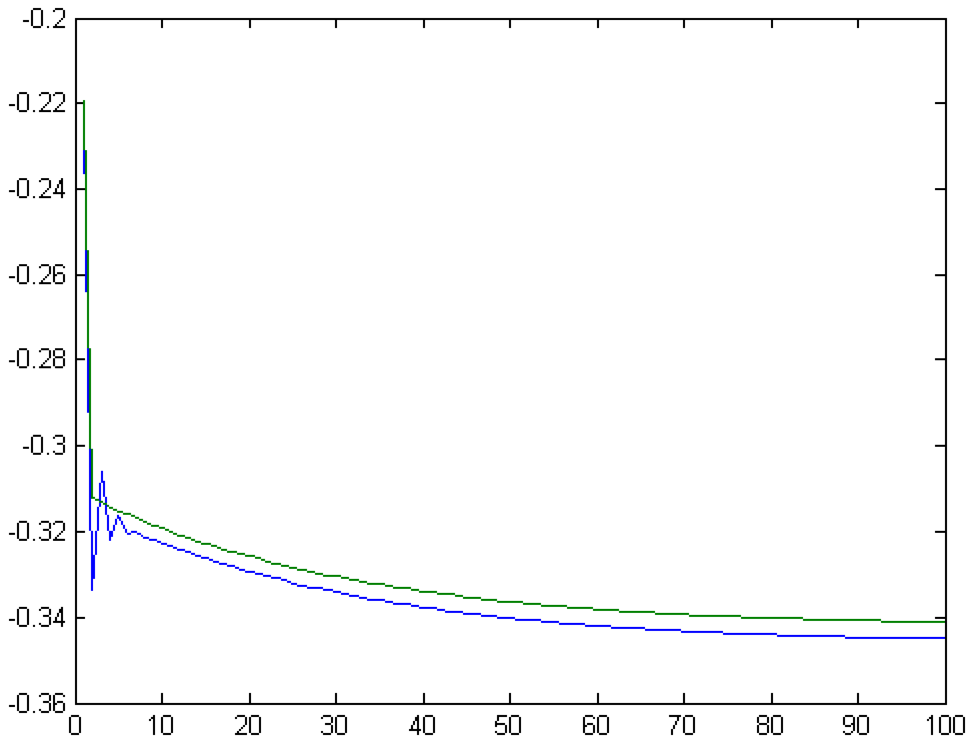
Blue – with tech choice



Qualitative predictions – CO_2

Green – without tech choice

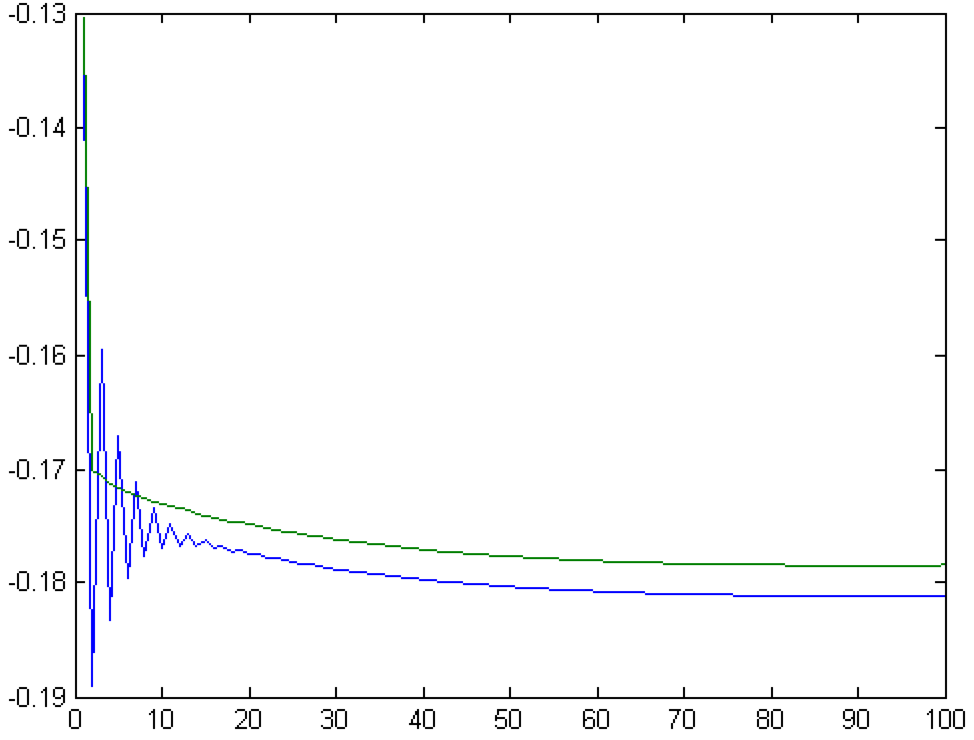
Blue – with tech choice



Qualitative predictions – employment in mining

Green – without tech choice

Blue – with tech choice



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Thank you for your attention

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