Promoting clean technologies under imperfect competition

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Starting point:

The conflicting literature on the performance of energy-saving subsidies

♣ **Effectiveness of fiscal instruments**, namely energy-saving subsidies, to favor investment in the new and cleaner technologies, and their impact on GDP.

♣♣ **Conflicting empirical studies**:

△ Jaffe and Stavins (1995): **Yes** on US data regarding the adoption of thermal insulation technology in new home construction;

△ Verhoef and Nijkamp (2003): **NO** on a Dutch firms data, **promotion of energy-saving technologies by means of subsidies may be counter-productive because it could actually increase energy use!**

Theory question

Under a given pace for energy-saving technical progress, do investment (in new capital goods) subsidies and/or scrappage subsidies have ultimately a positive impact on investment and output?

This question is far from obvious in a general equilibrium framework where **energy suppliers may also react** to such policies. This paper highlights **the crucial role of market structures** in this respect, in particular the energy market.

Two main characteristics of our theory

♣ **Vintage capital modelling**: Newer machines are less energy consuming, investment subsidies can be roughly interpreted as technology adoption subsidies without any additional specifications increasing the size of the model.

♣ **Imperfect competition**: Dixit-Stiglitz in the intermediate good sector, and two polar cases for the energy market: free entry and natural monopoly.

Model I: The final good sector

The final good is produced competitively and the representative final firm solves the following problem

$$\max_{\{y_j(t)\}} \left\{ y(t) - \int_0^1 p_j(t) y_j(t)\, \mathrm{d}j \right\}$$

where

$$y(t) = \left(\int_0^1 y_j(t)^{\frac{\epsilon-1}{\epsilon}}\, \mathrm{d}j \right)^{\frac{\epsilon}{1-\epsilon}}$$

Prices are taken as given by the representative firm, and elasticity of substitution is such that $\epsilon > 1$. As in Dixit and Stiglitz (1977), the corresponding inverse demand function takes the form

$$p_j(t) = \left(\frac{y_j(t)}{y(t)} \right)^{-\frac{1}{\epsilon}}$$

Model II: The intermediate goods sector

We consider that the technological progress is embodied in the new capital goods acquired by the firm. In any intermediate good sector, there exists a unique monopolistic firm, which maximizes:

$$\int_0^\infty \left[p_j(t)y_j(t) - p_e(t)e_j(t) - (1-s_q)i_j(t)\right] R(t)\mathrm{d}t$$

subject to

$$y_j(t) = b\int_{t-T_j(t)}^{t} i_j(z)\,\mathrm{d}z$$

$$e_j(t) = \int_{t-T_j(t)}^{t} q(z)i_j(z)\,\mathrm{d}z$$

$$p_j(t) = \left(\frac{y_j(t)}{y(t)}\right)^{-\frac{1}{\epsilon}}$$

$$q(t) = e^{-\gamma t}$$

At the symmetric equilibrium, $p_j(t) = 1$, $y_j(t) = y(t)$, $e_j(t) = e(t)$, $T_j(t) = T(t)$, $\lambda_j(t) = \lambda(t)$ and $i_j(t) = i$. In that case, $\forall\ t \geq 0$:

$$
\begin{aligned}
\lambda(t) &= \left(1 - \frac{1}{\epsilon}\right) \equiv \mu \\
R(t)(1 - s_q) &= \int_t^{t+J(t)} \left[b\mu - p_e(z)\, e^{-\gamma t}\right] R(z)\, \mathrm{d}z \\
b\mu &= p_e(t)\, e^{-\gamma(t - T(t))}
\end{aligned}
$$

with

$$R(t) = e^{-\int_0^t r(z)\, \mathrm{d}z}$$

$$J(t) = T(t + J(t))$$

Model III: The energy sector

In the energy sector, we assume that the production function only uses the final good according to:

$$f\left(h(t)\right) = \left(\frac{h(t)}{A(t)}\right)^{\alpha},$$

where $h(t)$ denotes the quantity of final good devoted to energy production, and $A(t)$ is an exogenous variable **intended to capture the complexity to produce energy**. Indeed, the specified production function implies that to produce one unit of energy, $A(t)$ units of the final good are needed. As it will be clear later, our model requires $A(t)$ to be growing over time for a regular balanced growth path to arise.

The profit of a firm in the energy sector is:

$$\pi(t) = p_e(t) f(h(t)) - h(t)$$

We shall distinguish two market structures:

1. **The natural monopoly**: This is the case of decreasing average cost, $\alpha > 1$ (**NM** structure).
2. **Free entry**: This is the case of increasing average cost, $\alpha < 1$ (**FE** structure).

In both cases, the pricing of energy will correspond to the zero profit condition:

$$p_e(t) = h(t)^{1-\alpha} \, A(t)^{\alpha}.$$

Model IV: Decentralized equilibrium

With Ramsey consumers **only consuming the final good** (logarithmic utility):

$$
\begin{aligned}
\frac{\dot{c}}{c} &= r - \rho \\
y(t) &= b \int_{t-T(t)}^{t} i(z)\,\mathrm{d}z \\
R(t)(1 - s_q) &= \int_{t}^{t+J(t)} \left[b\mu - p_e(z)\, e^{-\gamma t} \right] R(z)\,\mathrm{d}z \\
b\mu &= p_e(t)\, e^{-\gamma(t-T(t))} \\
f(h(t)) &= \int_{t-T(t)}^{t} i(z)\, e^{-\gamma z}\,\mathrm{d}z \\
y(t) &= i(t) + c(t) + h(t) + \tau(t) \\
J(t) &= T(t + J(t))
\end{aligned}
$$

with initial conditions $i(t)$, $\forall\, t \leq 0$ given.

Model V: Balanced growth paths-BGPs

Definition.- We assume that $c(t) = c\,e^{\gamma t}$, $p_e(t) = p_e\,e^{\gamma t}$, $y(t) = y\,e^{\gamma t}$, $i(t) = i\,e^{\gamma t}$. Accordingly, we set $\tau(t) = \tau\ e^{\gamma t}$ and $A(t) = A\,e^{\gamma t}$. *The BGP equilibrium is a situation where all endogenous variables growth at the same constant rate* γ *except* $J(t) = T(t) = T$.

$$r = \gamma + \rho$$

$$y = c + i + h + \tau$$

$$y = b\frac{i}{\gamma}(1 - e^{-\gamma T})$$

$$\frac{1 - s_q}{b\mu} = \int_t^{t+T} \left[1 - e^{\gamma(z-T)}e^{-\gamma t}\right] e^{-r(z-t)}\,\mathrm{d}z$$

$$p_e = b\mu\ e^{-\gamma T}$$

$$\int_{t-T}^{t} i(z)e^{-\gamma z}\,\mathrm{d}z = \left(\frac{h}{A}\right)^{\alpha}$$

$$p_e = h^{1-\alpha}\ A^{\alpha}$$

Results I: Existence-uniqueness of BGPs

Proposition 1 *A balanced growth path (BGP) exists if and only if* $\rho+\gamma < \frac{b\mu}{1-s_q}$. *If* γ *tends to zero,* T *tends to infinity. If* μ *tends to zero, no BGP can exist.*

It should be already noticed that the necessary and sufficient condition, $\rho + \gamma < \frac{b\mu}{1-s_q}$, for a BGP to exist does depend on the market power parameter μ: the more we depart from perfect competition in the intermediate inputs sector (that's the lower μ), the more the necessary and sufficient condition above is difficult to fulfill **ceteris paribus**, and the less likely the existence of a BGP.

Results II: Properties of scrapping age

Proposition 2 *Assuming that conditions in Proposition 1 hold, the following properties hold:*

(i) T *is a decreasing function of* b, μ *and* s_q. *It is increasing in* ρ.

(ii) T *does not depend on the parameters of the energy sector production function,* $f(h)$.

(iii) T *is decreasing with respect to* γ *provided* T *is lower than* $\frac{1}{\gamma}$.

Results III: Properties Energy price and supply

Proposition 3 *Assuming that conditions in Proposition 2 hold, the following properties hold:*

(i) $p_e = p_e(\gamma, b, s_q, \mu)$ *decreases with* γ*, but increases with* b*,* s_q *and* μ*.*

(ii) *Under the NM structure,* h *has the opposite comparative statics of the energy price* p_e*, it is increasing in* A*.*

(iii) *Under the FE structure,* h *has the same comparative statics as the energy price* p_e*, it is decreasing in* A*.*

Comments

1. In our model, a rise in investment subsidy does increase the price of energy either under free entry or natural monopoly. This property comes from the scrapping condition.

2. Broadly speaking, it appears clearly that a scrapping condition like ours necessarily generates a negative correlation between energy price and scrapping time for any shock which does not affect the productivity parameter, b, or the degree of competition in the intermediate goods sector, μ.

3. The negative correlation between energy prices and lifetime of capital goods is a fact which has been at the heart of a highly interesting discussion for decades. See Baily (1981) and Gordon (1981) on the oil shocks.

4. While the subsidy rise increases energy price, its effect on energy supply does depend on the market structure of the energy sector: it raises the quantity of energy under free entry but pushes it down under monopoly.

5. Therefore, at equilibrium, energy consumption will increase under free entry, and will decrease under natural monopoly. Henceforth, the latter seems to be better adapted to reduce energy use.

6. Nonetheless, given the complementarity between energy and capital, the latter supply effect may be paradoxically accompanied by a slower diffusion of clean technologies under natural monopoly. This is exactly what we will show.

Results IV: Effect of subsidy on investment

Proposition 4 *Assuming that conditions in Proposition 1 hold, and provided* $\gamma T < 1$*, the following properties hold:*

(i) *Under the FE structure, an increase in the investment subsidy* s_q *raises the investment level in the long-run.*

(ii) *Under the NM structure, an increase in investment subsidy stimulates long-run investment if and only if returns to the production function in the energy sector are large enough, i.e. if and only if* $\alpha > \alpha^0 = \frac{1}{1-\gamma T}$*. Otherwise, either investment is depressed (*$1 < \alpha < \alpha^0 = \frac{1}{1-\gamma T}$*) or insensitive to fiscal stimulus (*$\alpha = \alpha^0 = \frac{1}{1-\gamma T}$*).*

Comments

1. An increase in s_q has a priori an ambiguous effect on investment. On one hand, it shortens scrapping, inducing a more intense investment effort in the cleaner technologies (**demand effect**), but one the other hand, it also affects investment in the energy sector (variable h) and therefore the energy supply (**supply effect**).

2. The latter effect depends on the market structure of the energy sector. Thus the overall effect of subsidies on investment depends on whether the energy market is under FE or NM.

3. Under FE, a larger subsidy will yield both positive demand and supply effects, we get **the paradoxical property that subsidizing clean technologies speeds up diffusion but raises energy use!**

4. Things are much more complicated in the NM case where the supply effect lowering energy use pushes investment level down, and can offset the positive demand effect induced by the investment subsidy.

5. Proposition 4 shows that this happens under weak enough increasing returns in the production technology in the energy sector. In such a case, one gets the paradoxical property that while investment subsidies lower energy use, they do slowdown investment and therefore the diffusion of clean technologies.

Revisiting Stoneman and David (1986)

In Proposition 4, increase in investment subsidies generally triggers a higher diffusion of energy-saving technologies as new capital embodies energy-saving technological change, consistently with Stoneman and David (1986).

However, our analysis of subsidies bring out two new results.

♣ Larger diffusion rates do not necessarily mean lower energy consumption at equilibrium, which may explain certain empirical puzzles mentioned.

♣ It could even be the case that adoption subsidies do not induce larger investment into cleaner technologies at all: this is clearly the case under natural monopoly in the energy sector with weakly increasing returns and Ramsey-Boiteux pricing.

Open questions

1. Our results are extracted under linear production functions in the intermediate goods sector, and this linearity allows to solve for the balanced growth paths following a straightforward recursive scheme. **How the mechanisms are altered with a nonlinear production function?** Computational approach unavoidable.

2. Our results rely **on a very (too) simple modelling of the energy market**. Relaxing it looks like a daunting task but it is certainly a necessary step to take to understand the diffusion factors of clean technologies.

3. **Welfare analysis needed**