BANCA D'ITALIA
EUROSISTEMA

Technology trade and the environment

Daniela Marconi

Bank of Italy

Venice 9-10 June 2008

Introduction - trade, growth and the environment: how difficult are to reconcile?

- Environmental quality matters to the world economy
- But environmental policies place constraints on economic activity
- Environmental regulation might be too costly, without having much of an impact, if implemented in isolation (OECD, IMF, G20).
- Strong incentives for each country to “free-ride” on efforts of others

BANCA D'ITALIA
EUROSISTEMA

Environment is a global public good

- The environment is a public good: agents do not internalize their personal contribution to environmental degradation.

- Its provision or degradation is not confined within national boundaries.

- When we add international trade and capital mobility additional problems arise to design the right incentives.

- From a theoretical point of view, therefore, insert environmental regulation into an endogenous growth model with trade is not an easy task.

BANCA D'ITALIA
EUROSISTEMA

Introduction: What has been done, what I do.

- Trade and environment are generally treated in static models.

- Main questions: is trade good or bad for the environment? Do *dirty* productions tend to relocate in countries with lower environmental standards? (pollution heaven hypothesis) (Copeland and Taylor 2003).

- Endogenous growth models with environment are usually in closed economy. In these models there exists a trade off between the long-run rate of growth and the environment: cleaner technologies are less efficient (Aghion and Howitt (1998); Ricci (2007)).

- I consider an open economy endogenous growth model (modified and simplified version of Ricci 2007) to ask a simple question: what are the dilemmas posed by policy actions to reduce pullution when a country is open to international trade?

The model: motivations of general assumptions

- In what follow I consider only the environmental quality that results from pollution (do not consider non-renewable resources issue). To simplify the analysis I assume that polluting emissions in one country stays within it (no externalities across countries).
- Policies to abate pollution in open economy are very difficult to design because if a country taxes directly dirty productions and foreign countries do not, competitiveness of domestic firms is reduced, causing production to shift elsewhere ("pollution heaven" hypothesis).
- What should be taxed is the consumption of dirty goods (no matter where they are produced).
- Revenues, in turn, could be used to subsidize R&D to generate clean technologies. Taxes and subsidies can be more effective in shifting consumption towards cleaner goods. As cleaner goods are more costly to produce, a larger market for those goods might be beneficial not only to domestic producers but also to foreign ones.
- A tax on consumption reduces firm's profits, if foreign countries do not tax consumption as well, and firms can price discriminate, there is an incentive to sell a larger share of the production to foreign markets. **Keep in mind: the size of the market is crucial!**

BANCA D'ITALIA
EUROSISTEMA

The model

2 countries of same size: A and B, same size

Normalize population to 1 in each country

3 sectors:

consumption good (Y) – perfect competition – non tradable

Intermediate goods (X) – monopolistic competition – tradable

R&D sector – technology upgrading (Shumpeterian)

The number of intermediate firms is fixed in each country

Domestic innovation activity can only target domestic technology

Consumption good sector and pollution

$$(1)\, Y_{A\tau} = (1 - n_{A\tau})^{1-\alpha} \sum_{j=1}^{N_A+N_B} (A_{j\tau} Z_{j\tau})^{1-\alpha} x_{j\tau}^{\alpha}$$

$(1 - n_{A\tau})$ is the proportion of workers employed in sector Y

$x_{j\tau}$ is the j-th intermediate good

$Z_{j\tau}$ is the pollution intensity of the j-th intermediate good

A is a productivity parameter.
Aggregate pollution is:

$$(2)\; P_{A\tau} = \sum_{j=1}^{N_A+N_B} Z_{j\tau} x_{j\tau}$$

As in Stokey, the reduction of Z allows society to limit polluting emissions but implies a cost in terms of forgone production. Z can be reduced only through costly R&D activity and can be heterogeneous across industries. Emissions are complementary to intermediate goods, and their productivity depends on both, A and Z.

BANCA D'ITALIA
EUROSISTEMA

Consumption good sector (2)

The final good sector is subject to a green tax burden proportional to pollution per unit of intermediate good employed:

$$(3)\quad h_\tau \frac{P_{j\tau}}{x_{j\tau}} = h_\tau Z_{j\tau}$$

The final good sector, therefore, maximizes:

$$(4)\ \Pi_{y\tau} = (1-n_{A\tau})^{1-\alpha} \sum_{j=1}^{N_A+N_B} (A_{j\tau} Z_{j\tau})^{1-\alpha} x_{j\tau}^{\alpha} - w_\tau (1-n_{A\tau}) - \sum_{j=1}^{N_A+N_B} p_{j\tau} x_{j\tau} - \sum_{j=1}^{N_A+N_B} h_\tau Z_{j\tau} x_{j\tau}$$

Profit maximization yields:

$$(5)\quad w_{A\tau} = (1-\alpha)(1-n_{A\tau})^{-\alpha} \sum_{j=1}^{N_A+N_B} (A_{j\tau} Z_{j\tau})^{1-\alpha} (x_{j\tau}^{A})^{\alpha-1} = (1-\alpha) Y_{A\tau} / (1-n_{A\tau})$$

$$(6)\quad p_{j\tau}^{A} = \alpha (1-n_{A\tau})^{1-\alpha} (A_j Z_{j\tau})^{1-\alpha} (x_{j\tau}^{A})^{\alpha-1} - h_\tau Z_{j\tau}$$

BANCA D'ITALIA
EUROSISTEMA

Intermediate goods sector

I assume that new technologies (lower pollution intensity and higher productivity) replace completely older ones .

Domestic firms are symmetric. In both countries, one unit of finished good (Y) is needed to produce one unit of intermediate goods.

Let's suppose that the final good sector is not taxed in the foreign country, therefore foreign inverse demand function for intermediate goods j is

$$(7)\quad p_{j\tau}^{B} = \alpha(1-n_{B\tau})^{1-\alpha}(A_j Z_{j\tau})^{1-\alpha}(x_{j\tau}^{B})^{\alpha-1}$$

Intermediate goods sector (2)

Firms can price discriminate, in both countries the problem of the j-th intermediate good firm is

$$(8)\ \max_{x^A_{j\tau},\, x^B_{j\tau}} \Pi_{j\tau} = (p^A_{j\tau} - 1)x^A_{j\tau} + (p^B_{j\tau} - 1)x^B_{j\tau}$$

s.t.

$$(8c1)\ p^A_{j\tau} = \alpha(1 - n_{A\tau})^{1-\alpha}(A_j Z_{j\tau})^{1-\alpha}(x^A_{j\tau})^{\alpha-1} - h_\tau Z_{j\tau}$$

$$(8c2)\ p^B_{j\tau} = \alpha(1 - n_{B\tau})^{1-\alpha}(A_j Z_{j\tau})^{1-\alpha}(x^B_{j\tau})^{\alpha-1}$$

Intermediate goods sector (3)

Which yields the following equilibrium conditions:

$$(9)\ \hat{x}^{A}_{j\tau} = \left(\frac{\alpha^{2}}{1 + h_{\tau} Z_{j\tau}}\right)^{1/(1-\alpha)} (1 - n_{A\tau})(A_{j\tau} Z_{j\tau})$$

$$(9')\ \hat{x}^{B}_{j\tau} = \alpha^{2/(1-\alpha)} (1 - n_{B\tau}) A_{j\tau} Z_{j\tau}$$

$$(10)\ \hat{p}^{B}_{j\tau} = \frac{1}{\alpha}$$

$$(11)\ \hat{p}^{A}_{j\tau} = \frac{1 + (1-\alpha) h_{\tau} Z_{j\tau}}{\alpha}$$

$$(12')\ \hat{\Pi}_{jA} = (1-\alpha)\alpha^{(1+\alpha)/(1-\alpha)} A_{jA} Z_{jA} \left[\frac{(1 - n_{A})}{(1 + hZ_{jA})^{\alpha/1-\alpha}} + (1 - n_{B})\right]$$

In country A demand for intermediate goods is lower, domestic and foreign firms cha
higher price.

BANCA D'ITALIA
EUROSISTEMA

Balanced trade

$$N_A p_A^B x_A^B = N_B p_B^A x_B^A$$

$$N_A \alpha^{(1+\alpha)/(1-\alpha)} (1-n_B)(A_{A\tau} Z_{A\tau}) =$$

$$N_B \alpha^{(1+\alpha)/(1-\alpha)} \left(\frac{1+(1-\alpha)h_\tau Z_{B\tau}}{(1+h_\tau Z_{B\tau})^{1/(1-\alpha)}} \right) (1-n_A)\left(A_{B\tau} Z_{B\tau}\right)$$

The green tax on imported intermediate goods is levied according to their pollution intensity.

And since $\left(\frac{1+(1-\alpha)h_\tau Z_{B\tau}}{(1+h_\tau Z_{B\tau})^{1/(1-\alpha)}} \right) < 1$

It must be that

$$N_B (1-n_A)\left(A_{B\tau} Z_{B\tau}\right) > N_A (1-n_B)\left(A_{A\tau} Z_{A\tau}\right)$$

Balanced trade will be possible if only if the market of country A is large enough, or if foreign technolgy is sufficiently superior.

BANCA D'ITALIA
EUROSISTEMA

R&D sector

R&D activity is done only by outsiders. Incumbents buy the license to produce with the new technology.

Incumbents in sector j retains a monopoly right to produce the j-th intermediate good at that technological level, until the next generation of technology arrives.

Trade-off: innovation reduces the length of monopoly profits but increases productivity and reduces pollution of intermediate goods with a positive impact on profits.

The log-run growth rate of the economy ultimately depends on the growth rate of domestic and foreign technology.

R&D sector (2)

Technology is improved upon by employing researchers in the labs, the probability to get an innovation in sector *j* in a time interval of length $d\tau$ is $\lambda n_j d\tau$, where n*j* is the proportion of labor employed in R&D in sector *j*, and λ>0 and, $\lambda n_j \leq 1$.

When innovation arrives it increases A and reduces Z, according to the following law of motions:

$$\dot{A}_{ji\tau} = \lambda n_{j\tau} \overline{A}_{i\tau}$$

$$\dot{Z}_{ji\tau} = \phi \lambda n_{j\tau} \overline{Z}_{i\tau}; \quad -1 < \phi < 0$$

Where $\dot{A}_{ji\tau} = \dfrac{dA_{ji\tau}}{d\tau}; \overline{A}_{i\tau} \equiv \dfrac{1}{N_i} \sum_{j=1}^{N_i} A_{ji\tau}; \overline{Z}_{i\tau} \equiv \dfrac{1}{N_i} \sum_{j=1}^{N_i} Z_{ji\tau}$

BANCA D'ITALIA
EUROSISTEMA

R&D sector / Free entry condition

Free entry condition applies. Given that the probability of an innovation during the period $d\tau$ is $\lambda n_{j\tau} d\tau$, and the cost is $w_\tau n_{j\tau} d\tau$, an innovator can get the value V of the firm (equal to the present value of the flow of future profits), with the same probability of an innovation; therefore an innovator maximization problem is:

$$\max_{n_j} V_{j(\tau+d\tau)} \lambda n_{j\tau} - w_{j\tau} n_{j\tau}$$

$$F.O.C.\ V_{j(\tau+d\tau)} \lambda = w_{j\tau}$$

The the free-entry (zero-profit) condition is:

$$w_\tau n_{j\tau} \geq \lambda n_{j\tau} V_{j(\tau+d\tau)} \ \textit{with equality if}\ n_{j\tau} \geq 0$$

R&D sector / Arbitrage condition

Assuming a constant interest rate, the arbitrage condition can be written as:

(21) $rV_{j(\tau+d\tau)} = \pi_{j(\tau+d\tau)} - \lambda n_{j(\tau+d\tau)} V_{j(t+d\tau)}$

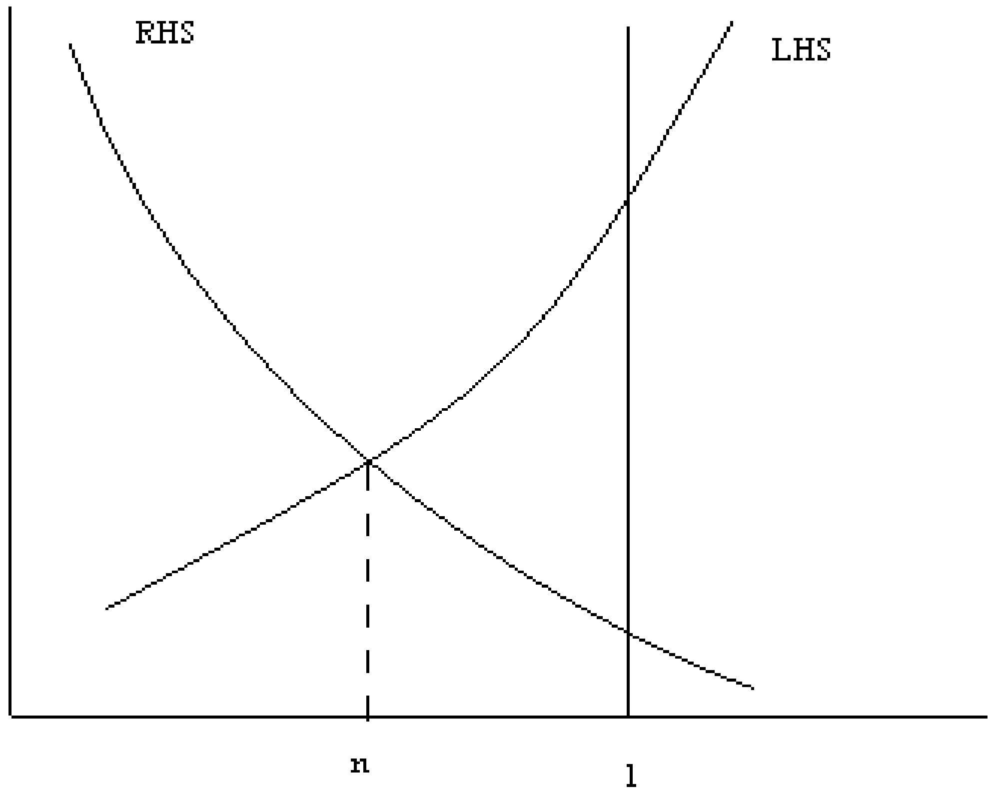
Expected income from an innovation at time t+dt is given by the flow of monopoly profits attainable by the innovation minus the capital loss that occurs when a new invention is introduced, which happens with probability $\lambda n_{j\tau}$.

Imposing the free entry condition we get:

(22) $w_{\tau} = \dfrac{\lambda\pi_{j(\tau+d\tau)}}{(r + \lambda n_{j(t+d\tau)})}$

At a given moment in time, LHS is an increasing function of n, since labor productivity in the final good sector increases if n increases. RHS, instead, is a decreasing function of n for two reasons: first a larger n reduces the size of the market for the intermediate goods and second it increases the probability to get an innovation and therefore to incur in capital losses.

Equilibrium *n*



BANCA D'ITALIA
EUROSISTEMA

The same arbitrage condition can be worked out in continuos time, since $\pi_{j(\tau+d\tau)} = (\pi_{j\tau} + \dot{V}_{j\tau})d\tau$ we can write:

$$(21')\ rV_{j\tau}d\tau = \left(\pi_{j\tau} + \dot{V}_{j\tau} - \lambda n_{j\tau}V_{j\tau}\right)d\tau$$

The (capitalized) value of the firm is equal to the flow of profits plus the capital gain if the innovation does not occur in the time interval $d\tau$, minus the capital loss if innovation succeeds (which occurs with probability $\lambda n_{j\tau}d\tau$).

$$(22')\ \frac{\dot{V}_j}{V_j} = r + \lambda n_j - \frac{\pi_j}{V_j}$$

Imposing the free entry condition $\frac{\dot{V}}{V} = \frac{\dot{w}}{w}$ and the labor market clearing condition we get:

$$(23)\ \frac{\dot{w}_A}{w_A} = r + \lambda\left(\frac{n_A}{N_A} - \frac{\pi_{jA}}{w_A}\right)$$

BANCA D'ITALIA
EUROSISTEMA

Wage rates

$$w_A = (1-\alpha)(1-n_A)^{-\alpha} \sum_{j=1}^{N_A+N_B} (A_j Z_j)^{1-\alpha} x_j^{\alpha}$$

$$= (1-\alpha)\alpha^{2\alpha/(1-\alpha)} \sum_{j=1}^{N_A+N_B} (A_j Z_j) \left(\frac{1}{1+hZ_j} \right)^{\alpha/(1-\alpha)}$$

$$(24^*)\ w_B = (1-\alpha)\alpha^{2\alpha/(1-\alpha)} \sum_{j=1}^{N_A+N_B} (A_j Z_j)$$

The first thing to note is that country A's wage rate is lower than country B's because less x is employed in production. Given the simmetry of firms in each country we can define the green tax burden for fim *j* in country *i* as $hZ_{ji} \equiv H_i$

Long run growth

In the long run the growth rate of final output is equal to the growth rate of wage. If the technological parameters are the same across countries, the growth rate in country A is:

$$\frac{\dot{w}_A}{w_A} =$$

$$(1+\phi)\lambda\left[s_A^A n_A + (1-s_A^A) n_B\right] - \frac{\alpha}{1-\alpha}\left[s_A^A \frac{\dot{H}_A}{(1+H_A)^{\alpha/(1-\alpha)}} + (1-s_A^A)\frac{\dot{H}_B}{(1+H_B)^{\alpha/(1-\alpha)}}\right]$$

In steady state the allocation of workers between sectors must be constant. In the long run the wage rate is constant only if the market share and H are constant.

$$s_A^A \equiv \frac{(1+H_B)^{\alpha/(1-\alpha)}(A_A Z_A)}{(1+H_B)^{\alpha/(1-\alpha)}(A_A Z_A)+(1+H_A)^{\alpha/(1-\alpha)}(A_B Z_B)}$$

If we assume that the green tax must guarantee constant revenue to the government at from domestic firms, h must adjust to domestic Z, meaning

$$\frac{d(h_\tau Z_\tau)}{d\tau} = \frac{dh_\tau}{d\tau} Z_{A\tau} + \frac{dZ_{A\tau}}{d\tau} h_\tau = 0 \Rightarrow \frac{dh_\tau}{d\tau} = -\phi\lambda \bar{n}_A h_\tau$$

And

$$\frac{d(h_\tau Z_{B\tau})}{d\tau} = \phi\lambda \bar{Z}_{B\tau} h_\tau (\bar{n}_B - \bar{n}_A)$$

Which implies that with the same innovation technology, market shares (on the dor market) can be constant in the lung-run only if the proportion of workers employed in R the same in the two countries. In this case, the last term of ($\frac{\dot{w}_A}{w_A}$) is zero.

BANCA D'ITALIA
EUROSISTEMA

Let us suppose for the moment that domestic firms do not receive any subsidy (and do not consider for the moment what the government does with the tax revenues). Let us further suppose that $H_{A\tau} = H_{B\tau}$.We ask the following question: in absence of subsidies to R&D and with taxation of consumption only in country A, how does the innovation activity respond to an increase of H?

That is, we want to know if $\frac{dn_i}{dH_i} > 0$. From the arbitrage condition we know that: $n_A = \frac{N_A}{\lambda}\left(\frac{\dot{w}_A}{w_A} + \frac{\lambda \pi_{jA}}{w_A}\right) - r$, therefore $\frac{dn_A}{dH_A} = \frac{N_A}{\lambda}\left[d\frac{\dot{w}}{w} / dH_A + \lambda d\frac{\pi_{jA}}{w_A} / dH_A\right]$,

if $\dot{H}_A$ and $\dot{H}_B$ are nil and $H_A = H_B$ (so that market shares do not depends on H),
this derivatives boils down to

$$(28)\ \frac{dn_A}{dH_A} = N_A d\frac{\pi_{jA}}{w_A} / dH_A = \frac{\alpha^2}{1-\alpha} s_A^A (1 + H_A)^{(2\alpha-1)/(1-\alpha)} (1 - n_B) > 0$$

BANCA D'ITALIA
EUROSISTEMA

But, if $H_A = H_B$

$$\frac{\pi_{jB}}{w_B} = \alpha \frac{1}{N_B}(1 - s_A^A)\left[\frac{(1-n_A)}{(1+H_B)^{\alpha/(1-\alpha)}} + (1-n_B)\right]$$

$$\frac{\partial n_B}{\partial H_B} N_B = \partial \frac{\pi_{jB}}{w_B} / \partial H_B = -\frac{\alpha^2}{1-\alpha}(1-s_A^A)(1+H_B)^{(1-2\alpha)/(1-\alpha)}(1-n_A) < 0$$

BANCA D'ITALIA
EUROSISTEMA

Summing up

(a) If countries are symmetric and firms are symmetric within each country;

(b) if consumption of polluting goods is taxed only in one country:

1. Balanced trade will be possible if only if the market of country A is large enough or if foreign technology is sufficiently superior or the number of intemediate goods produced in the foreign countries is sufficiently large.
2. The wage rate tend to be lower in the country where consumption is taxed.
3. In order for market shares to be constant, the green tax burden on each intermediate good must be constant over time and this in turn requires that the speed of innovation must be the same in the two countries.

4. But innovation activity does not respond in the same way if H increases:
5. it increases in country A (where the wage rate decreases);
6. it decreases in country B (because the foreign market size shrinks).
7. If incentives to do R&D are not the same, then market shares cannot be constant over time.
8. What if we also add R&D subsidies in country A?
9. Can we immagine positive spillovers for growth and the environment in country B as well, as trade give access to cleaner technologies that are improved faster compared to domestic technologies?

Workshop on
Trade, Growth
and Environment

June 9 – 10, 2008
Venice International University
Isola di San Servolo
Venice