The More the Merrier?

The Role of Green Research and Development Subsidies under Different Environmental Policies

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Motivation

- Introduction of the US' Inflation Reduction Act (IRA) green research and development (R&D) subsidies received new interest
- IRA is publicized as an environmental policy but also contains industrial policies
- To avoid a competitive disadvantage, many countries followed suit with their own green industrial policy package
- Accordingly, many replicate and pledge to match subsidy levels of IRA
- However, each country is embedded in different environmental policies
- **What is the role of green R&D subsidies under different environmental policies?**

Related Literature

- Fischer and Newell (2008) analyze the contribution of both environmental and technology policies for climate mitigation, showing that using R&D policies is the leas cost-effective method to achieve emission reductions
- Fischer et al. (2021) analyze second-best policies, showing that a welfare improvement can be achieved by an adjustment of a second policy.
  - Nevertheless, they do not explicitly study the relationship between insufficient climate policies and R&D subsidies
- Reichenbach and Requate (2012) study learning-by-doing (LBD) spillovers, finding that there is an emission tax and an subsidy to offset knowledge spillovers
- In this paper, we deploy a stylized equilibrium model to analyze the role of R&D subsidies in different environmental policy settings on their effect on competitiveness, the environment as well as welfare

The Model

- We have a two-period, stylized, closed economy model with a clean C and dirty sector D, which produce perfect substitutes, $q^D_{t,i}$ and $q^C_{t,i}$
- The model includes a single environmental policy - an emission tax or cap - and a R&D subsidy
- Each period covers a time horizon of n_t time intervals (e.g. years or decades), where $t = 1, 2$ and the future period is discounted by the discount factor δ.

The Dirty Sector

- There are m symmetric firms in the dirty sector and we assume no entry and exit
- Each firm producing the identical output $q_t^D \rightarrow$ total output: $Q_t^D = n_t m q_t^D$
- The production process releases emissions $e_t \rightarrow$ total emissions: $E_t = n_t m e_t$
- The firm faces a carbon price $\tau \geq 0$
- Firms are price takers and maximize profits according to:

$$\max_{q_t^D, e_t} \quad \Pi^D = \sum_{t=1}^{2} \delta^{t-1} n_t [p_t q_t^D - C_t^D(q_t^D, e_t) - \tau e_t] \tag{1}$$

$$C_{q_t^D}^D = p_t \quad \forall \quad t = 1, 2 \tag{2}$$

$$-C_{e_t}^D = \tau_t \quad \forall \quad t = 1, 2 \tag{3}$$

The Clean Sector

- There are k symmetric firms in the clean sector and we assume no entry and exit
- Each firm producing the identical output $q_t^C \rightarrow$ total output: $Q_t^C = n_t k q_t^C$
- Each firm faces R&D expenditures $R(h)$, producing R&D knowledge h
- Firms also gain knowledge via knowledge spillovers, which occur at rate $\rho \in [0, 1]$
- A firm's combined R&D knowledge is given by $H_i = n_1(h_i + \sum_{j=1}^{K} \rho h_j)$, $j \neq i$.
- Since firms are symmetric, aggregate R&D knowledge is given by $H = n_1(1 + \rho(k-1))h$
- Due to the presence of knowledge spillovers, firms receive a subsidy σ for R&D.

The Clean Sector

- Firms are price takers and maximize profits according to:

$$\max_{q_1^C, q_2^C, h} \quad \Pi^C = n_1[p_1 q_1^C - C^{C1}(q_1^C) - (1-\sigma)R(h)] + \delta n_2[p_2 q_2^C - C^{C2}(q_2^C, H)] \quad (4)$$

$$\text{FOCs:} \qquad C_{q_t^C}^{C,t} = p_t \quad \forall \quad t = 1,2 \qquad (5)$$

$$(1-\sigma)R_h = -\delta n_2 C_H^{C2}. \qquad (6)$$

  - (5): Marginal production costs equal output price
  - (6): Marginal investment costs equal discounted gains from private R&D knowledge

The Consumer

- The consumer is indifferent between the dirty good q_t^D and the clean good q_t^C and derives utility from consumption
- We assume that demand equals to supply to close the model:

$$Q_t = Q_t^D + Q_t^C = mq_t^D + kq_t^C. \quad (7)$$

- The utility maximization problem of the consumer looks as follows:

$$\max_{Q_1,Q_2} \quad U(Q) = n_1[u(Q_1) - p_1 Q_1] + \delta n_2[u(Q_2) - p_2 Q_2] \quad (8)$$

$$\text{FOC:} \quad u_{Q_t} = p_t. \quad (9)$$

Welfare

- We have a central planner, who maximizes welfare recognizing the aforementioned players in addition to environmental damages
- Emissions lead to environmental damages denoted by $\Gamma(E_t)$
- Note: the carbon price and the R&D subsidy are pure transfers
- The welfare maximization problem boils down to:

$$
\begin{aligned}
\max_{q_t^i, e_t, h} \quad W &= n_1[u(Q_1) - mC^D(q_1^D, e_1) - kC^{C1}(q_1^C) - kR(h) - \Gamma(E_1)] \\
&+ \delta n_2[u(Q_2) - mC^D(q_2^D, e_2) - kC^{C2}(q_2^C, H) - \Gamma(E_2)] && (10) \\
\text{FOCs:} \quad U_{Q_t^i} &= C^i_{q_t^i} && (11) \\
-C^D_{e_i} &= \Gamma_{e_i} && (12) \\
R_h &= \delta n_2(-C_h^{C2})(1 + (k-1)\rho). && (13)
\end{aligned}
$$

Optimal Policy

- We equate (12) and (3) as well as (13) and (6) to obtain the optimal carbon price and R&D subsidy:

$$\tau^* = D_{e_i} \tag{14}$$

$$\sigma^* = \frac{\rho(k-1)h}{H}. \tag{15}$$

Proposition 1:

The optimal R&D policy increases in both the spillover rate ρ and the number of firms k in the clean sector

The Role of an R&D Subsidy

- To study the role of an R&D subsidy under different environmental policies, we use a comparative statics analysis
- It tells us the effect of an increase in the R&D subsidy
- For the comparative statics analysis, we totally differentiate all first-order conditions (equations (2)-(3), (5)-(6), (9), and (7)) with respect to the R&D subsidy σ
- Depending on the policy, either τ_t is held fixed or the emissions e_t

The Role of an R&D Subsidy under a Carbon Tax

Proposition 2:

An increase in an R&D subsidy in the presence of a carbon tax $\tau \neq \tau^*$ *leads to...*

- *...an increase in knowledge,* $dh/d\sigma > 0$,
- *...an increase in the overall output of the second period,* $dq_2/d\sigma > 0$,
- *...a decrease in the output price of the second period,* $dp_2/d\sigma < 0$,
- *...a decrease in emissions of the second period,* $de_2/d\sigma < 0$,

Proposition 3:

In the presence of a carbon tax τ, an increase in the R&D subsidy leads to an increase (decrease) in welfare if $\sigma < \sigma^*$ $(\sigma > \sigma^*)$ and $\tau_2 \leq \tau_2^*$ $(\tau_2 \geq \tau_2^*)$.

$$\frac{dW}{d\sigma} = \delta n_2(\tau_2 - \tau_2^*) m \frac{de_2}{d\sigma} + \delta n_2 \left[\frac{(\sigma^* - \sigma)(1 + \rho(k-1))}{1-\sigma} \right] k(-C_h^{C2}) \frac{dh}{d\sigma}. \qquad (16)$$

	$\tau_2 < \tau_2^*$	$\tau_2 = \tau_2^*$	$\tau_2 > \tau_2^*$
$\sigma < \sigma^*$	$\frac{dW}{d\sigma} > 0$	$\frac{dW}{d\sigma} > 0$	$\frac{dW}{d\sigma} = ?$
$\sigma > \sigma^*$	$\frac{dW}{d\sigma} = ?$	$\frac{dW}{d\sigma} < 0$	$\frac{dW}{d\sigma} < 0$

Second-Best R&D Subsidy

Proposition 4:

In case of a sub-optimal or non-existent carbon tax, there is a second-best R&D subsidy level greater than the first-best subsidy level, $\sigma^{**} > \sigma^{*}$ and which is the higher, the larger the difference $\tau_2 - \tau_2^{*}$ is.

$$\sigma^{**} = \frac{m\Delta_2^{\tau}\epsilon_{\sigma}^{e_2}e_2 + k\rho(k-1)(-C_h^{C2})\epsilon_{\sigma}^{h}h}{m\Delta_2^{\tau}\epsilon_{\sigma}^{e_2}e_2 + k[1+\rho(k-1)](-C_h^{C2})\epsilon_{\sigma}^{h}h} > \sigma^{*} \qquad (17)$$

- where the elasticity of emissions in Period 2 and of R&D investments with respect to a change in the R&D subsidy are $\epsilon_{\sigma}^{e_2} = \frac{de_2}{e_2}\frac{\sigma}{d\sigma}$ and $\epsilon_{\sigma}^{h} = \frac{dh}{h}\frac{\sigma}{d\sigma}$
- an $\Delta_2^{\tau} = \tau_2 - \tau_2^{*}$ is the difference between the optimal and actual carbon tax

The Role of an R&D Subsidy under an Emission Cap

Proposition 5:

An increase in an R&D subsidy in the presence of an emission cap leads to...

- *...an increase in R&D knowledge,* $dh/d\sigma > 0$,
- *...an increase in the overall output of the second period,* $dq_2/d\sigma > 0$, *and hence,*
- *...a decrease in the output price of the second period,* $dp_2/d\sigma < 0$.
- *...a decrease in the carbon price of the second period,* $d\tau_2/d\sigma < 0$.

Welfare Effect

Proposition 6:

Under an emission cap, an increase in the R&D subsidy leads to an increase (decrease) in welfare if the R&D subsidy is smaller (larger) than the optimal R&D subsidy: $dW/d\sigma > 0$ $(dW/d\sigma < 0)$.

$$\frac{dW}{d\sigma} = \frac{\sigma^* - \sigma}{1-\sigma}\delta n_2(-C_h^C)\frac{dh}{d\sigma}. \tag{18}$$

- Since the welfare effect is now solely driven by the change $dh/d\sigma$, there is no second-best subsidy to correct for an inefficient emission cap.

Conclusion: Tax vs. Cap

- An increase in the R&D subsidy under a carbon tax leads to a decrease in emissions but has no effect on the carbon price $\rightarrow$ environmental gains
- Under an emission cap, an increase in the R&D subsidy decreases the carbon price but has no effect on emissions $\rightarrow$ competitive gains
- Green R&D instigates a shift in production from dirty to clean as the clean output becomes relatively cheaper $\rightarrow$ competitive gains
- In cases of sub-optimal (or non-existent) carbon prices, an increase in the R&D subsidy can offset an inefficient carbon price without causing a welfare loss
- A sub-optimal emission cap cannot be offset by an increase in the R&D subsidy
- We find no evidence of temporal carbon leakage

Extension 1: Learning-by-doing (LBD)

- We introduce LBD into the clean sector, which is also subjected to knowledge spillovers
- Accordingly, LBD spillovers are corrected through an output subsidy:

$$s^* = \delta n_{''} \gamma (k-1)(-C_L^{C''}) \tag{19}$$

- We find that an increase in the R&D subsidy now also affects the first period with the same sign

Learning-by-doing and a Carbon Tax

Proposition 7:

In the presence of a carbon tax and LBD (spillovers), an increase in the R&D subsidy σ *leads to...*

- *...an increase in R&D knowledge,* $\frac{dh}{d\sigma} > 0$
- *...an increase in output,* $\frac{dq_t}{d\sigma} > 0$,
- *...a decrease in output price,* $\frac{dp_t}{d\sigma} < 0$,
- *...a decrease in emissions,* $\frac{de_t}{d\sigma} < 0$

where $t = 1, 2$.

Learning-by-Doing and Emission Caps

Proposition 8:

In the presence of an emission cap and learning-by-doing (spillovers), an increase in the R&D subsidy σ leads to ...

- *...an increase in R&D knowledge,* $\frac{dh}{d\sigma} > 0$
- *...an increase in output,* $\frac{dq_t}{d\sigma} > 0$,
- *...a decrease in output price,* $\frac{dp_t}{d\sigma} < 0$,
- *...a decrease in carbon price,* $\frac{d\tau_t}{d\sigma} < 0$

Learning-by-Doing and Emission Caps

Proposition 9:

In the presence of an emission cap and LBD (spillovers), an increase in the R&D subsidy σ leads to an increase (decrease) in welfare if $\sigma^* > \sigma$ and $s^* \geq s$.

- The welfare effect of a change in the R&D subsidy under an emission cap is:

$$\frac{d\tilde{W}}{d\sigma} = k\left[\frac{(\sigma^* - \sigma)(1 + \rho(k-1))}{1-\sigma}\right]\frac{dh}{d\sigma} + kn_1(s^* - s)\frac{dq_1^C}{d\sigma}. \tag{20}$$

	$s^* < s$	$s^* = s$	$s^* > s$
$\sigma < \sigma^*$	$\frac{d\tilde{W}}{d\sigma} = ?$	$\frac{d\tilde{W}}{d\sigma} > 0$	$\frac{d\tilde{W}}{d\sigma} > 0$
$\sigma > \sigma^*$	$\frac{d\tilde{W}}{d\sigma} < 0$	$\frac{d\tilde{W}}{d\sigma} < 0$	$\frac{d\tilde{W}}{d\sigma} = ?$

Learning-by-Doing and Emission Caps

Proposition 10:

There is a second-best R&D subsidy $\tilde{\sigma}^{**}_{cap} > \sigma^*$ *that corrects for a sub-optimal output subsidy* $s < s^*$*.*

$$\tilde{\sigma}^{**}_{cap} = \frac{\rho(k-1)\delta n_2(-C_H^{C2})\epsilon_\sigma^h h + n_1 \Delta^s \epsilon_\sigma^{q_1^C} q_1^C}{(1+\rho(k-1))\delta n_2(-C_H^{C2})\epsilon_\sigma^h h + n_1 \Delta^S \epsilon_\sigma^{q_1^C} q_1^C} > \sigma^*. \tag{21}$$

- where $\Delta^S = s^* - s$ and $\epsilon_\sigma^{q_1^C} = \frac{dq_1^C}{q_1^C}\frac{\sigma}{d\sigma}$ is the elasticity of first period output q_1^C with respect to the R&D subsidy σ

Extension 2: Governmental Budget

- Now: Governments can only invest what they have earned through taxation:

$$me_1\tau_1 = k\sigma R(h) \tag{22}$$

Proposition 10:

In the presence of a governmental budget, optimal policies decrease due to the consideration of the shadow cost of public funds λ.

$$\tau_t^+ = \frac{\Gamma_{e_t}}{1+\lambda} < \tau_t^* \tag{23}$$

$$\sigma^+ = \frac{\rho(k-1)}{1+\lambda+(k-1)\rho^C} < \sigma^* \tag{24}$$

where λ is the shadow cost of public funds

Governmental Budget and Climate Policy

Proposition 12

An increase in the R&D subsidy in the presence of a budget constraint, leads to...

- ...**AMBIGUOUS RESULTS :(**

Outlook

- We want to say something about the direction of technological change, i.e:
  - extend the model to infinite time horizon,
  - include both green R&D in the clean sector and the dirty sector,
  - calibrate the model to a non-energy sector

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