North-South diffusion of climate-mitigation technologies: The crowding-out effect on relocation

Julie Ing*, Jean-Philippe Nicolaï†

APPENDICES

A Proof of Proposition 1

Let us define the northern firms' incentives to relocate (IR):

$$IR = \pi_S^c\left(m_S^c + 1, m_S^d, m_N - 1\right) - C^R - \pi_N\left(m_N, m_S^c, m_S^d\right).$$

Using $\pi_S^c\left(m_S^c, m_S^d, m_N\right) = r_{SS}^c\left(m_S^c, m_S^d, m_N\right)^2 + r_{SN}^c\left(m_S^c + 1, m_S^d, m_N - 1\right)^2$
and $\pi_N^c\left(m_N, m_S^c, m_S^d\right) = r_{NS}^c\left(m_N, m_S^c, m_S^d\right)^2 + r_{NN}^c\left(m_N, m_S^c, m_S^d\right)^2$,

$$\begin{aligned} IR &= r_{SS}^c\left(m_S^c + 1, m_S^d, m_N - 1\right)^2 + r_{SN}^c\left(m_S^c + 1, m_S^d, m_N - 1\right)^2 - C^R \\ &\quad - r_{NS}^c\left(m_N, m_S^c, m_S^d\right)^2 - r_{NN}^c\left(m_N, m_S^c, m_S^d\right)^2 \\ &= \left(r_{SS}^c\left(m_S^c + 1, m_S^d, m_N - 1\right) - r_{NS}^c\left(m_N, m_S^c, m_S^d\right)\right)\left(r_{SS}^c\left(m_S^c + 1, m_S^d, m_N - 1\right) + r_{NS}^c\left(m_N, m_S^c, m_S^d\right)\right) \\ &\quad + \left(r_{SN}^c\left(m_S^c + 1, m_S^d, m_N - 1\right) - r_{NN}^c\left(m_N, m_S^c, m_S^d\right)\right)\left(r_{SN}^c\left(m_S^c + 1, m_S^d, m_N - 1\right) + r_{NN}^c\left(m_N, m_S^c, m_S^d\right)\right) \\ &\quad - C^R. \end{aligned}$$

*University of Rennes 1, CREM (Centre de Recherche en Economie et Management), Rennes, France.
†EconomiX-CNRS, University of Paris Nanterre, France and ETH Zürich, Switzerland. Contact autor. E-mail: nicolai.jeanphilippe@parisnanterre.fr

To show that a decrease in the dirty southern firms' emission intensity reduces the incentives to relocate, we have to prove that IR increases with μ^d. Using

$$r^c_{SS}(m^c_S+1, m^d_S, m_N-1) - r_{NS}(m_N, m^c_S, m^d_S) = \frac{(m_N+m_S)\ (X+t)}{m_N+m_S+1}$$
$$r^c_{SN}(m^c_S+1, m^d_S, m_N-1) - r_{NN}(m_N, m^c_S, m^d_S) = \frac{(m_N+m_S)\ (X-t)}{m_N+m_S+1},$$

IR can be rewritten as:

$$\begin{aligned} IR = & \frac{(m_N+m_S)\ (X+t)}{m_N+m_S+1} \left(r^c_{SS}\left(m^c_S+1, m^d_S, m_N-1\right) + r^c_{NS}\left(m_N, m^c_S, m^d_S\right)\right) \\ & + \frac{(m_N+m_S)\ (X-t)}{m_N+m_S+1} \left(r^c_{SN}\left(m^c_S+1, m^d_S, m_N-1\right) + r^c_{NN}\left(m_N, m^c_S, m^d_S\right)\right) \end{aligned}$$

Finally, using

$$\begin{aligned} & \frac{\partial\, r^c_{SN}(m^c_S+1, m^d_S, m_N-1)}{\partial\, \mu^d} = \frac{\partial\, r^c_{SS}(m^c_S+1, m^d_S, m_N-1)}{\partial\, \mu^d} \\ & = \frac{\partial\, r_{NN}(m_N, m^c_S, m^d_S)}{\partial\, \mu^d} = \frac{\partial\, r_{NS}(m_N, m^c_S, m^d_S)}{\partial\, \mu^d} = \frac{m^d_S\, \tau_S}{m_N+M_S+1}. \end{aligned}$$

We conclude

$$\begin{aligned} \frac{\partial\, IR}{\partial\, \mu^d} & = \frac{(m_N+m_S)\ (X+t)}{m_N+m_S+1} \frac{2\, m^d_S\, \tau_S}{m_N+m_S+1} + \frac{(m_N+m_S)\ (X-t)}{m_N+m_S+1} \frac{2\, m^d_S\, \tau_S}{m_N+m_S+1} \\ & = \frac{4\, m^d_S\ (m_N+m_S)\ \tau_S\, X}{(m_N+m_S+1)^2} > 0. \end{aligned}$$

B Proof of Proposition 2

Using $m^d_S = m_S - m^c_S$, the incentives to relocate are given by:

$$\begin{aligned} IR = & r^c_{SN}\left(m^c_S+1, m_S-m^c_S, m_N-1\right)^2 + r^c_{SS}\left(m^c_S+1, m_S-m^c_S, m_N-1\right)^2 - C^R \\ & - r_{NN}\left(m_N, m^c_S, m_S-m^c_S\right)^2 - r_{NS}\left(m_N, m^c_S, m_S-m^c_S\right)^2. \end{aligned}$$

Using $\frac{\partial r_{SN}^d}{\partial m_S^c} = \frac{\partial r_{SN}^c}{\partial m_S^c} = \frac{\partial r_{NN}}{\partial m_S^c} = \frac{\partial r_{SS}^d}{\partial m_S^c} = \frac{\partial r_{SS}^c}{\partial m_S^c} = \frac{\partial r_{NS}}{\partial m_S^c} = -\frac{\Delta\,\mu\,\tau_S}{m_N+m_S+1}$, we get:

$$\begin{aligned}\frac{\partial\,IR}{\partial\,m_S^c} &= 2\,\left(r_{SN}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right)+r_{SS}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right)\right)\,\frac{\Delta\,\mu\,\tau_S}{m_N+m_S+1}\\ &\quad -2\,\left(r_{NN}\left(m_N, m_S^c, m_S-m_S^c\right)+r_{NS}\left(m_N, m_S^c, m_S-m_S^c\right)\right)\,\frac{\Delta\,\mu\,\tau_S}{m_N+m_S+1},\end{aligned}$$

since $r_{SN}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right)+r_{SS}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right)-r_{NN}\left(m_N, m_S^c, m_S-m_S^c\right)+ r_{NS}\left(m_N, m_S^c, m_S-m_S^c\right) = \frac{2\,(m_N+m_S)X}{m_N+m_S+1}$, we deduce $\frac{\partial\,IR}{\partial\,m_S^c} = -\frac{4\,\Delta\,\mu\,(m_N+m_S)\,\tau_S\,X}{(m_N+m_S+1)^2} < 0$.

C Proof of Proposition 3

Using $\frac{\partial r_{NN}}{\partial m_S^c} = \frac{\partial r_{SN}^c}{\partial m_S^c} = -\frac{X-t}{m_S^d+m^c+1}$ and $\frac{\partial r_{NS}}{\partial m_S^c} = \frac{\partial r_{SS}^c}{\partial m_S^c} = -\frac{X+t}{m_S^d+m^c+1} < 0$, we get:

$$\begin{aligned}\frac{\partial\,IR}{\partial\,m_S^c} &= 2\,\left(r_{NN}\left(m_N, m_S^c, m_S-m_S^c\right)-r_{SN}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right)\right)\,\frac{X-t}{m_S^d+m^c+1}\\ &\quad +2\,\left(r_{NS}\left(m_N, m_S^c, m_S-m_S^c\right)-r_{SS}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right)\right)\,\frac{X+t}{m_S^d+m^c+1}.\end{aligned}$$

Using $r_{NN}\left(m_N, m_S^c, m_S-m_S^c\right)-r_{SN}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right) = -\frac{(m_S^d+m^c)\,(X-t)}{m_S^d+m^c+1}$ and $r_{NS}\left(m_N, m_S^c, m_S-m_S^c\right)-r_{SS}^c\left(m_S^c+1, m_S-m_S^c, m_N-1\right) = -\frac{(m_S^d+m^c)\,(X+t)}{m_S^d+m^c+1}$, we obtain:

$$\begin{aligned}\frac{\partial\,IR}{\partial\,m_S^c} &= -2\,\left(\frac{(m_S^d+m^c)\,(X-t)}{m_S^d+m^c+1}\right)\,\frac{X-t}{m_S^d+m^c+1} - 2\,\left(\frac{(m_S^d+m^c)\,(X+t)}{m_S^d+m^c+1}\right)\,\frac{X+t}{m_N+m^c+1}\\ &= -\frac{4\,(m_S^d+m^c)\,(X^2+t^2)}{m_S^d+m^c+1} < 0.\end{aligned}$$

D Proof of Lemma 2

Note that $\frac{\partial l^{WG}}{\partial \mu^d} = \frac{m_S^{d\,0} X \tau_S}{X^2+t^2}$ and that $l^{WG} - l^G = \frac{\Delta \mu m_S^{d\,0} \tau_S}{t^2+X^2}$.

The subsidy affects the individual production and the northern price as follows:

$$r_{NN}^{WG} - r_{NN}^{G} = {r_{SN}^{c}}^{WG} - {r_{SN}^{c}}^{G} = p_N^{WG} - p_N^{G} = \frac{\Delta \mu\, m_S^{d\,0} \tau_S\, t\, (t+X)}{\left(m_N^0 + m_S^{d\,0} + 1\right) (t^2 + X^2)} > 0$$

$$r_{NS}^{WG} - r_{NS}^{G} = {r_{SS}^{c}}^{WG} - {r_{SS}^{c}}^{G} = p_S^{WG} - p_S^{G} = -\frac{\Delta \mu\, m_S^{d\,0} \tau_S\, t\, (X-t)}{\left(m_N^0 + m_S^{d\,0} + 1\right) (t^2 + X^2)}$$

$$r_{N}^{WG} - r_{N}^{G} = r_{NN}^{WG} + r_{NS}^{WG} - r_{NN}^{G} - r_{NS}^{G} = \frac{2\,\Delta \mu\, m_S^{d\,0} \tau_S\, t^2}{\left(m_N^0 + m_S^{d\,0} + 1\right) (t^2 + X^2)}$$

$$\frac{\partial {r_{SN}^{d}}^{WG}}{\partial \mu^d} = -\frac{\frac{\partial l^{WG}}{\partial \mu^d}\, (X-t) + (m_N^0 + 1)\, \tau_S}{m_N^0 + m_S^{d\,0} + 1}$$

$$\frac{\partial {r_{SS}^{d}}^{WG}}{\partial \mu^d} = -\frac{\frac{\partial l^{WG}}{\partial \mu^d}\, (t+X) + (m_N^0 + 1)\, \tau_S}{m_N^0 + m_S^{d\,0} + 1} < 0$$

$$\frac{\partial {r_{SN}^{d}}^{WG}}{\partial \mu^d} + \frac{\partial r_{SS}^{d}}{\partial \mu^d} = -\frac{2\,\frac{\partial l^{WG}}{\partial \mu^d}\, X + 2\,(m_N^0 + 1)\, \tau_S}{m_N^0 + m_S^{d\,0} + 1} < 0$$

The effect of subsidy on the emissions is given by:

$$\begin{aligned}
E^G - E^{WG} &= \frac{m_S^{d\,0}\, \Delta \mu\, \left(2\left(\mu^c + \mu^d\right) \tau_S + t + 2\,c_N - a_N - a_S + 2\,m_N^0\, \Delta \mu\, \tau_S\right)}{m_N^0 + m_S^{d\,0} + 1} \\
&+ \frac{2\,X\, \left(m_S^{d\,0}\, \Delta \mu\, \left(l^{WG} - m_N^0\right) - \mu^c\, \left(l^{WG} - l^G\right)\right)}{m_N^0 + m_S^{d\,0} + 1} \\
E_N^G - E_N^{WG} &= \frac{\mu^c\, \left(l^G - l^{WG}\right) \left(2\mu^c \tau_N + t + 2\,c_N - a_N - a_S + 2\,X\, \left(l^{WG} + l^G + m_S^{d\,0} - m_N^0\right)\right)}{m_N^0 + m_S^{d\,0} + 1} \\
&+ \frac{2\,m_S^{d\,0}\, \mu^c\, \Delta \mu\, \left(l^{WG} - m_N^0\right) \tau_S}{m_N^0 + m_S^{d\,0} + 1} \\
E_S^G - E_S^{WG} &= \frac{\left(\Delta \mu\, m_S^{d\,0} - \mu^c\, \left(l^G - l^{WG}\right)\right) (2\mu^c \tau_S + t + 2\,c_N - a_N - a_S)}{m_N^0 + m_S^{d\,0} + 1} \\
&- \frac{2\Delta \mu\, m_S^{d\,0}\, \left(\mu^c\, l^{WG} - (1 + m_N^0)\, \mu^d\right) \tau_S}{m_N^0 + m_S^{d\,0} + 1} \\
&- \frac{2\,X\, \left(\mu^c\, \left(l^G - l^{WG}\right) \left(l^{WG} + l^G + m_S^{d\,0} - m_N^0\right) + \Delta \mu\, m_S^{d\,0}\, \left(m_N^0 - l^{WG}\right)\right)}{m_N^0 + m_S^{d\,0} + 1}.
\end{aligned}$$