Professor Ian Sheldon: Trade Seminar
CUCEA, Universidad de Guadalajara
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Topic 2: Trade and the Environment

Articles:

Brian Copeland and Scott Taylor: "North-South Trade and the Environment", *Quarterly Journal of Economics*, 1994: 755-787

Werner Antweiler, Brian Copeland and Scott Taylor: "Is Free Trade Good for the Environment", *American Economic Review*, 2001: 877-908

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Motivation (Copeland and Taylor, 1995)

- **Much debate about impact of trade on environment**
- **Proponents of free trade argue environmental quality is normal good, income gains from trade creating demand for stricter environmental standards – brings forth cleaner *techniques* of production**
- **Skeptics argue pollution will rise as trade increases *scale* of economic activity**
- **If environmental quality is normal good, less developed countries will adopt weak environmental standards**
- **Due to asymmetries in world income distribution, free trade affects *composition* of output, developing countries producing pollution-intensive goods**

Model - Production

- **Assume two countries, developed North and less developed South, latter being denoted with ***
- **Continuum of goods, indexed as $z \in [0,1]$, and one primary input, effective labor ℓ**
- **Pollution *d* produced jointly with consumption goods; assume output *y* takes following functional form:**

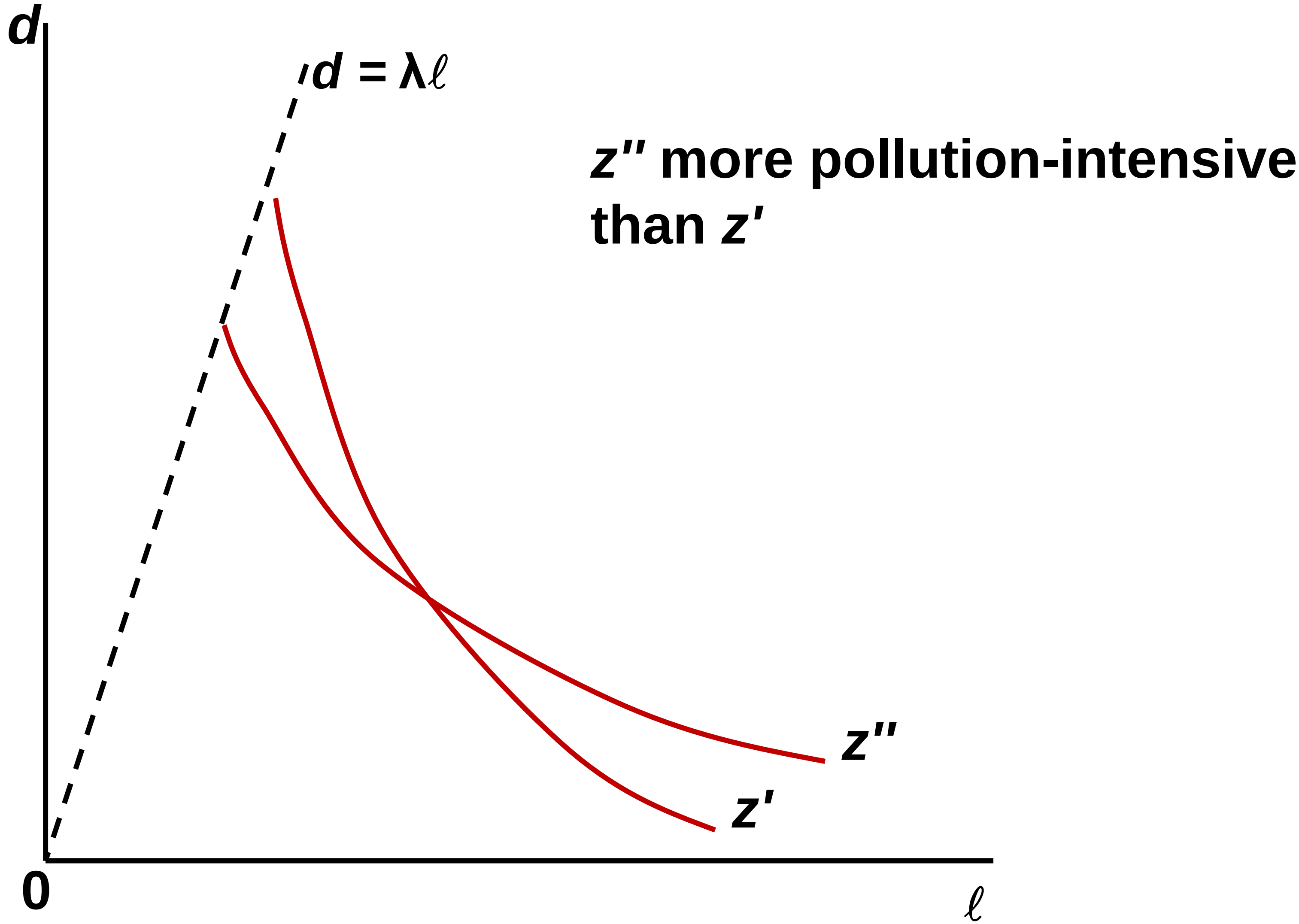
$$y(d,\ell;z) = \begin{cases} \ell^{1-\alpha(z)} d^{\alpha(z)} & \text{if } d \le \lambda\ell \\ 0 & \text{if } d > \lambda\ell \end{cases} \qquad (1)$$

where $\lambda > 0$, $\alpha(z)$ varies across goods, with:

$$\alpha(z) \in [\bar{\alpha}, \hat{\alpha}], \text{ with } 0 < \bar{\alpha} < \hat{\alpha} < 1$$

- **Isoquants for two goods, *z′* and *z″* in Figure 1**

Figure 1: Production Technology



Model - Production

- **(1) available to North and South, each has same number of workers L, supply of effective labor being $A(h)L>A(h^*)L$, where h is human capital/worker, and $h > h^*$**

- **Pollution tax τ, set for level of local public bad, and given return to effective labor $w_e=w/A(h)$, cost minimization implies:**

$$\frac{w_e}{\tau} = \frac{1-\alpha(z)}{\alpha(z)}\frac{d}{\ell} \qquad (2)$$

- **Share of pollution charges in cost of producing goods is $\alpha(z)$, goods being ordered in terms intensity of d, $\alpha'(z) > 0$**

Model - Consumption

- Consumers in North and South have identical indirect utility functions, *z* and *d* being separable in utility, and share of spending on each *z* is constant:

$$V = \int_0^1 b(z)\ln[b(z)]dz - \int_0^1 b(z)\ln[p(z)]dz + \ln\frac{I}{L} - \frac{\beta D^{\gamma}}{\gamma} \quad (3)$$

  x(*z*) is consumption of *z*, *b*(*z*) is budget share for each good in continuum, $\int_0^1 f(z)dz = 1$

  D is aggregate production of public bad; β is disutility from public bad, γ≥1 implies willingness to pay for reducing bad is non-decreasing in level of bad

Trading Equilibrium – Exogenous Taxes

- Given (1) and (2), unit cost function for good *z* is:

$$a(w,\tau;h,z) = \mathrm{K}(z)\tau^{\alpha(z)}[w/A(h)]^{1-\alpha(z)} \qquad (4)$$

where $\mathrm{K}(z) \equiv \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$, and *w* is wage rate for raw labor; for given taxes and wages in North and South, good *z* produced in North if its unit costs are lower $c(w,\tau;h,z) \leq c^*(w^*,\tau^*;h^*,z)$, i.e., if:

$$\omega \equiv \frac{w}{w^*} \leq \frac{A}{A^*}\left(\frac{\tau^*}{\tau}\right)^{\alpha(z)/(1-\alpha(z))} \equiv T(z) \qquad (5)$$

$T(z)$ is decreasing in z as $\tau > \tau^*$, and $\alpha'(z) > 0$

- For any ω, $T(z)$ determines point where goods are produced in North $z \in [0,\bar{z}]$, and South $z \in [\bar{z},1]$

Trading Equilibrium – Endogenous Taxes

- **Given (3), government chooses τ to maximize *V*, treating *p*(*z*) as given:**

$$\tau = -L(V_D / V_I) = \beta D^{\gamma-1} I \qquad (6)$$

i.e., pollution tax is set equal to marginal damage caused by emissions; tax is increasing in income, and non-decreasing in aggregate pollution level

- **Using (6):**

$$\frac{\tau^*}{\tau} = \frac{I^*}{I}\left(\frac{D^*}{D}\right)^{\gamma-1} \qquad (7)$$

and solve for income and pollution in terms of *z*

Trading Equilibrium – Endogenous Taxes

- **Let $\varphi(\bar{z}) = \int_0^{\bar{z}} b(z)dz$ denote share of world spending on Northern goods, balanced trade requiring:**

$$I = \varphi(\bar{z})(I + I^*) \qquad (8)$$

- **Aggregate Northern pollution *D* is:**

$$D = \int_0^{\bar{z}} d(z)z = \int_0^{\bar{z}} \left[\frac{\alpha(z)p(z)y(z)}{\tau} \right] dz = \int_0^{\bar{z}} \left[\frac{\alpha(z)b(z)(I + I^*)}{\tau} \right] dz \qquad (9)$$

- **Combining (8) and (9):**

$$D = I\theta(\bar{z}) / \tau\varphi(\bar{z}) \qquad (10)$$

where $\theta(\bar{z}) = \int_0^{\bar{z}} \alpha(z)b(z)dz$ is share of Northern pollution taxes in world income

Trading Equilibrium – Endogenous Taxes

- Use (6) to eliminate τ from (10), and do same for South:

$$D = \left(\frac{\theta(\bar{z})}{\beta\varphi(\bar{z})} \right)^{1/\gamma} \text{ and } D^* = \left(\frac{\theta^*(\bar{z})}{\beta\varphi^*(\bar{z})} \right)^{1/\gamma} \qquad (11)$$

where $\varphi^*(\bar{z}) = 1 - \varphi(\bar{z})$ is share of world spending on Southern goods, and $\theta^*(\bar{z}) = \int_{\bar{z}}^{1} \alpha(z) b(z) dz$ is share of Southern pollution taxes in world income

- Using (8) and (11), (7) can be re-written as:

$$\frac{\tau^*}{\tau} = \left(\frac{\theta^*(\bar{z})}{\theta(\bar{z})} \right)^{(\gamma-1)/\gamma} \left(\frac{\varphi^*(\bar{z})}{\varphi(\bar{z})} \right)^{1/\gamma} = \zeta(\bar{z}) \qquad (12)$$

Trading Equilibrium – Endogenous Taxes

- **Substituting (12) into (5) yields result that North produces all goods in interval $[0, \bar{z}]$ if:**

$$\omega = \frac{A}{A^*}\left[\zeta(\bar{z})\right]^{\alpha(z)/(1-\alpha(z))} \equiv S(z) \qquad (13)$$

provided $\tau > \tau^*$, which requires $\zeta(\bar{z}) < 1$, thus (13) is only valid for $\bar{z} > \hat{z}$, where $\zeta(\hat{z}) \equiv 1$

In this region, *S* is decreasing in *z*, and $S(\hat{z}) = A / A^*$, and *S*(1)=0 (see Figure 2)

- **To determine $\bar{z}$ need to combine *S*(*z*) with balance of trade schedule that takes account of resource constraints**

Trading Equilibrium

- Northern income is sum of wages and pollution taxes (rebated to consumers), hence:

$$I = wL + \tau D \qquad (14)$$

Using (10) to eliminate *D* in (14) and rearranging:

$$I = \frac{wL\varphi(\bar{z})}{\int_0^{\bar{z}} b(z)[1-\alpha(z)]dz} \qquad (15)$$

A similar expression can be derived for the South, and substitute into (8):

$$\omega = \frac{\int_0^{\bar{z}} b(z)[1-\alpha(z)]dz}{\int_{\bar{z}}^1 b(z)[1-\alpha(z)]dz} \equiv B(z) \qquad (16)$$

$B(0)=0$, $B(1)=\alpha$, and $dB/dz>0$

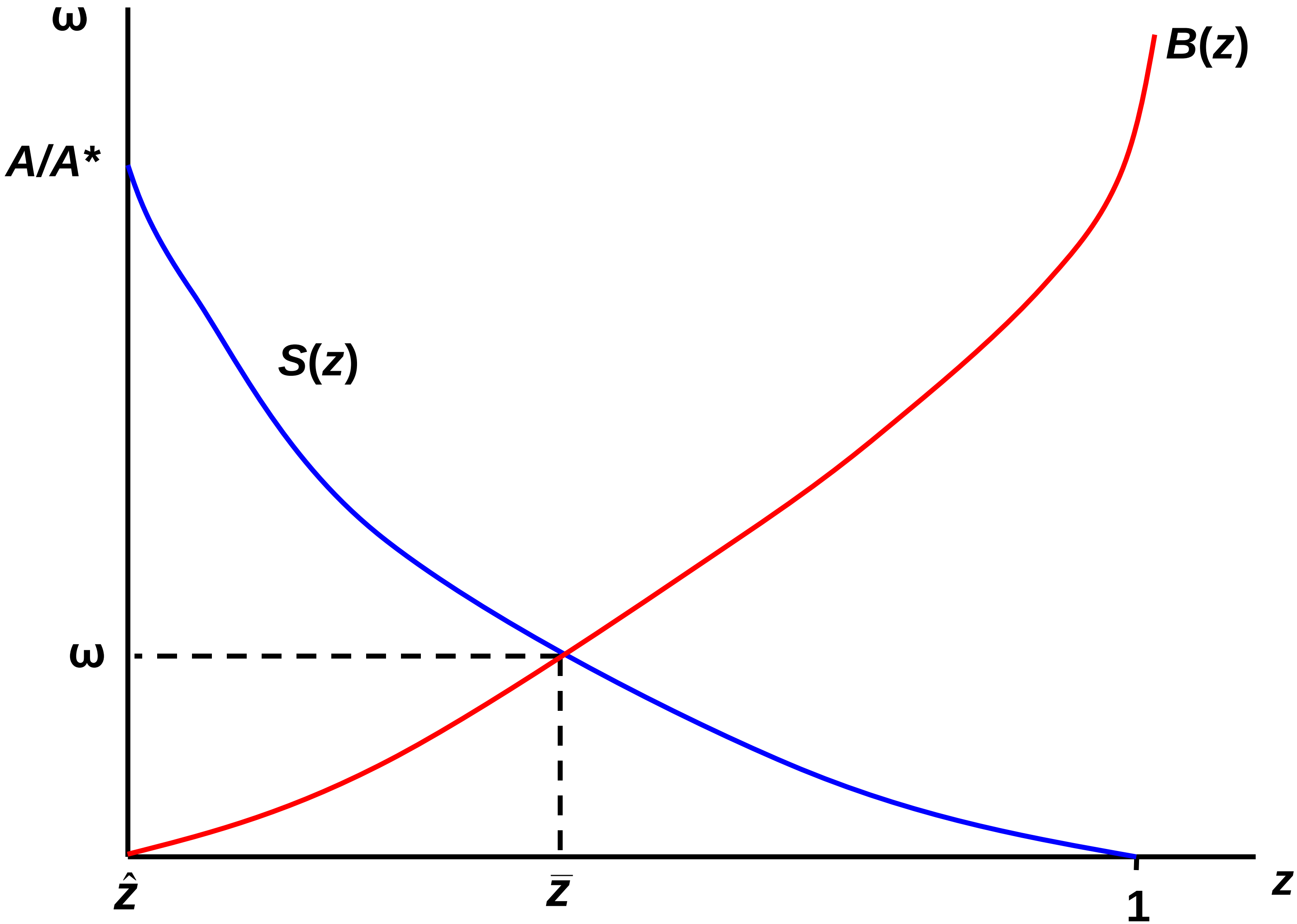
Trading Equilibrium

- $B(z)$ schedule positively sloped as increase in range of goods produced in North raises their exports and lowers imports, requiring increase in North's wages relative to those in South so as to balance trade

- Proposition 1: Equilibrium with $\tau > \tau^*$, where North produces all goods $z \in [0, \bar{z}]$, and South produces $z \in [\bar{z}, 1]$ iff $A / A^* > \delta > 1$, where $\delta \equiv B(z)$ (see Figure 2)

- Intuition: if North has higher income, chooses higher pollution tax, forcing pollution-intensive industries to locate in South – result relies on relative factor endowments being sufficiently different between North and South

Figure 2: Trading Equilibrium



Trade and Pollution

- **<u>Proposition 2</u>: If assumptions of Proposition 1 hold, trade always lowers pollution in North, increases pollution in South, and increases worldwide pollution**

- **Totally differentiating (10), evaluated at equilibrium:**

$$dD = \frac{\partial D}{\partial I} dI + \frac{\partial D}{\partial \tau} d\tau + \frac{\partial D}{\partial \bar{z}} d\bar{z} \qquad (17)$$

(similarly for the South and world pollution)

- **First term is *scale effect* – increase in pollution due to increased economic activity, holding technology and composition of output constant**

Trade and Pollution

- **Scale effect is positive, pollution rising in direct proportion to income with homothetic tastes, and constant returns; differentiating (10):**

$$\frac{\partial D}{\partial I} = \frac{\theta(\bar{z})}{\tau\varphi(\bar{z})} > 0, \text{ and } \frac{\partial D}{\partial I}\frac{I}{D} = 1 \quad (\text{also } \partial D^*/\partial I^* > 0) \quad (18)$$

- **Second term is *technique effect* – change in aggregate pollution from switch to less pollution-intensive techniques, *I* and range of goods constant - effect must be negative:**

$$\frac{\partial D}{\partial \tau} = -\frac{I\theta(\bar{z})}{\tau^2\varphi(\bar{z})} < 0, \quad (\text{also } \partial D^*/\partial \tau^* < 0) \qquad (19)$$

Trade and Pollution

- **Third term is *composition* effect, differentiating (10):**

$$\frac{\partial D}{\partial \bar{z}} = D\left[\frac{\theta'(\bar{z})}{\theta(\bar{z})} - \frac{\varphi'(\bar{z})}{\varphi(\bar{z})}\right] = \frac{Ib(\bar{z})}{\tau\varphi(\bar{z})^2}\int_0^{\bar{z}}\left[\alpha(\bar{z}) - \alpha(z)\right]b(z)dz > 0 \quad (20)$$

since α is increasing in *z*

- **Pollution rises in response to range of goods produced in North, if *I* and τ are constant – marginal goods added in North are more pollution-intensive than original goods**
- **Also, in South:**

$$\frac{\partial D^*}{\partial \bar{z}^*} = \frac{I^* b(\bar{z})}{\tau^*\varphi^*(\bar{z})^2}\int_{\bar{z}}^{1}\left[\alpha(z) - \alpha(\bar{z})\right]b(z)dz > 0$$

Trade and Pollution

- **Composition effect in South is also positive – as range of goods increases in North, it declines in South; but as $\bar{z}$ increases South loses cleanest industries, leading to higher average pollution intensity**

- **Composition effect dominates scale and technique effects; using (18)-(20) to rewrite (17) in % notation:**

$$\hat{D} = \hat{I} - \hat{\tau} + (\hat{\theta} - \hat{\varphi}) \qquad (21)$$

- **Derive change in pollution tax from (6):**

$$\hat{\tau} = (\gamma - 1)\hat{D} + \hat{I} \qquad (22)$$

Trade and Pollution

- **Combining (21) and (22):**

$$\hat{D} = -\left[(\gamma - 1)/\gamma\right](\hat{\theta} - \hat{\varphi}) + (\hat{\theta} - \hat{\varphi}) \qquad (23)$$

First term is net result of scale and technique effects. If γ=1, technique effect exactly offsets scale effect.

When γ>1, pollution taxes respond more than proportionately to change in income if pollution rises – technique effect fully offsets scale effect, but also offsets fraction (γ-1)/γ of composition effect

However, composition effect always dominates, determined by sign of $(\hat{\theta} - \hat{\varphi})$

Trade and Pollution

- **Reinterpret trade as trade in factor services, so model is two-factor Heckscher-Ohlin model**

- **Combining (6) and (14) yields inverse supply of pollution in North under autarky:**

$$\frac{\tau}{w_e} = \frac{\beta A(h)LD^{\gamma-1}}{1-\beta D^{\gamma}} \qquad (25)$$

Upward-sloping function N_s in Figure 3 – supply of pollution increasing in τ / w_e as consumers willing to accept increases in D if compensated with higher revenue from taxes

- **Derived demand for pollution under autarky derived from assuming $\bar{z} = 1$ in (10), and combining with (14):**

Trade and Pollution

$$\frac{\tau}{w_e} = \frac{A(h)L\theta(1)}{D[1-\theta(1)]} \qquad (26)$$

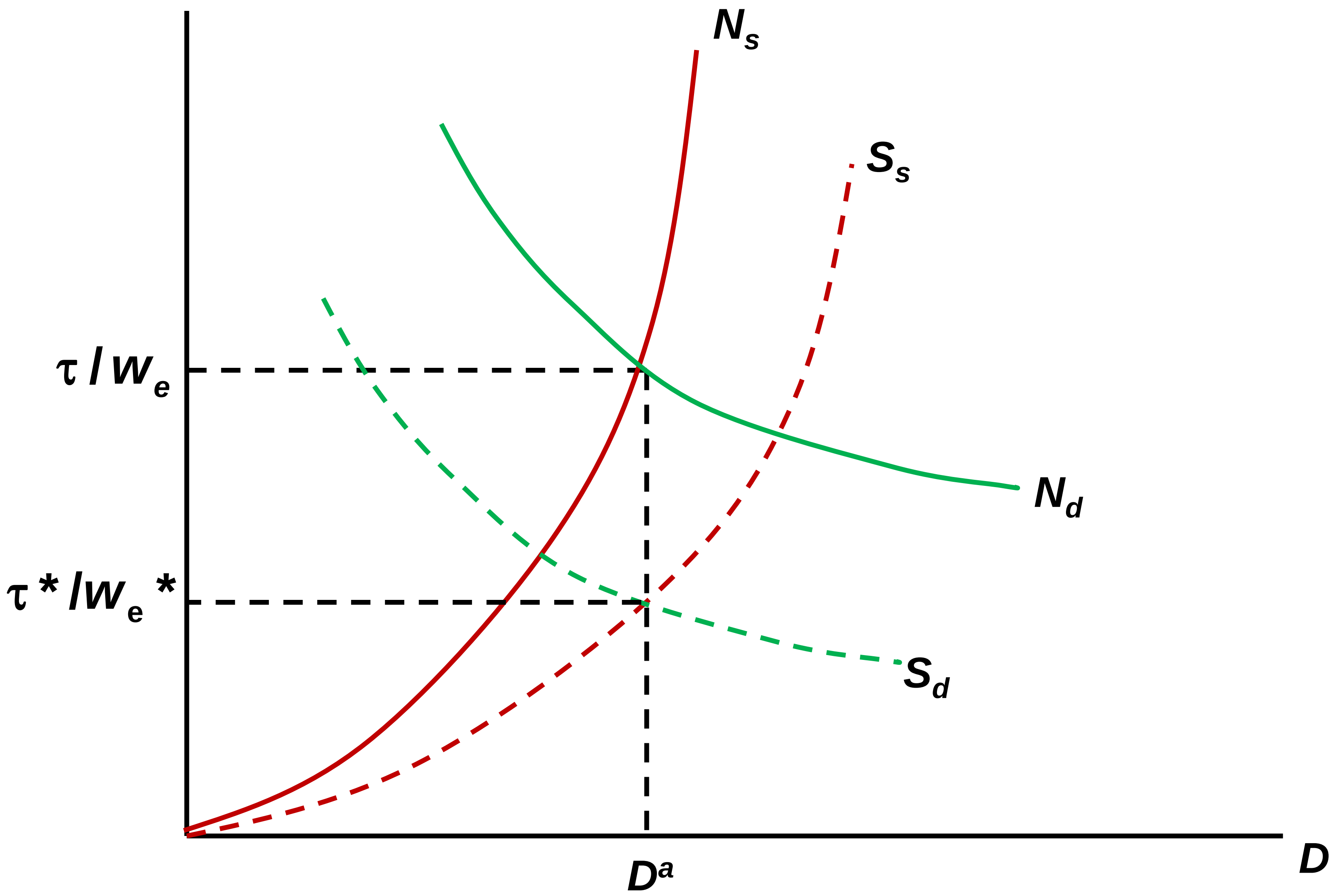
Plotted as N_d in Figure 3, derived demand for pollution decreasing in relative price τ / w_e

- Under autarky, factor-price ratio is τ / w_e , and autarky pollution is:

$$D^a = \left(\frac{\theta(1)}{\beta} \right)^{1/\gamma} \qquad (27)$$

- Reduction in human capital shifts demand and supply down by same proportion to S_s and S_d

Figure 3: Pollution Supply and Demand



Trade and Pollution

- **Leaves pollution level unchanged, but reduces factor-price ratio**

- **As South differs only from North in having less human capital, pollution relatively scarce input in North prior to trade, $D^a / AL < D^a / A^* L$, and hence pollution is relatively more costly for firms in North, $\tau / w_e > \tau^* / w_e^*$**

- **Provides basis for trade: North willing to export effective labor services in exchange for imports of pollution services, and vice-versa in South - result is that τ / w_e falls and τ^* / w_e^* rises – North moves down pollution supply, South moves up pollution supply**

Trade and Pollution

- **Trade shifts some labor in North from dirty to clean industries, and vice-versa in South**

- **Shifting unit of effective labor from dirty (z'') to clean industry (z') in North, change in pollution can be inferred from local ratio, $d(z)/\ell(z)$ using (2):**

$$\Delta d_N = \frac{d(z')}{\ell(z')} - \frac{d(z'')}{\ell(z'')} = \frac{w_e}{\tau}\left[\frac{\alpha(z')}{1-\alpha(z')} - \frac{\alpha(z'')}{1-\alpha(z'')}\right] < 0$$

since $\alpha(z') < \alpha(z'')$. Also, $\Delta d_S > 0$

- **Adding effects:**

$$\Delta d_N + \Delta d_S = \left[\frac{\alpha(z'')}{1-\alpha(z'')} - \frac{\alpha(z')}{1-\alpha(z')}\right]\left[\frac{w^*_e}{\tau^*} - \frac{w_e}{\tau}\right] > 0$$

Trade and Pollution

- **Since trade reduces but does not eliminate gap between relative prices, $\tau / w_e > \tau^* / w_e^*$, i.e., combined composition effect raises pollution, provided factor prices not equalized across North and South**

- **With equi-proportionate labor-augmenting technical progress, world pollution remains constant**

- **With increase in human capital in North, Northern pollution increases, and also Southern pollution**

- **Economic development in South lowers pollution in both countries**

Motivation (Antweiler et al., 2001)

- **Theoretical work has identified series of hypotheses linking trade to environmental quality, but lack of empirical verification**
- **Pollution-haven hypothesis suggests dirty industries locate in low-income countries; factor endowments suggest dirty, capital-intensive industries locate where capital is relatively abundant**
- **Paper develops model dividing trade impact on pollution into *scale*, *technique* and *composition* effects, and tests with data on SO_2 concentrations**
- **General equilibrium model of trade generates a pollution demand and supply model, from which estimating equation can be derived and tested**

Theory – The Model

- ***N*** **agents in small open economy, producing** ***X*** **and** ***Y*** **with labor** ***L*** **and capital** ***K*****;** ***Y*** **is labor-intensive, and** ***X*** **is capital-intensive,** ***X*** **production generating pollution**
- **Assume constant returns, production technology being described via unit cost functions,** $c^X(w,r)$**, and** $c^Y(w,r)$
- ***Y*** **is** ***numeraire*****, relative price of** ***X*** **being** ***p*****; domestic prices not identical to world prices due to location and trade barriers, hence:**

$$p = \beta p^w \qquad (1)$$

where β measures trade friction, p^w **is common world price of** ***X*** **-** $\beta>1$ **if country imports** ***X*****, and** $\beta<1$**, if country exports** ***X***

Pollution Abatement

- **Abatement of emissions *Z* is costly, but abatement has same factor-intensity as in *X*, hence treat units of *X* as inputs into abatement**
- **If firm's gross output is *x*, and it allocates x_a to abatement, net output is $x_n = x(1-\theta)$, where $\theta = x_a/x$ is abatement intensity**
- **If pollution is proportional to output and abatement is constant returns activity, emissions are:**

$$z = e(\theta)x \qquad (2)$$

where *e*(θ) is emissions per unit of *X* produced, which is decreasing in θ

- **Abatement assumed worthwhile [$e'(0)=-\infty$], but with physical limits [$e(1)>0$]**

Pollution Abatement

- **Given pollution tax τ, firm's profits are:**

$$\pi^x = p^N x - wLx - rKx \qquad (3)$$

where $p^N = [p(1\text{-}\theta) - \tau e(\theta)]$ is net price for gross output, and first-order condition for choice of θ implies:

$$p = -\tau e'(\theta) \qquad (4)$$

- **Hence, $\theta=\theta(\tau/p)$ with $\theta'>0$ and emissions per unit output are:**

$$e = e(\tau / p) \qquad (5)$$

where $e'<0$; production equilibrium being (2), (4), and zero profit and full employment conditions:

$$p^N = c^X(w,r) \qquad 1 = c^Y(w,r) \qquad (6)$$

$$K = c_r^X x + c_r^Y y \qquad L = c_w^X x + c_w^Y y$$

Consumers

- **Consumers differ in preferences over pollution, with two groups in society, *Greens*, N^g and *Browns*, $N^b = N - N^g$; each consumer maximizes utility, with pollution given, indirect utility of consumer in i^{th} group being:**

$$V^i(p, G/N, z) = u\left(\frac{G/N}{\rho(p)}\right) - \delta^i z \qquad (7)$$

for $i = \{g,b\}$ and where $\delta^g > \delta^b \geq 0$, G is national income, and $\rho(p)$ is price index, and u is increasing and concave

(7) implies homothetic preferences over consumption goods; can re-write indirect utility as $u(I) - \delta^i$, where $I = [G/N]/\rho(p)$ is real per capita income

Government

- Assume government chooses τ to maximize weighted sum of each group's preferences:

$$\max_{\tau} N[\lambda V^{g} + (1-\lambda)V^{b}] \qquad (8)$$

where λ is weight put on *Greens*, and it may vary across governments

- Optimal pollution tax maximizes (8) subject to private sector behavior, production possibilities, fixed world prices and trade frictions

- Private sector revenue is GNP net of taxes, while overall income includes revenue plus rebated pollution taxes, $G=R(p^{N},K,L)+\tau z$, first-order condition being:

$$u'(I)\frac{dI}{d\tau} - [\lambda\delta^{g} + (1-\lambda)\delta^{g}]\frac{dz}{d\tau} = 0$$

Government

- **With fixed world prices:**

$$\frac{dI}{d\tau} = \frac{1}{N\rho(p)}\left[R_{p^N}\frac{dp^N}{d\tau} + z + \tau\frac{dz}{d\tau}\right] = \frac{\tau}{N\rho(p)}\frac{dz}{d\tau}$$

Re-arranging first-order condition gives amended Samuelson rule:

$$\tau = N[\lambda MD^g(p,I) + (1-\lambda)MD^b(p,I)] \qquad (9)$$

where $MD^i(p,I)=\delta^i\rho(p)/u'$ is marginal damage per person, and $MD^i_I > 0$; simplifying (9):

$$\tau = T\phi(p,I) \qquad (10)$$

where $T=\lambda N\delta^g+(1-\lambda)N\delta^b$ is country type, and right-hand side of (10) is effective marginal damage (MD)

Theory – Pollution Demand and Supply

- **Define economy's scale *S* as value of national output at base-year world prices:**

$$S = p_x^0 x + p_y^0 y \qquad (11)$$

Choosing units so base-year prices are unity, pollution emissions re-written as:

$$z = ex = e\varphi S \qquad (12)$$

where φ is share of *X* in total output

- **(12) provides simple decomposition, where pollution depends on: pollution intensity of dirty industry, *e*(θ), relative importance of dirty industry, φ, and overall scale of economy *S***

Theory – Pollution Demand and Supply

- **Writing (12) in differential form:**

$$\hat{z} = \hat{S} + \hat{\varphi} + \hat{e} \qquad (13)$$

- $\hat{S}$ is *scale* effect, measuring increase in pollution if economy was scaled up, holding mix of goods φ and production techniques *e*(θ) constant

- $\hat{\varphi}$ is *composition* effect, i.e., holding *S* and *e*(θ) constant, increase in pollution due to more resources being used in producing *X*

- $\hat{e}$ is *technique* effect, i.e., all else constant, increase in emission intensity increases pollution

- **Use quantity index of output to measure scale effect, but necessary to divide composition and technique effects up as price changes create opposite effects**

Theory – Pollution Demand and Supply

- Using (6), solve for φ as a function of capital-labor ratio $\kappa = K/L$, net producer price p^N and base-year world prices (suppressed), $\varphi = \varphi(\kappa, p^N)$, composition effect is:

$$\hat{\varphi} = \varepsilon_{\varphi,\kappa}\hat{\kappa} + \varepsilon_{\varphi,p}\hat{p}^N \qquad (14)$$

where elasticities $\varepsilon_{\varphi,\kappa} > 0$and $\varepsilon_{\varphi,p} > 0$

- Differentiate p^N and use (1) and (4) to find:

$$\hat{p}^N = (\hat{\beta} + \hat{p}^w)(1 + a) - a\hat{\tau} \qquad (15)$$

where $a = e(\theta)\tau/p^N$ is importance of taxes in net price

- Also, use (1) and (5) to find:

$$\hat{e} = \varepsilon_{e,p/\tau}(\hat{\beta} + \hat{p}^w - \hat{\tau}) \qquad (16)$$

where $\varepsilon_{e,p/\tau} > 0$

Theory – Pollution Demand and Supply

- **Combining (13)-(16), get demand for pollution:**

$$\hat{z} = \hat{S} + \varepsilon_{\varphi,\kappa}\hat{\kappa} + [(1+a)\varepsilon_{\varphi,p} + \varepsilon_{e,p/\tau}]\hat{\beta}$$
$$+ [(1+a)\varepsilon_{\varphi,p} + \varepsilon_{e,p/\tau}]\hat{p}^{w} \qquad (17)$$
$$- [a\varepsilon_{\varphi,p} + \varepsilon_{e,p/\tau}]\hat{\tau}$$

- **If (17) is drawn in {*z*,τ} space, increase in *S*, κ, or p^w shifts demand for pollution to right**
- **Reduction in trade frictions, β→1, causes demand for pollution to shift to right for a dirty good exporter $(\hat{\beta} > 0)$ and to left for dirty good importer $(\hat{\beta} < 0)$**
- **Increase in τ reduces pollution demand through raising abatement and lowers output of *X*, strength depending on *a* and $\varepsilon_{\varphi,p}$**

Theory – Pollution Demand and Supply

- **From (1) and (10), get decomposition of pollution supply:**

$$\hat{\tau} = \hat{T} + \varepsilon_{MD,p}\hat{\beta} + \varepsilon_{MD,p}\hat{p}^{w} + \varepsilon_{MD,I}\hat{I} \qquad (18)$$

where $\varepsilon_{MD,p} > 0$, and $\varepsilon_{MD,I} > 0$

- **Drawing (18) in $\{z,\tau\}$ space, increases in real income, relative prices (substitution to abatement), country type and $\beta \rightarrow 1$, shift pollution supply curve upwards;**
- **Combining (17) and (18), reduced form linking pollution emissions to set of economic factors:**

$$\begin{aligned} \hat{z} &= \pi_1\hat{S} + \pi_2\hat{\kappa} - \pi_3\hat{I} \\ &+ \pi_4\hat{\beta} + \pi_5\hat{p}^{w} - \pi_6\hat{T},\ \text{all}\ \pi_i > 0 \end{aligned} \qquad (19)$$

Trade-Induced Composition Effect

- <u>Proposition</u>: if two economies differ only in trade frictions: (i) if both export dirty good, pollution higher in country with lower trade frictions; (ii) if both import dirty good, pollution lower in country with lower trade frictions
- With freer trade, for exporters and importers of dirty good, pollution demand effects dominate, exporter emissions increasing, importer emissions falling, i.e., emissions not related to openness in systematic way
- Result captures partial effect of trade liberalization, ignoring scale and technique effects
- Result also conditioned on given trade patterns, ignoring factors such as comparative advantage

Full Impact of Trade Openness

- **Differentiating (12) with respect to β, holding world prices, country type, and factor endowments constant:**

$$\frac{dz}{d\beta}\frac{\beta}{z} = \pi_1 \frac{dS}{d\beta}\frac{\beta}{S} - \pi_3 \frac{dI}{d\beta}\frac{\beta}{I} + \pi_4 \qquad (20)$$

- **Fall in trade frictions generates scale, technique and composition effects**
- **Possible that trade liberalization for dirty good exporter leads to less pollution *if* composition and scale effects are overwhelmed by technique effect**
- **Result illustrated in Figure 1, where top panel illustrates production response of dirty good exporter, and bottom panel illustrates pollution of changes**

Full Impact of Trade Openness

- **Before trade, production at *A*, world price is p^w, net price is p^N, and as country assumed exporter of dirty good, consumption to north-west of A (not shown)**
- **Value of output *A* at world prices measures scale *S*; with emissions intensity $e(\theta^A)$, pollution is z^A**
- **As trade frictions fall, domestic price approaches world price, production moves to C at $p^{N'}$, where real income is higher, and production technique changes to $e(\theta^C)$, pollution falling to z^C**
- **Holding scale of economy and techniques of production fixed, change in composition of output is A to B, i.e., z^A to z^B; then B to C is scale effect, z^B to z^S, and technique effect is z^S to z^C**

Theory – Adding Up Effects

- **Taking factor endowments as fixed, lowering trade costs raises value of domestic output and income by same percentage, creating scale and technique effects; simplifying (20):**

$$\frac{dz}{d\beta}\frac{\beta}{z} = [\pi_1 - \pi_3]\frac{dI}{d\beta}\frac{\beta}{I} + \pi_4 \qquad (21)$$

- **In some cases, can add up effects without knowing trade's effect on income or scale; e.g., for dirty goods exporter, $dI/d\beta > 0$ due to lower trade frictions, and if $\pi_1 > \pi_3$, and $\pi_4 > 0$, trade liberalization raises pollution; however, effects ambiguous with clean good exporter**
- **So who exports dirty goods and why?**

Pollution Haven vs. Comparative Advantage

- **Comparative advantage in model due to relative factor abundance and relative incomes, and both likely to matter**
- **Let *RD*(*p*) be demand for *X* relative to *Y*, relative autarky price of *X* given by intersection of (net) relative demand and supply:**

$$RD(p) = (1-\theta)\chi(\kappa, p^N) \qquad (22)$$

where χ=x/y from (6), and net relative supply is (1-θ)χ

- **Totally differentiating, and using (15), (16) and (18), and re-arranging:**

$$\hat{p} = \frac{\varepsilon_{MD,I}\left[a\varepsilon_{\chi,p^N} + \frac{\theta}{1-\theta}\varepsilon_{\theta,\tau/p}\right]\hat{I} - \varepsilon_{\chi,\kappa}\hat{\kappa}}{\Delta} \qquad (23)$$

Pollution Haven vs. Comparative Advantage

- **With all elasticities and Δ positive, (23) shows in general, pattern of trade driven by both factor abundance, and income-driven differences**
- ***Factor endowments*: as *X* is capital-intensive, an increase in a country's κ, ceteris paribus, increases relative supply of *X*, and lowers relative price – country exports pollution-intensive goods**
- ***Income differences*: with similar relative factor endowments, richer country has stricter pollution policy, raising relative price, leading to comparative advantage in exporting clean goods**
- **In empirical analysis, measure trade frictions via trade intensity, and capital abundance and real income relative to world averages**

Empirical Analysis

- **Data: 2,555 observations of SO_2 concentrations from 290 observation sites in 108 cities, representing 43 countries for period 1971-1996**

$$Z^{C}_{ijkt} = X'_{jkt}\alpha + Y'_{ijkt}\gamma + \varepsilon_{ijkt}$$

$$X'_{jkt}\alpha = \alpha_0 + \alpha_1 SCALE_{jkt} + \alpha_2 KL_{kt} + \alpha_3 INC_{kt} + \alpha_4 \psi_{kt} TI_{kt}$$

$$\psi_{kt} = \psi_0 + \psi_1 REL.KL_{kt} + \psi_2 REL.KL^2_{kt} + \psi_3 REL.INC_{kt} + \psi_4 REL.INC^2_{kt} + \psi_5 REL.KL_{kt} REL.INC_{kt} \quad (24)$$

***Z*=emissions, *X*=concentrations, *Y*=site-specific weather and physical characteristics, SCALE=city-specific GDP/km², KL=national K/L ratio, INC=GNP/N, TI=(X+M)/GDP, REL.KL=capital/labor relative to world average, REL.INC=real income relative to world average, ε_{ijkt} = site-specific error, *i*=station, *j=city*, *k*=country, *t*=year**

Empirical Analysis

- **Model A is assumed linear, while Model B adds squared INC, KL and cross-product INC.KL terms, while Model C adds squared SCALE term (See Table 1)**
- **Scale, Composition, and Technique Effects:**

  - scale effect positive

  - composition effect positive

  - technique effect negative
- **Trade-Induced Composition Effect:**

  - for average country in sample, effect negative
- **Site-Specific and Country-Type Considerations**

  - Communist country-type, site-specific land use and weather variables matter; Helsinki protocol on acid rain does not matter

Conclusions

- **Results indicate scale, technique and composition effects can be identified and magnitude measured**
- **Once measured, play role in determining environmental impact of technical progress, capital accumulation and increased trade**
- **Estimates indicate increases in international integration create small but measurable changes in pollution by altering pollution intensity of output**
- **Greater trade intensity creates only relatively small changes in pollution via composition effect; but scale and technique effects also have impact on pollution**
- **Estimates indicate if trade results in 1% increase in output and income, pollution concentrations fall by 1%**