Knowledge Production Matrix

Predicting The Efficiency Improvement

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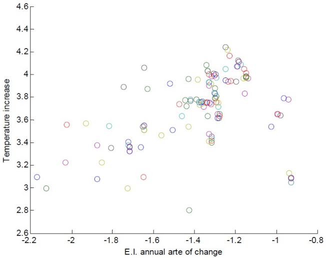
Motivation



determinants of climate change: 1. income 2. energy intensity 3. population 4. carbon intensity of energy

Motivation (2)

- Energy Intensity can be lowered with technological change.
- However some technological progress may in fact increase demand for energy
- We need *directed* technological change:
  - improvement of an energy intensive good that has inelastic demand (e.g. metalurgical sector)
  - improvement of a good that could substitue energy intensive good (e.g. hybrid automobiles)
- The rate of the energy saving technological change determined by energy expenditures.

Contribution

1. derive the relation between energy expenditure and energy saving technological change.
2. to do so in such a way that we can intuitively meassure the forces that determine energy saving TC.
3. estimate the *energy expenditure - energy patents* relation for all major economies, with spillovers
4. examine the relation between energy efficiency growth and flow of patents
5. build a simple technology module which can be easily fed into large scale Integrated Assessment Models, which are used to evaluate policy impacts.

Literature

- Theoretical literature on energy saving technological change: Popp (2003), Bosetti et al. (2006), Acemoglu et al (2010), Andre and Smulders (2014)
- Empirical literature:
  - Popp (2002): effect of energy price on patents in energy intensive industries.
  - Sue Wing (2008): decomposition of changes in the energy intensity into shifts in the structure of sectoral composition and improvements in the efficiency.
- Hybrid: Aghion, Dechezlepretre, Hemous, Martin and Van Reenen (2012): effect of fuel prices on patents in auto industry.

Analytical Framework

theoretical model:

energy expenditure → research investment → flow of new ideas → efficiency improvement

production of innovations

Knowledge generation funcion

The Flow of New Knowledge,
novel ideas on energy efficiency improvement

$$P(R, k, K)$$

Inputs:

R, R&D Investment
k, Knowledge Stock
K, International Knowledge

elasticities:

$\frac{dP}{dR}\frac{R}{P} = \varepsilon_{P,R}$ Decreasing Returns: $\varepsilon_{P,R} < 1$
$\frac{dP}{dk}\frac{k}{P} = \varepsilon_{P,k}$ Intertemporal Spillover $\varepsilon_{P,k} > 0$
$\frac{dP}{dK}\frac{K}{P} = \varepsilon_{P,K}$ International Spillover $\varepsilon_{P,K} > 0$

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Knowledge production

Energy Efficiency

how well we can transform energy into final good

$$A_{t+1}(A_t, P_t, k_t)$$

- Energy effiviency is improved by today's novel ideas
- Impact of ideas may be decreasing as the stock of past ideas grows

P_t, the flow of new knowledge

A_t, current energy efficiency

k_t, stock of past ideas

$$\frac{dA_{t+1}}{dP_t}\frac{P_t}{A_{t+1}} = \varepsilon_{A_{t+1}P_t}$$
$$\frac{dA_{t+1}}{dA_t}\frac{A_t}{A_{t+1}} = \varepsilon_{A_{t+1}A_t}$$
$$\frac{dA_{t+1}}{dk_t}\frac{k_t}{A_{t+1}} = \varepsilon_{A_{t+1}k_t}$$

Production

Final good produced using energy (E) and other inputs (vector $\mathbf{z}$):

$$y_t\left(A_t E_t, \mathbf{z_t}\right)$$

The planner maximization problem is described with the following Bellman equation:

$$V\left(A, k\right) = \max_{E, \mathbf{z}, R} \left\{ y\left(AE, \mathbf{z}\right) - p_E E - \mathbf{p_z z} - R + \beta V\left(A', k'\right) \right\}$$

subject to

$$A' = A'\left(P, A\right),\ P = P\left(R, k, K\right) \text{ and } k' = k'\left(P, k\right)$$

[apostrophe denotes the next period value of the variable]

Solving the model

FOC + manipulation ▶

$$\begin{bmatrix} R_t \\ \frac{dV(A_t,k_t)}{dA_t} A_t \\ \frac{dV(A_t,k_t)}{dk_t} k_t \end{bmatrix} =$$

$$\begin{bmatrix} 0 & \varepsilon_{PR}\varepsilon_{A'P} & \varepsilon_{PR}\varepsilon_{k'P} \\ 1 & \varepsilon_{A'A} & 0 \\ 0 & \varepsilon_{A',P}\varepsilon_{P,k} & \varepsilon_{k',P}\varepsilon_{P,k} + \varepsilon_{k',k} \end{bmatrix} \begin{bmatrix} p_t x_t \\ \beta \frac{dV(A_{t+1},k_{t+1})}{dA_{t+1}} A_{t+1} \\ \beta \frac{dV(A_{t+1},k_{t+1})}{dk_{t+1}} k_{t+1} \end{bmatrix}$$

The research expenditure depends solely on energy expenditure, the current stock of knowledge, the current productivity and the R&D production function

if the elasticities in the matrix in are constant in all periods, then research expenditure, R, is a simple linear function of future energy expenditures.

Solving the model

FOC + manipulation ▶

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Solving the model

Are the elasticities constant?

$$\begin{bmatrix} R_t \\ v_t \\ u_t \end{bmatrix} = \begin{bmatrix} 0 & \varepsilon_{P_t R_t}\varepsilon_{A_{t+1}P_t} & \varepsilon_{P_t R_t}\varepsilon_{k_{t+1}P_t} \\ 1 & \varepsilon_{A_{t+1}A_t} & 0 \\ 0 & \varepsilon_{A_{t+1}P_t}\varepsilon_{P_t,k_t} & \varepsilon_{k_{t+1}P_t}\varepsilon_{P_t k_t} + \varepsilon_{k_{t+1}k_t} \end{bmatrix} \begin{bmatrix} p_{Et}E_t \\ \beta v_{t+1} \\ \beta u_{t+1} \end{bmatrix}$$

- with $P = R^{\phi_1} k^{\phi_2} K^{\phi_3}$(standard in EGM) $\varepsilon_{P_t R_t}$ and $\varepsilon_{P_t k_t}$ are constant
- Since variation in $\varepsilon_{k_{t+1}P_t}$, $\varepsilon_{k_{t+1}k_t}$ and $\varepsilon_{A_{t+1}A_t}$ have very little impact, they are assumed constant
- $\varepsilon_{A_{t+1}P_t}$ depends on a specification

From knowledge to energy efficiency

We assume the Cabalerro and Jaffe (1994) specification:

$$\Delta \log (A_t) = \log (\theta_h) P_t + \log (\theta_f) fP_t$$

where fP is a flow of foreign patents.
Then $\varepsilon_{A_{t+1} P_t} = \log (\theta_h) P_t$ and

$$\log R_t = c_1 + \frac{1}{1-\phi_1} \log (p_{x,t+1} E_{t+1})$$

Sum up of model results

The prediction of the theoretical model:

$$\log\left(P_{it}\right)=\frac{\phi_1}{1-\phi_1}\log\left(p_{Eit+1}E_{it+1}\right)+\phi_2\log\left(k_{it}\right)+\phi_3\sum_{j\neq i}w_{ji}\log\left(k_{jt}\right)+c_{i1}$$

$$\Delta\log\left(A_{t+1}\right)=\psi_1 P_{it}+\psi_2 fP_{it}+c_{i2}$$

where

- P_{it} is a flow of new ideas in country i at time t , fP_{it} is a (weighted) flow of patents in other countries.
- $p_{Eit+1}E_{it+1}$ is energy expenditure,
- k_{it} is a knowledge stock: $\log\left(k_{it}\right)=\sum_{s=0}^{t}P_{is}$
- $\sum_{j\neq i}w_{ji}\log\left(k_{jt}\right)$ is a stock of foreign knowledge,
- A_{it} is a meassure of energy efficiency.

Predicting Efficiency Growth

theoretical models

energy expenditure → research investment → flow of new ideas → efficiency improvement

empirical models

energy expenditure ⟶ flow of new ideas → efficiency improvement

Data

- We construct a proxy for the flow of new innovations, P_{it} using the number of patents on innovations in energy intensive processes.
- The data on GDP, energy supply and energy prices are taken from stats.OECD.
- The data on patents come from the PATSTAT dataset

Flow of patents for country i:

	Granted EPO			
	(1)	(2)	(3)	(4)
energy expenditure	1.523***	0.532***	0.363***	0.378***
own knowledge		0.655***	0.656***	0.656***
foreign knowledge		0.182***	0.180***	0.179***
GDP per capita			0.787***	0.786***
policy index				0.0192**

Table: The dependent variable is count of patents related to one of demand for energy patent categories. ***, **, * indicate significance of the coefficients at the 1%, 5% and 10% level, respectively. 'Energy supply patents' is a count of patents related to production of energy (such as solar or wind energy patents). All regressions contain full set of country, time and patents category dummy variables. All variables are transformed with a log function. The estimations are obtained using a Maximum Likelihood estimator. The probability distribution assumed is the negative binomial.

Flow of patents for country i:

	Granted EPO		
	aggregate	industry	household
	(1)	(2)	(3)
energy expenditure	0.363***	0.222***	0.156
own knowledge	0.656***	0.666***	0.442***
foreign knowledge	0.180***	0.207***	0.385***
GDP per capita	0.787***	0.874***	1.996***

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Energy demand:

	Granted EPO			
	total		industry	household
	(1)	(2)	(3)	(5)
GDP growth	0.499***	0.494***	0.499***	0.503***
Price growth	-0.0953**	-0.102***	-0.0949**	-0.104***
total patents count	-0.0052*	-0.00011	-0.0054*	-0.162
patents X Stock		-0.00322		

Table: The dependent variable is growth of total primary energy supply. Dependent variables are flow of patents in country *i* flow, weighted sum of patents invented in other countries (weights are constructed using citation data), growth of GDP, growth of energy price index and interactions between flows of patents and world stock of patents (home plus foreign). Energy, GDP and price data are smoothed using HP filter. ***, **, * indicate significance of the coefficients at the 1%, 5% and 10%. All regressions include country fixed effects. Column (3) reports results for regression with robust standard error.

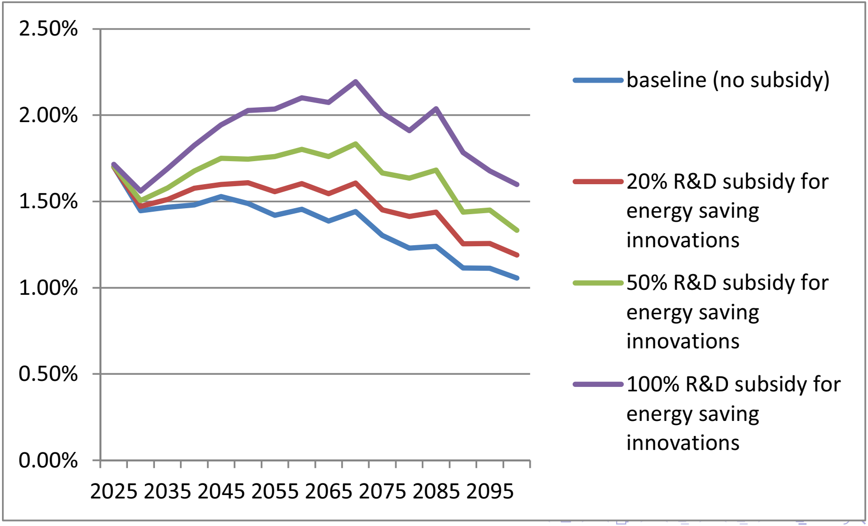
Integration into IAMs

- 2 estimated equations provide a technology module which can be implemented in an integrated assessment model

1. (first equation) information on the energy expenditure growth predicted by the IAM and initial flow of patents allows to predict the growth in production of patents
2. (second equation) use this to predict growth of energy efficiency and update the knowledge stock available to the country in future periods.

- The module allows to evaluate effect of carbon taxes and R&D subsidy on energy efficiency.

Integration into IAMs



Thanks!