On pollution and R&D-based growth in a trade model between countries concerned and unconcerned about climate change

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- Full cooperation difficult in a global environmental problem (Barret 2003 and Finus 2001).
- Kyoto protocol: Annex I vs. Non-annex I countries. Countries concerned and countries who disregard global warming
- Emissions from non-renewable fossil fuels → Carbon leakage

Research question

Conditions to reverse/alleviate the carbon leakage hypothesis

- Emissions from final output production, using a renewable resource, forest products (timber), as an input
- Forest: provides a productive input + carbon sink

Bilateral trade model

- Small group of technological leading countries (Coe *et al.* (1997))→ Annex I - concerned countries
- Developing countries are not investing in R&D. They are well endowed with natural resources timber → Non-annex I - unconcerned countries

Pattern of trade:
Non-abating developing countries export timber in exchange for technology intensive goods from abating technologically leading countries

Research question

Sustainability of the economic growth in both regions

Outline

1. Introduction ✓
2. The model
3. The business as usual (BAU) scenario. Countries disregard global warming
4. Commitment by technologically leading countries to acknowledge global warming
5. Comparison of emissions, concentration of pollutants and economic growth

Technologically leading region

Technological progress: expansion in the number of varieties of intermediate inputs Grossman & Helpman (1997), Barro & Sala-i-Martin (2004)

- **Output producers**: Produce final output using a growing number of intermediate inputs, labor and timber. Perfectly competitive markets. Production dependent on the environmental quality.
- **Innovators**: Create new intermediate inputs and produce one monopolistically. Static maximization of profits from sales in the leading and the forest regions.
- **Consumers**: Decide between consumption and assets accumulation. Dynamic maximization of utility from consumption and environmental quality.

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- **Output producers**: $Y_L = AZ^{-\phi} L_L^{1-\alpha-\beta} \sum_{j=1}^{N} X_{Lj}^{\alpha} H_L^{\beta},$

  Z concentration of pollutants, L_L labor, N number of intermediate inputs, X_{Lj} intermediate input j, H_L timber.

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- **Innovators**: $\pi_j = (p_j - 1)\left(X_{Lj} + X_{Fj}\right),$

  p_j price of the intermediate input j

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- **Consumers**:

$$\max_{c_L} \int_0^{\infty} \left[\frac{c_L^{1-\varepsilon}}{1-\varepsilon} - \theta \frac{Z^{1+\mu}}{1+\mu} \right] e^{-\rho t} dt, \qquad \rho, \varepsilon, \mu, \theta > 0,$$

$$\text{s.t.: } \dot{a}_L = r a_L + w_L - c_L, \quad a_L(0) = a_{L0}.$$

c_L consumption, a_L assets, w_L wages, r rate of return.

Forest region

- **Output producers**: Produce final output using a growing number of intermediate inputs, labor and timber. Perfectly competitive markets. Production dependent on the environmental quality.
- **Consumers/harvesters**: Do not accumulate assets. Own the forest in equal shares. Decide the share of labor to harvest and to produce final output. Maximize utility from consumption and environmental quality.

Forest region

- **Output producers**: $Y_F = \tilde{A} Z^{-\phi} (v L_F)^{1-\alpha-\beta} \sum_{j=1}^{N} X_{Fj}^{\alpha} H_F^{\beta},$

  v share of labor in the final output sector, Z concentration of pollutants, L_F labor, X_{Fj} intermediate input j, H_F timber.

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- **Consumers/harvesters**:

$$\max_{v} \left\{ \frac{c_F^{1-\tilde{\varepsilon}}}{1-\tilde{\varepsilon}} - \tilde{\theta} \frac{Z^{1+\tilde{\mu}}}{1+\tilde{\mu}} \right\},$$

$$\text{s.t.: } c_F = v w_F + p_h h,$$

$$h = b(1-v)^{1-\varphi}, \quad b > 0, \varphi \in (0,1).$$

c_F consumption, w_F wages, p_h price of timber.

Forest and the accumulation of pollutants

Forest: Dynamics of the forest in aggregate terms:

$$\dot{S} = G(S) - H = gS\,(1 - S/C) - L_F b(1-v)^{1-\varphi}, \quad S(0) = S_0$$

$G(S)$ logistic gross reproduction rate, $H = L_F h$ harvestings.

Concentration of pollutants in the atmosphere

$$\dot{Z} = E_L + E_F - \delta(S,Z) = E_L + E_F - \delta_1 Z - \delta_2 S, \quad Z(0) = Z_0, \delta_1, \delta_2 > 0.$$

E_L, E_F emissions from producers in L and F.

Assumption: $\dfrac{E_i}{Y_i} = g_i(N),\ g_i'(N) < 0, i \in \{L, F\}$.

Emissions if $g_i(N)$ is a hyperbolic function:

$$\frac{E_L}{Y_L} = \frac{\tau}{N} \Rightarrow E_L = \tau\frac{Y_L}{N}, \qquad \frac{E_F}{Y_F} = \frac{\tilde{\tau}}{N} \Rightarrow E_F = \tilde{\tau}\frac{Y_L}{N}.$$

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BAU vs Commitment to acknowledge global warming

BAU: Countries disregard global warming.
Commitment: agreement in technologically leading countries to:

1. consider global warming in their decision making process,
2. settle the price of intermediate inputs in a centralized manner.

Equivalent to a central planner in this region, who maximizes:

$$\max_{c_L, H_L, X_L, p_j} \int_0^\infty \left(\frac{c_L^{1-\varepsilon}}{1-\varepsilon} - \theta \frac{Z^{1+\mu}}{1+\mu} \right) e^{-\rho t} dt,$$

$$\dot{N} = \frac{1}{\eta+\nu} \left[Y_L + N(p_j - 1) X_F(p_j) - N X_L - p_h H_L - c_L L_L \right], \quad N(0) = N_0 > 0$$

$$\dot{Z} = \tau \frac{Y_L}{N} + \tilde{\tau} \frac{Y_F}{N} - \delta_1 Z - \delta_2 S, \quad Z(0) = Z_0 > 0,$$

$$\dot{S} = gS \left(1 - \frac{S}{C} \right) - (H_L + H_F), \quad S(0) = S_0 > 0,$$

Emissions: BAU vs Commitment

- Emissions under BAU

$$E_L = \left(\tau \Lambda L_L \overline{H}^{\frac{\beta}{1-\alpha}}\right) Z^{-\frac{\phi}{1-\alpha}} = \bar{E}_L Z^{-\frac{\phi}{1-\alpha}},$$

$$E_F = \left(\frac{\tilde{\tau}\beta}{\alpha \overline{p}_F} \Lambda L_L \overline{H}^{\frac{\beta}{1-\alpha}}\right) Z^{-\frac{\phi}{1-\alpha}} = \bar{E}_F Z^{-\frac{\phi}{1-\alpha}}.$$

Λ = CST (parameters), $\overline{p}_F$ the terms of trade

- Emissions under Commitment

$$E_L = \left(\frac{1+\tau\Psi}{\alpha}\right)^{\frac{\alpha}{1-\alpha}} Z^{\frac{-\phi}{1-\alpha}} = \bar{E}_L^C Z^{\frac{-\phi}{1-\alpha}},$$

$$E_F = \left(\frac{\alpha p_F + \tilde{\tau}\Psi}{\alpha \overline{p}_F}\right)^{\frac{\alpha}{1-\alpha}} Z^{-\frac{\phi}{1-\alpha}} = \bar{E}_F^C Z^{-\frac{\phi}{1-\alpha}}.$$

$\Psi = \lambda_Z \tilde{c}_L L_L$, $\tilde{c}_L = C_L/N$, λ_Z shadow price of Z, p_F the terms of trade

Steady-State equilibrium

Steady-State equilibrium

- $v, X_L, X_F, E_L, E_F, Z, H_L, H_F$ remain constant
- $C_L, C_F, N, Y_L, Y_F, w_L, w_F, p_h$ grow at the same constant rate

Existence and uniqueness

Under the assumption $gC > 4\overline{H}$ a saddle-path stable Steady-State equilibrium exists and is unique.

Growth rate of consumption

$$\gamma^* = \frac{(1-\alpha)(\alpha+\beta)}{\varepsilon(\eta+\nu)} \frac{\bar{E}_L}{\tau} (Z^*)^{\frac{-\phi}{1-\alpha}} - \frac{\rho}{\varepsilon}$$

$$(\gamma^C)^* = \frac{B^C}{(\eta+\nu)} \frac{\bar{E}_L^C}{\tau} ((Z^C)^*)^{\frac{-\phi}{1-\alpha}} - \rho$$

with $Z^*, (Z^C)^*$ implicitly given.

Comparison of emissions

Emissions under the two scenarios:

$$E_L = \bar{E}_L Z^{-\frac{\phi}{1-\alpha}}, \quad E_F = \bar{E}_F Z^{-\frac{\phi}{1-\alpha}}, \quad E = \bar{E} Z^{-\frac{\phi}{1-\alpha}},$$

$$E_L^C = \bar{E}_L^C Z^{-\frac{\phi}{1-\alpha}}, \quad E_F^C = \bar{E}_F^C Z^{-\frac{\phi}{1-\alpha}}, \quad E^C = \bar{E}^C Z^{-\frac{\phi}{1-\alpha}}.$$

Autonomous variation in emissions (no change in Z)

$$\boxed{\frac{\bar{E}_L^C - \bar{E}_L}{\bar{E}_L} > \frac{\bar{E}_F^C - \bar{E}_F}{\bar{E}_F}}$$

Two possibilities for global emissions reductions:

Condition	Leader	Forest	World Economy
$\alpha > 1 + \tau\Psi$	$\bar{E}_L^C < \bar{E}_L$	$\bar{E}_F^C << \bar{E}_F$	$\bar{E}^C < \bar{E}$
$\alpha < 1 + \tau\Psi < \alpha^\alpha$	$\bar{E}_L^C > \bar{E}_L$	$\bar{E}_F^C < \bar{E}_F$	$\bar{E}^C < \bar{E}$

Comparison of emissions

Price of intermediate inputs charged to forest region producers

$$\boxed{p_j^C > p_j}$$

Assumption: $\bar{E}_L^C + \bar{E}_F^C \equiv \bar{E}^C < \bar{E} \equiv \bar{E}_L + \bar{E}_F$

At the steady state it follows:

1. The concentration of pollutants decreases

$$(Z^C)^* < Z^*$$

2. Global emissions decrease

$$\left(E^C\right)^* \equiv \bar{E}^C((Z^C)^*)^{\frac{-\phi}{1-\alpha}} < \bar{E}(Z^*)^{\frac{-\phi}{1-\alpha}} \equiv E^*$$

Comparison of growth rates

Growth rates under BAU and Coommitment:

$$\gamma^* = \frac{B}{(\eta+\nu)\tau}\bar{E}_L^*(Z^*)^{\frac{-\phi}{1-\alpha}} - \rho, \quad (\gamma^C)^* = \frac{B^C}{(\eta+\nu)\tau}(\bar{E}_L^C)^*((Z^C)^*)^{\frac{-\phi}{1-\alpha}} - \rho.$$

with $B < B^C$.

Commitment does not necessarily reduces growth

$$\bar{E}_L^C < \bar{E}_L \Rightarrow (Z^C)^* < Z^*$$

$$\not\Downarrow \left(B^C > B, ((Z^C)^*)^{\frac{-\phi}{1-\alpha}} > (Z^*)^{\frac{-\phi}{1-\alpha}}\right)$$

$$(\gamma^C)^* < \gamma^*$$

Numerical Results

Parameters values:

$$\alpha = 0.5,\ \beta = 0.2,\ \delta = 0.5,\ \rho = \tilde{\rho} = 0.01,\ \eta = 0.2,\ \nu = 0.1,\ \tau = \tilde{\tau} = 0.3,$$
$$\delta_1 = \delta_2 = 0.1,\ g = 4, A = \tilde{A} = b = L_L = L_F = \theta = \mu = C = 1.$$

	$\widehat{\frac{p_j}{p_F}}$	$\widehat{\bar{E}_L^*}$	$\widehat{\bar{E}_F^*}$	$\widehat{\bar{E}^*}$	$\widehat{Z^*}$	$\widehat{E_L^*}$	$\widehat{E_F^*}$	$\widehat{E^*}$	$\widehat{\gamma^*}$
$\phi = 0.5$ $\alpha > 1 + \tau\Psi$	$+$	$-$	$-$	$-$	$-$	$+$	$-$	$-$	$+$
$\phi = 0.3$ $\alpha < 1 + \tau\Psi < \alpha^\alpha$	$+$	$+$	$-$	$-$	$-$	$+$	$-$	$-$	$+$

$$\widehat{X} = \frac{X^C - X}{X}$$

Conclusions

- Sustainable growth is feasible and saddle-path stable in a bilateral trade model. Technology developed in one region is traded in exchange for timber harvested in its counterpart.
- If technologically leading countries commit to acknowledge global warming and agree on a coordinated price for traded technology:
    - Willingness to reduce emissions transferred from countries concerned to countries who disregard global warming. Mechanism: a higher price of the intermediate inputs.
    - Forest countries reduce emissions stronger than the technologically leading countries.
    - Concentration of pollutants decreases and still emissions are globally reduced.
    - Growth does not necessarily shrink. Numerically it grows.