THREE ESSAYS ON THE INTERACTION OF INTERNATIONAL TRADE AND ENVIRONMENTAL OUTCOMES AND POLICIES

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ABSTRACT

BIDISHA LAHIRI: Three essays on the interaction of international trade and environmental outcomes and policies
(Under the direction of Patrick Conway)

Economic literature on international trade identifies the sources of comparative advantage like endowments and technology that drive international trade and result in gains from trade. Comparative advantage is however also affected by environmental standards. Stricter environmental standards are commonly believed to erode an existing comparative advantage of developing countries and hence result in lower gains from trade. Based on this popular belief, developing economies might legislate weak environmental standards or fail to enforce existing standards in the hope of encouraging "dirty" industries. My essays take a more sophisticated look at the trade and environment relation and find that the relation between welfare gains from trade and environmental quality is not one of simple trade-off of one against the other as popularly believed.

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Symbol

X_t Production of commodity X by home economy in period t

Y_t Production of commodity Y by home economy in period t

X_t* Production of commodity X by foreign economy in period t

Y_t* Production of commodity Y by foreign economy in period t

C_t Consumption bundle for home economy in period t

C_{Xt} Consumption of X commodity by home economy in period t

C_{Yt} Consumption of Y commodity by home economy in period t

C_t* Consumption bundle for foreign economy in period t

C_{Xt}* Consumption of X commodity by foreign economy in period t

C_{Yt}* Consumption of Y commodity by foreign economy in period t

P_{Xt} Price of X commodity relative to Y in period t

P_t Price of consumption bundle in period t

E_t Expenditure on consumption bundle for home economy in period t

Z_t Aggregate emission level in home economy in period t

Z_{Xt} Emissions from X industry in home economy in period t

Z_{Yt} Emissions from Y industry in home economy in period t

Z_t* Aggregate emission level in foreign economy in period t

Z_{Xt}* Emissions from X industry in foreign economy in period t

Z_{Yt}* Emissions from Y industry in foreign economy in period t

L	Labor endowment for home economy
L^*	Labor endowment for foreign economy
K_t	Capital stock for home economy in period t
K_t^*	Capital stock for foreign economy in period t
B_t	Flow of capital from home to foreign economy in period t
r_t	Return to physical and financial capital in the world market in period t
τ_t	Per unit emission tax imposed by home economy in period t
τ_t^*	Per unit emission tax imposed by foreign economy in period t
θ_{Yt}	Fraction of resources spent by home economy for abatement activity in sector Y in period t
w	Weight of commodity X in consumption bundle
sx	Degree of returns to scale for X industry
sy	Degree of returns to scale for Y industry
α	Degree of return for abatement technology in Y industry
β	Degree of return for abatement technology in X industry
γ	Marginal disutility of pollution for home economy
γ^*	Marginal disutility of pollution for foreign economy
ρ	Rate of time preference
s	Ratio of foreign economy income to home economy income
EKC	Environmental Kuznets curve

LIST OF SYMBOLS FOR CHAPTER 3

Symbol

px	Price of X commodity in home economy
Px	Price of X commodity in foreign economy
py	Price of Y commodity in home economy
Py	Price of Y commodity in foreign economy
x	Every period endowment of commodity X in home economy
X	Every period endowment of commodity X in foreign economy
y	Every period endowment of commodity Y in home economy
X	Every period endowment of commodity Y in foreign economy
m	Maximum per unit emission from x
M	Maximum per unit emission from X
n	Maximum per unit emission from y
NN	Maximum per unit emission from Y
ux	Every period welfare to home economy from X market
uy	Every period welfare to home economy from Y market
u	Every period welfare to home economy
Ux	Every period welfare to foreign economy from X market
Uy	Every period welfare to foreign economy from Y market
U	Every period welfare to foreign economy
t	Import tariff imposed by home economy in Y market

T	Import tariff imposed by foreign economy in X market
e	Per unit emission from x in home economy
EE	Per unit emission from X in foreign economy
f	Per unit emission from y in home economy
F	Per unit emission from Y in foreign economy
br	Best response
δ	Time discount rate
ICC	Incentive compatibility constraint
λ	Lagrange multiplier on budget constraint
HOV	Hecksher-Ohlin-Vanek framework

LIST OF SYMBOLS FOR CHAPTER 4

Symbol

a_{ij} Input j used for every unit of production of commodity i

b_{ij} Input j used for production and abatement purposes for every unit of commodity i

θ_{ij} Share of expenditure on j-th input in the i-th sector.

λ_{ij} Share of industry i's use of input j

s_{Ai} Abatement's share in total expenditure on input i for commodity Y

σ_i Elasticity of substitution between labor and capital in sector i

δ_i Percent savings in use of factor i associated with one percent rise in relative factor price

I Aggregate income of the economy

γ_{Li} Elasticity of labors marginal productivity curve in sector i

SIC Standard industrial classification

CHAPTER 1

INTRODUCTION

Economic literature on international trade identifies the sources of comparative advantage like endowments and technology that drive international trade and result in gains from trade. Comparative advantage is also affected by environmental standards. Stricter environmental standards are commonly believed to erode an existing comparative advantage of developing countries and hence result in lower gains from trade. Based on this popular belief, developing economies might legislate weak environmental standards or fail to enforce existing standards in the hope of encouraging "dirty" industries to grow or locate there.

My essays take a more sophisticated look at the trade and environment relation and find that the relation between welfare gains from trade and environmental quality is not a simple trade-off of one against the other as popularly believed.

In my first essay I find that with growth of an economy, when environmental standards become stricter at a higher income, the relation between income and environment is likely not monotonic. Instead it follows an inverted U-shape, with environmental quality deteriorating at the earlier phase of economic growth and improving at a later phase of economic growth. In terms of welfare gains, when the environmental standards become stricter to reflect the preferences of the richer residents, the community welfare level is maximized. The economy could implement weaker environmental standards and sustain a greater volume of production and trade, but at a cost in terms of welfare lost. If environmental standards are reduced below optimum, welfare levels are reduced also.

In this essay, I also find that two economies that have different relative incomes at the beginning of international trade have very different time paths of environmental quality, trade pattern and welfare levels even when they independently and optimally set their environmental policy each period. This indicates that it is not sufficient for countries to consider only environmental quality while setting environmental standards; the impact that the environmental policy has in influencing the trade pattern and capital flows needs to be considered while designing a truly optimal environmental policy.

This insight is further explored in the second essay where the impact of trade policies on environmental quality and the impact of environmental policy on production and trade patterns are considered holistically. The second essay abstracts from growth issues in order to focus on this more sophisticated interaction of trade and environmental policies. I once more derive results that refute the popularly believed trade-off between gains from trade and gains from environmental quality. In a repeated game framework, I find that when each economy acts non-cooperatively, it sets low environmental standards and high tariffs. When the economies cooperate on trade policy, they reduce their tariffs but simultaneously they choose to lower their environmental standards. They then end up with higher welfare than under non-cooperation. This seemingly supports the trade-environment trade off. However, when I consider the more interesting scenario of a jointly negotiated trade and environment treaty, I find that lower tariffs and stricter environmental standards can be sustained compared to non-cooperation. This is also associated with significant gains over the non-cooperative as well as over the trade only cooperative situations. This re-emphasizes the fact that better environmental quality is not necessarily in conflict with international trade and with gains from international trade.

My third essay looks at another trade-off between international trade and environmental standards known as the Pollution Haven hypothesis. It has been commonly believed that stricter environmental standards will result in dirtier industries migrating to countries with weaker environmental standards. This has made economies wary of tightening their environmental standards due to the fear of losing comparative advantage in the high polluting industries. It also has encouraged other economies to maintain low environmental standards with the hope of attracting the dirty industries. In my third essay, I find that dirtiness of an industry is not a sufficient indicator to predict the impact of a stricter environmental regime. It is important to consider the interaction of "dirtiness" and input use intensity of an industry to predict the impact of a stricter environmental standard. For two equally dirty industries, the one that has an input requirement more similar to the abatement technology will be affected more negatively, while a dirty industry whose input requirement is very different from the abatement technology could experience increased production in the stricter regime. These results indicate that the relation between environmental standards and comparative advantage in dirty industries does not have the simple inverse relation as believed.

My research design abstracts from various real world regularities as outlined below.

My first essay builds a growth model and assumes production functions to be decreasing returns. However, in the real world, production functions might exhibit increasing returns at the earlier stages of growth and decreasing returns at later stage of growth. My model abstracts from this potentially variable-returns-to-scale phenomenon.

My second model abstracts from growth issues in an infinitely repeated game to allow for a more complex analysis of trade and environmental policies.

My first and second essays assume that the abatement technology has the same factor intensity as the industry where the abatement is undertaken. This makes the scenario equivalent to the abatement technology using up some of the final commodity. This assumption is a simplification made in order to focus on the growth issues in the first essay and the strategic issues in the second one. The assumption is relaxed in the third essay where difference in input use by the abatement technology and by the production sectors drive interesting results. The third essay in turn abstracts from growth and strategic issues to keep the analysis tractable.

A fourth abstraction from real world phenomena centers around the sources of environmental degradation. Environmental degradation occurs from two sources. The first source is production-driven degradation – when firms pollute air, or put industrial by-products in water, or cut down forests to use as inputs in production. The second source is consumption-driven environmental degradation where pastures are eroded due to excessive use by households for cattle grazing, deforestation occurs due to households use of firewood for heating or cooking, air pollution follows from family owned cars, and plastic, metal and other consumption related wastes degrade the environment. However environmental degradation associated with consumption is tied to the location where the consumption is made and hence international trade does not directly play a role in consumption-driven degradation. Hence all my three essays deal with production related environmental degradation.

Additionally, the essays do not consider feedback effects of environmental degradation on productivity. Some researchers, (e.g. Pizer) consider scenarios where pollutants like green house gases potentially increase the temperature, which negatively impacts production. In those models, the welfare cost of environmental degradation arises from production loss. In my models the welfare loss arises due to disutility from consumption of pollution by affected residents.

CHAPTER 2

INTERNATIONAL TRADE, CAPITAL MOBILITY AND THE ENVIRONMENTAL KUZNETS CURVE IN AN OPEN ECONOMY GROWTH MODEL

1. INTRODUCTION:

Empirical studies driven primarily by cross-sectional variation find an inverted U shaped relation between per capita income and environmental degradation (especially for local pollutants) that is called the Environmental Kuznets curve (henceforth EKC). This has led to speculation whether growth in income is sufficient to correct for poor environmental quality. To infer whether such conclusions are true for a specific economy, it is necessary to analyze the income-environment relation over the inter-temporal growth path of the economy.

To investigate the time series properties of a single country's EKC I construct a two country open economy growth model with an environmental externality. Through analytical and simulation analysis of this model I draw three conclusions: First, I conclude that growth in income is not a sufficient condition for eventual improvement in environmental quality. I find that the two conditions necessary for the EKC relation to emerge in the growth path of the economies are that the environmental policy of the economy should become increasingly strict with growth in per-capita income and also that the economy should be sufficiently far from its steady state. Second, in the absence of other sources of comparative advantage, the intertemporal income-environment relationship for an economy under trade will be better compared to autarky if the trade partner is poorer and worse if the trade partner is richer. Third, the transition from autarky to international trade will confound the EKC outcome for an individual economy while for a cross section of economies this autarky-trade transition will result in an EKC relationship even when it is not true for the individual economies.

In this growth model the choice of environmental policy embodies a tradeoff between environmental quality and long-term growth. An EKC will emerge for individual economies with anti-pollution policies in place if at lower levels of per-capita income emissions due to the strong investment-led production growth overwhelm the incentive to producers to reduce emission per unit of production and the incentive to move production to cleaner sectors where the pollution tax payment is low. As the economy nears it steady state, the same anti-pollution policy regime induces lower emission-intensity and cleaner production-composition effects that dominate the contributions to emission from economic growth and result in the downward sloping segment of the EKC. When the policy regime is such that emissions taxes do not increase with per-capita income, these two pressures negating the growth effect are absent and hence environmental quality worsens monotonically. Thus whether the EKC emerges for an economy or not depends crucially on the environmental policy. When the economy is sufficiently close to its steady state, the increasing strictness of environmental policy will result only in the downward sloping segment of the EKC because the initial burst of economic activity has already been observed.

International trade matters because at every point in time, the poorer economy, whatever its level of per-capita income, values pollution less than its rich partner and hence accepts foreign productive capital that flows wherever returns are higher. Although the returns on the foreign capital are remitted abroad, the effects of the pollution remain domestically. In this case, it would be misguided for less developed countries, at any given income level, to expect environmental quality to be the same as the level the developed country had enjoyed at an identical per-capita income. Allowing for the standard sources of comparative advantage in the form of different relative endowments of the internationally immobile resource shifts the environmental-income relation but it does not change the intertemporal properties derived here.

In my model, the transition from an autarky EKC to an open-economy EKC generates a jump in income and environmental quality. In the real world this shift is observed over a period of time in the form of the dismantling of export-import tariffs or removal of capital flow restrictions. When an economy that was close to its autarky steady state enters international trade with a larger partner, it accepts foreign capital and experiences a deterioration in environmental quality instead of the improvement predicted by the EKC. Similarly, when an economy that was on the rising segment of the autarkic EKC starts trading with a much smaller trade partner, it will invest its domestic capital abroad and experience both an improvement in environmental quality and increasing income. This is a result unlike the prediction from its original EKC. For a cross section of countries these movements in trade and capital during the transition will generate an EKC even though it might not hold for the individual economies.

The majority of the studies on EKC are empirical. They look at environmental outcomes explained by per-capita income and other explanatory variables. The few existing theoretical studies are limited along one or more of the following dimensions: they are static in nature, they do not explicitly model the environmental policy, they consider a single production commodity or they consider closed economies. These prevent the models from capturing one or more of the growth, intensity, composition or trade effects. My model fills this void by allowing these effects to interact in determining the final outcome.

These dimensions of the exercise provide a more comprehensive understanding of the economic reasons underlying the Environmental Kuznets Curve. I examine whether and when it is realistic for polluted economies to pin their hope on higher incomes as a engine of improved environmental quality. Lastly, comparison of the predictions of the model with information from U.S. emissions data sheds light on actual changes in environmental patterns.

The remainder of the paper is organized as follows: section 2 presents a brief literature review; section 3 presents a theoretical framework of the model. The broad features of the theoretical model are presented in section 3a. The specific equations of transition are presented and explained in section 3b. Section 3c compares the implications of the model in the context of private agents versus a social planner's problem, which is especially important when taxes are not set in a welfare maximizing manner. Numerical simulation results will be illustrated in section 4. Interpretation of empirical observations in the light of the model will be presented in section 5. Finally, conclusions are drawn in section 6.

2. LITERATURE REVIEW:

An empirical study by Grossman and Krueger (1991) uncovered the inverted U shaped relation between income and local air and water pollutants. This study spawned multiple empirical studies to measure and analyze the EKC. This body of cross-sectional and panel empirical studies motivates my research to examine the relation between income and environmental quality for a specific economy and the forces that underlie the observed relation.

Theoretical papers by Andreoni and Levinson (1998), John and Pecchenino (1994), Jones and Manuelli (1995), Selden and Song (1995) and Stokey (1998) have derived patterns for the transition path of pollution for a growing economy. They differ in the forms of the welfare function, the production functions, abatement functions and intergenerational considerations. However, none of them model the impact of international trade and of different environmental policy regimes as important influences on the change in pollution in the context of economic growth.

Smulders, Bretschger and Egli (2005) construct a dynamic simulation EKC model. In a closed economy scenario, they distinguish subsequent phases when better technologies become available exogenously. Also, the environmental tax structure changes exogenously in the different phases. These two characteristics affect the profit maximization decision of firms in adopting the new technology or continuing with the old. In my dynamic model, I examine both exogenous and endogenous changes in tax policy. Also, the technique of production is determined within the model. The interaction between the two trading partners, usually absent in the EKC literature, is an important addition in my analysis.

Starting with two countries that differ in capital and labor endowment, Copeland and Taylor (1997) outline a static framework to examine the implication of trade on each country's production pattern and environmental outcomes. They allow capital to be mobile, so that a country could employ its domestically owned capital abroad. I start from this framework and extend it to a dynamic model so that it is suitable for analyzing the intertemporal relation between income and environmental for an economy. The differences in initial relative endowments play a weaker role in my model because in a dynamic context the endogenously determined intertemporal savings rate is the primary determinant of the capital owned by the country. The endogenously determined pollution tax in each country has both dynamic and static implications in my model. The pollution tax path determines the amount of capital that is accumulated over time, while every period it affects the location where the capital is employed and the intensity of emission. The interaction of the intertemporal and static effects of the tax determines the final emission outcome in my model.

The classic Ramsey-Cass-Koopmans (RCK) Neoclassical Growth Model with an endogenous savings rate provides the dynamic structure for my model. I simplify the instantaneous utility function to be the log function instead of constant-elasticity-of-substitution in the original RCK framework. However the consumption bundle comprises of two goods instead of the single commodity in the RCK model, while the disutility from pollution is added in the welfare function. While the original RCK model was for a closed economy, my model applies it to two country trading framework.

In recent research Roe (2005) has used the RCK framework to conduct a simulation exercise in an open economy framework in a non environmental context. He however simplifies the openness of the model by assuming a small open economy trading with the rest of the world at steady state implying constant prices. Also there is no international capital mobility.

3A. THEORETICAL MODEL:

I start with a dynamic general equilibrium model with two types of goods (X_t and Y_t) and two inputs (L_t and K_t) observed at each time period t. For every economy there are three sets of economic agents: consumers who maximize lifetime welfare, social planner who sets environmental policy either optimally to maximize the social welfare or sub-optimally without reference to social welfare, and producers who take the environmental taxes as given while maximizing profits.

The consumption bundle is of the Cobb-Douglas form $C_t = (C_{Xt})^{\omega}(C_{Yt})^{(1-\omega)}$. Expenditure on consumption is $E_t = P_{Xt}C_{Xt} + C_{Yt} = P_tC_t$ where P_t is the price index of the consumption bundle.

The every-period utility function is additive in consumption and pollution. It is concave is consumption C_t and linear in pollution Z_t where γ is the constant marginal disutility from pollution. The inter-temporal social welfare function is

$$U_t = \sum_{t=0}^{\infty} \rho^t u_t = \sum_{t=0}^{\infty} \rho^t [\ln(C_t) - \gamma.Z_t]$$

subject to the intertemporal budget constraint

$$P_tC_t + (K_{t+1} - K_t) + (B_t - B_{t-1}) = Y_t + P_{Xt}X_t + r_tB_t$$

In this welfare expression the disutility parameter associated with pollution is constant, but the marginal valuation of disutility nevertheless increases as economies get richer[1]. This can be seen from the ratio of the marginal utilities. If $P_{Z,t}$ is the marginal valuation of pollution, and P_t is the marginal valuation of consumption, then $\frac{P_{Z,t}}{P_t} = \frac{-\partial u_t / \partial Z_t}{\partial u_t / \partial C_t}$, or $P_{Z,t} = \gamma P_t C_t$

Production of each commodity uses one specific physical input, and emits pollution Z as byproduct. Y uses K and X uses L as specific factors[2]. K can be created and accumulated and is internationally mobile. L is internationally immobile and also cannot be accumulated (example: land).

In the absence of any abatement activity $Y_t = (K_t)^{sy}$, $Z_{Yt} = K_t$

$$X_t = (L_t)^{sx}, \; Z_{Xt} = L_t$$

As in the standard growth models, the production functions are decreasing returns in the specific factor. s_X is degree of returns in X industry, s_Y is degree of returns in Y industry. The production function can also be interpreted as constant returns where a sectorally immobile third input (labor or entrepreneurship) has not been explicitly modeled.

Pollution emission can be abated if some resources are diverted for this purpose. Following the approach popularized by Copeland and Taylor[3] the production of output and production of the emission byproduct are combined into a single function using the

[1] As the valuation of pollution disutility becomes larger as P_tC_t increases even with a constant γ, no further insight is gained by making γ itself a function of P_tC_t.

[2] The specific factors assumption is used for analytical simplicity. Similar results emerge when both inputs are used allowed to be mobile across both sectors. Please refer to appendix 1D.

[3] Copeland and Taylor (1997), “A Simple Model of Trade, Capital Mobility and the Environment,” NBER Working Paper 5898

abatement technology. If θ_{Yt} is the fraction of resources spent for abatement activity in sector Y_t, then output level with abatement activity is

$$Y_t = \{K_t(1-\theta_{Yt})\}^{sy} \quad (1)$$

Emission level after abatement activity is

$$Z_{Yt} = (1-\theta_{Yt})^{1/\alpha} K_t \quad (2)$$

where α is the parameter from abatement technology in the Y sector. Similarly β is the parameter from abatement technology in the X sector.

Combining (1) and (2) by eliminating θ_{Yt} between the above two production functions results in the Cobb Douglas form of production relation[4].

$$Y_t = Z_{Yt}^{\alpha} K_t^{sy-\alpha} \quad (3)$$

Similarly $$X_t = Z_{Xt}^{\beta} L_t^{sx-\beta} \quad (4)$$

Y_t emits more pollution per unit of production relative to X_t. This happens because $\alpha > \beta$ implies that it is easier to abate emission in the X_t sector compared to Y_t. Emissions appears like an input for production; higher emission is associated with a higher production level because fewer resources are diverted for abatement of the pollution. Y is treated as the numeraire good[5].

As there is no uncertainty, the social cost of disutility from pollution for next period is taken into account when making input decisions for the next period. If τ_t is the

[4] Please refer to appendix 1A.

[5] According to the above interpretation production technology is fixed and the input mix changes with changing price of the inputs. Nancy Stokey, "Are there limits to growth" International Economic Review 1998, Vol 39, Issue 1, Page 1-31, provides an alternate explanation for the production process where technology can be interpreted to be changing. All the information for the spectrum of cleanest to dirtiest technology is available. $Z \in [0,1]$ is the index of the technology actually adopted in an economy depending on the prevailing incentives. Higher values of Z indicates that a dirtier technology is adopted which yields more goods but also more pollution..

shadow price of disutility from pollution, then maximization of social welfare requires that the marginal cost τ_t imposed on emissions should equal the value of social benefit or value of marginal product from allowing the last unit of emission.

$$\tau_t = \frac{\beta.P_{Xt} X_t}{Z_t} \tag{5}$$

Using this condition to substitute for Z_t in the production function makes X_t production a function of L_t and relative prices.

$$X_t = (\frac{\beta.P_{Xt}}{\tau_t})^{\frac{\beta}{1-\beta}} (L_t)^{\frac{sx-\beta}{1-\beta}} \qquad \text{i.e. } X_t = X_t(P_{Xt}, L_t; \beta, sx, \tau_t) \tag{6}$$

Similarly $Y_t = (\frac{\alpha}{\tau_t})^{\frac{\alpha}{1-\alpha}} (K_t)^{\frac{sy-\alpha}{1-\alpha}}$ i.e. $Y_t = Y_t(K_t; \alpha, sy, \tau_t)$ (7)

Given the prevailing market incentives, there is efficient allocation of resources in every period both for consumption and production. However, investment motives cause the sequence of static equilibria to evolve and move towards the steady state, where there is no further desire for change. Comparison of the evolution towards the relevant steady states provides interesting insights about the environmental-quality outcomes.

3B. EQUATIONS OF TRANSITION:

Under free trade, both goods X_t and Y_t are traded. Capital K_t accumulates over time without any depreciation and is internationally mobile. In every period capital moves to where the payments are higher, until the payments in both economies are equalized. The second input land/labor L_t is assumed to be fixed and internationally immobile. The two economies are assumed to have an identical endowment of this fixed input. An international financial market for bonds B_t also exists and an interest r_t is earned on each bond held. To focus on environmental issues, we assume that the exchange rate equals unity and that purchasing power parity is satisfied.

For the two economies interacting with each other, the equations are similar in form. I denote the foreign variables with *. The model has 23 variables {C_t, K_t, B_t, P_t, r_t, C_t*, K_t*, C_{Xt}, C_{Yt}, C_{Yt}*, C_{Xt}*,Y_t, X_t, Y_t*, X_t*, Z_{Yt}, Z_{Xt}, Z_{Yt}, Z_t, Z_{Yt}*, Z_{Xt}*, Z_t*, P_{Xt}}under free trade when the two economies are considered. So the strategy in solving this model is to identify a smaller subset of variables which are solved from the dynamic equations. Once the time path of these key variables is known, the rest of the system is solved using the static equations of the model.

With free trade, the core subset of dynamic relations is the seven difference equations below.

$$P_t C_t + (K_{t+1} - K_t) + (B_t - B_{t-1}) = Y_t + P_{Xt} X_t + r_t B_t \qquad (8)$$

$$P_t C_t^* + (K_{t+1}^* - K_t^*) - (B_t - B_{t-1}) = Y_t^* + P_{Xt} X_t^* - r_t B_t \qquad (9)$$

$$\frac{1}{P_t C_t} = \rho \ [\frac{1}{P_{t+1} C_{t+1}} \{1 + Y_{t+1}^{'}(K_{t+1})\} - \gamma Z_{t+1}^{'}(K_{t+1})] \qquad (10)$$

$$\frac{1}{P_t C_t} = \rho \ [\frac{1}{P_{t+1} C_{t+1}} \{1 + r_{t+1}\}] \qquad (11)$$

$$\frac{1}{P_t C_t^*} = \rho [\frac{1}{P_{t+1} C_{t+1}^*} \{1 + Y^{*'}(K_{t+1}^*)\} - \gamma Z^{*'}(K_{t+1}^*)] \qquad (12)$$

$$\frac{1}{P_t C_t^*} = \rho [\frac{1}{P_{t+1} C_{t+1}^*} \{1 + r_{t+1}\}] \qquad (13)$$

$$X_t(P_t, L_t) + X_t^*(P_t, L_t^*) = \frac{wP_t C_t + wP_t C_t^*}{P_{Xt}} \qquad (14)$$

$$Y_t(K_t)+Y_t^*((K_t^*)= (1-w)P_t(C_t+C_t^*)+(K_{t+1}-K_t)+(K_{t+1}^*-K_t^*) \qquad (15)$$

Equations (8) and (9) are the budget equations of the two economies. While interpreting these equations it is important to distinguish between the stock of capital that is employed in an economy and the amount of capital that is actually owned by the economy. This discrepancy occurs because the residents of an economy may own capital which they decide to employ in a foreign country, and enjoy the returns earned on the capital in the foreign economy. The K_t and K_t* in equations (8) and (9) denote the amount of capital employed in the two countries respectively. The B_t represents flow of domestic wealth to foreign nations for purpose of consumption smoothing and investments in production both of which earn returns at the rate r_t[6]. The profits from employing capital stay with the country where it is employed, while the owners receive only the rental returns.

Equation (10) and (11) are the first order conditions of welfare maximization with respect to K_{t+1} and B_t respectively, alternately known as Euler equations. Equations (12) and (13) are the corresponding equations for the foreign economy. These four equations together imply that the investments in capital located domestically, capital located abroad and in bond-holding earn equal marginal return every period.

Equations (14) and (15) are the market clearing conditions for X and Y in the world market. For the X commodity, consumption demand is the only source of demand. Since the Y commodity is used both for consumption and as capital, the demand has consumption demand and investment demand components.

[6] Refer to Appendix C for details

Since the individual budget conditions are being considered, one of the market clearing conditions given by equation (14) or (15) is redundant by Walras Law. So equations (8) – (15) represent 7 equations in the 7 variables C_t, K_t, B_t, P_t, r_t, C_t*, K_t*. Once the time paths of these 7 variables are known, the remaining 16 variables of the system can be determined using the static equations[7].

At the start of trade, I assume that capital is reallocated across economies so that the marginal return to every unit of capital employed in any country is the same. This represents the familiar jump of variables as countries relocate on the new saddle path on their journey to the new steady state. There is no cost to capital reallocation in this model. Hence the jump of a large amount of capital to the country with weaker environmental standards is an expected result and serves as a check for the model.

The system of dynamic equations does not assume intrinsic asymmetries of the two economies. For two otherwise identical economies, this approach makes transparent the importance of difference in relative incomes and different environmental policy regimes in determining the outcome. Asymmetric modeling moves the outcome in expected directions and does not uncover unexpected results. For example, if the disutility parameter is different for the two economies, the one with the smaller parameter would accept more capital, have weaker environmental standards and sustain a higher income for the integrated economy. If the production technology is different for the two economies, then more capital flows to the economy where capital is more productive. For these reasons, I have abstracted from intrinsic asymmetries of the two economies in my core model to focus on the relative income and environmental policy effects on the

[7] Note that the price index P_t for the consumption bundle C_t is an unique transformation of P_{Xt}:
$P_t = (P_{Xt})^{\omega} / [\omega^{\omega}(1-\omega)^{(1-\omega)}]$

pattern of international trade[8]. The contribution of this paper to the asymmetric modeling literature is important because instead of the obvious asymmetries it highlights that asymmetries like difference in initial relative income, or environmental policy regimes, still have an important role in determining the outcome.

The first-order conditions for optimization are solved for the steady state. The steady state is defined as a situation where all variables maintain a constant level. Then the first order conditions, which are first order difference equations, are linearized around the steady state to get an idea about the evolution of the variables. The steady state in this model exhibits saddle path stability and the stable eigenvalues define the movement of the variables along the saddle path over time[9].

To find the necessary conditions for an EKC, I analyze the evolution of emissions.

$$Z = Z_Y + Z_X$$

or, $\hat{Z} = \frac{Z_Y}{Z}\hat{Z}_Y + \frac{Z_X}{Z}\hat{Z}_X$

or, $\hat{Z} = \frac{(\alpha/\tau)Y}{(\alpha/\tau)Y + (\beta/\tau)P_X X}\widehat{\overline{(\frac{\alpha}{\tau})^{\frac{1}{1-\alpha}}(K_t)^{\frac{sy-\alpha}{1-\alpha}}}} + \frac{(\beta/\tau)P_X X}{(\alpha/\tau)Y + (\beta/\tau)P_X X}\widehat{\overline{(\frac{\beta.P_{Xt}}{\tau})^{\frac{1}{1-\beta}}(\overline{L}_t)^{\frac{sx-\beta}{1-\beta}}}}$

Use w_Y to represent $\frac{(\alpha/\tau)Y}{(\alpha/\tau)Y + (\beta/\tau)P_X X}$ and (1- w_Y) to represent $\frac{(\beta/\tau)P_X X}{(\alpha/\tau)Y + (\beta/\tau)P_X X}$

or, $\hat{Z} = w_Y\{\frac{sy-\alpha}{1-\alpha}\hat{K}_t - \frac{1}{1-\alpha}\hat{\tau}\} + (1-w_Y)\{\frac{1}{1-\beta}(\hat{P}_{Xt} - \hat{\tau})\}$ (16)

---

[8] I present comparative dynamics with two asymmetric modeling cases: one where the two economies have different endowments of the fixed input, and the second where the two economies have different disutility parameters, on pages 31 and 136 respectively.

[9] Refer to Appendix B for technical details

Equation (16) tells us that growth in pollution is an increasing function of the growth in K, the increase in prices, and the share of the dirty industry. It is a decreasing function of growth in taxation. The necessary conditions for the EKC to emerge are that initially the positive effects of capital accumulation on emissions should dominate and later the negative impact of stricter policy in emissions should dominate. The first condition is satisfied when an economy is distant from its steady state and has a strong investment demand. The second necessary condition is satisfied when environmental policy becomes proportionally stricter with income.

In the early stages of growth, there is strong impetus for growth in output to satisfy the consumption demand and the desire to build up capital stock. Hence the positive scale component dominates. Although emissions taxes are also on the rise, the effect is not strong enough to negate the scale effects of growth. As the economy approaches its steady state, the growth rate declines and the effect of growing taxes becomes relatively more important. On one hand, it reduces the profit-maximizing emissions per unit, and on the other hand, it provides an incentive for producers to shift to the less dirty industry. These result in the declining segment of the EKC.

3C. DERIVATION OF OPTIMAL EMISSIONS TAXES THROUGH COMPARISON OF SOCIAL PLANNER'S PROBLEM AND ECONOMY WITH PRIVATE AGENTS:

Having looked at the social planner's problem until this point, it becomes important to examine whether such an outcome can be sustained with decision-making by private agents. The consumers make consumption and savings decision every period, taking the interest rate, which is the returns to capital, as given. In his optimization decision each individual consumer also takes the aggregate emissions level Z_t as exogenous, which cannot be affected by his individual savings decision.

$$U_t \equiv \sum_{t=0}^{\infty} \rho^t u_t \equiv \sum_{t=0}^{\infty} \rho^t [\ln(C_t) - \gamma . Z_t]$$

subject to $P_tC_t+b_t= (1+r_t)b_{t-1}+$ Lumpsum income from aggregate emission tax collected

The above maximization with respect to consumption expenditure shows that equations (11) and (13) are relevant consumer choice equations.

The profit maximizing producers choose the amount of capital to be employed every period, taking the environmental taxes as exogenous. The emissions tax serves the purpose of making the producers abate as long as their abatement cost is less than the per unit tax. The amount of tax collected $\tau . Z_t$ on the emission actually produced is distributed in lump sum to the consumers. From the profit-maximizing behavior $\tau_t . Z_t = \alpha Y_t$, the increase in pollution due to increase in capital employed is calculated as $Z'(K_t) = (\frac{\alpha}{\tau_t}) Y'(K_t)$. An additional unit of capital employed increases the amount of Y_t produced. However, the additional unit of capital also increases the profit maximizing amount of pollution emitted, which is levied a tax at the rate τ_t

$$\partial \Pi_t / \partial K_t = Y'(K_t) - \tau_t Z'(K_t) - r_t$$

Profit maximization implies $\partial \Pi_t / \partial K_t = 0 \quad \Rightarrow (1-\alpha) Y'(K_t) = r_t$ (17)

Equation (17) thus emerges from profit maximizing conditions irrespective of the pollution-tax scenario.

The corresponding equation for the foreign economy is $(1-\alpha) Y^{*\prime}(K_t^*) = r_t$ (18)

Equations (17) and (18) are the relations of transition that link the emissions taxes to the level of capital with private agents, replacing equations (10) and (12) under the social planner's optimization. Elimination of current consumption expenditure between equations (10) and (11) of the social planner's problem results in the relation

$$r_t = Y'(K_t)(1 - \gamma P_t C_t \frac{\alpha}{\tau_t}) \qquad (10')$$

Equation (10') is typical of the standard Ramsey-Caas-Koopman type of dynamic model where zero cost of adjustment of capital and absence of uncertainty ensures that the marginal return to capital equals the interest rate every period. The optimal time path of capital stock satisfies this in each period. The optimal pollution tax is defined as one that ensures that equation (10') of the social optimum conditions is identical with the profit-maximizing relation (17). This turns out to be $\tau_t = \gamma P_t C_t$. Hence these optimal taxes can sustain the social planner's outcome even when private agents make the decisions.

When taxes are low, i.e. $\tau_t < \gamma P_t C_t$, then the social optimal payment to capital as captured by equation (10') should be lower than what is paid by profit-maximizing producers as reflected in equation (17). This is because with low emission taxes, every unit of capital is associated with a higher emission, causing a higher disutility, the valuation of which should be reduced from the payment to capital to provide it with the correct incentives. When the payment to capital is not corrected by the taxation, the private economy will follow an evolution path that is different from the socially optimal path.

In the static case, the tax on capital was not important because once the pollution had occurred, that was the end of the story. In the dynamic model, payment to capital is an important consideration because it determines the incentive for building future capital stock in each economy and hence future pollution and consumption.

A fixed pollution tax in an economy may arise due to the governing institution's lack of capability in evaluating pollution disutility every period or else to a desire to provide an incentive to produce for some reason other than maximizing social welfare. It may be unrealistic to expect that this governing body will be able or willing to set a complicated and instantaneously changing capital tax in order to partially offset the effect of its inefficient pollution taxes. This makes it important to compare the evolution of an economy where emission taxes are efficient against one where the emission taxes are suboptimal and corresponding capital taxes are absent.

So the system of equations for the private economy with pollution tax and no subsequent tax on capital comprises of equation (17) and (18) replacing equations (10) and (12). These sets of equations are identical only when emissions taxes are set optimally.

Every period the government imposes a tax $\{\tau_t\}$ per unit of emission. Three different policy regimes are considered. First, as in the static model, the pollution tax is assumed to be set efficiently as the shadow price of pollution every period in both economies $\tau_t = P_{Z,t} = \gamma P_t C_t$. This is more realistic for developed economies where wealthier residents, who are more aware of the cost of environmental degradation, can expect the policy making agency to reflect their concerns through stricter regulations. However for economies with fewer resources, the cost of monitoring as well as the administrative costs of changing the standards may make periodic synchronization of pollution tax with consumer demands infeasible. Hence the second pollution tax framework is such that the emission tax remains fixed for the period under consideration, zero environmental taxes being a special case of this fixed-tax $\tau_t = \bar{\tau}$. This may be a more realistic institutional setup if one identifies the efficient-tax economy as the developed countries and the fixed-tax economy as the less developed countries. A third possibility considered is one where the emissions tax rises either too strongly or too weakly with growth and not according to the marginal valuation of pollution disutility. Refer to diagram 1.1 for illustration of these optimal and suboptimal environmental tax setting scenarios.

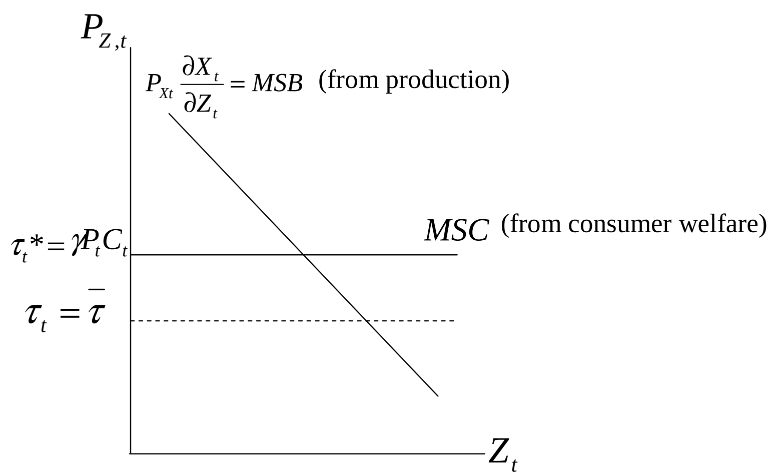

Diagram 1.1: Optimal and sub-optimal emission taxes for any given period

3D. LESS TARGETED ENVIRONMENTAL TAXES:

For many developing countries, pollution taxation as modeled above is not an option. Hence it would be useful to introduce a less targeted production taxation of the dirty industry. As the tax is not on emissions, the relation (5) is not valid in this scenario. Hence the production function and the abatement function cannot be combined as before to express production as a function of environmental taxes as was done in expressions (6) and (7) by eliminating emissions.

Production of output: $Y_t=K_t^{sy}$

Production of emissions: $Z_t= K_t$

The government imposes a tax τ_t on per unit of K_t because in the absence of tax specifically on emissions, once the capital stock is selected there will not be any further incentive to reduce emissions during use of that capital. This would result in emissions $Z_t= K_t$, causing disutility to consumers. In this scenario, equation (10) derived from intertemporal maximization takes the specific form below:

$$\frac{1}{P_t C_t} = \rho \ [\frac{1}{P_{t+1} C_{t+1}} \{1 + sy.(K_{t+1})^{sy-1}\} - \gamma] \qquad (19)$$

Other than equation (19), the rest of the system of equations remains unaffected. Combining equation (19) with (11) provides below an alternative expression under social optimum. $r_t = s_y (K_t)^{sy-1} - \gamma P_t C_t$ (20)

Profit maximizing producers have to pay the tax τ_t for every unit of capital employed. Hence the profit maximizing payment to capital is $r_t = s_y (K_t)^{sy-1} - \tau_t$ (21)

The optimal emission tax can be derived as before as one that help achieve equation (20) for an economy with private agents. Comparison of (20) and (21) determine the optimal tax structure to be $\tau_t = \gamma P_t C_t$ (22)

Hence the optimal tax structure has the same functional form whether it is a targeted emissions tax or a less targeted one imposed on the dirty input capital.

4. NUMERICAL SIMULATIONS AND INTERPRETATIONS:

Starting with a set of benchmark parameters, I vary the parameters to see the implications of the results and the relevance with real world scenarios.

Parameter	Explanation
ω=0.25	Weight of the X commodity in the consumption bundle
s_x=0.9	Degree of returns to scale for X production
s_y=0.9	Degree of returns to scale for Y production
β=0.5	Pollution emission coefficient for X production
α=0.7	Pollution emission coefficient for Y production
γ = 0.04	Awareness parameter in home
γ^* = 0.04	Awareness parameter in foreign economy
ρ = 0.99	Discount rate
s=1	Ratio of income of foreign economy and home economy

Table 1.1: Benchmark parameter values and interpretations

The X commodity can be thought of as an agricultural commodity whose weight in the consumption bundle is small (ω=0.25). The decreasing-return parameters are meaningful if the Y industry is intensive in capital, the X industry is intensive in land. The discount rate “ρ” is chosen to be the commonly used value of 0.99 while the relative size of the economies “s” is varied in the numerical simulations. The pollution disutility parameters are small relative to the unit weight on consumption utility, the specific value chosen is for convenience.

4A. BENCHMARK SITUATION:

The two economies are of equal size (s=1) and have the same pollution disutility. Both set emission taxes in the socially optimal manner and start trade at an early level of economic development. (Please refer to Diagram 1.2 at end of this essay)

This is a scenario where both necessary conditions for the EKC are satisfied, and the complications of international trade have also been simplified. In this scenario with two identical economies, the local pollutant and income do show the traditional inverted U shaped relation. The volume of international flow of goods and capital is zero as the economies are identical.

These forces will be clearer if we look at the time series of emissions instead of at the income-pollution relationship (Refer to diagram 1.3). Couched in terms of the familiar scale, composition and technique effects[10], the same mathematical outcome can be seen diagrammatically. Compared to an initial period, the effects of use of cleaner techniques as well as a shift towards a cleaner product mix partially counteract the effects of degradation due to increased scale of production. With efficient taxes the growth of scale is restrained and even is reduced as residents value the environment more strongly when rich. This does not necessarily mean that the consumption level goes down. As the economy approaches its steady state, the eagerness to accumulate capital declines and investment demand falls. Consumption grows but at an increasingly slower rate, out of production using existing capital stock. The cleaner impact of lower emission intensity and cleaner product mix induced by stricter emission taxes dominate the growth-of-production effect as the economy approaches the steady state along the downward arm of EKC.

4B. INTERTEMPORALLY FIXED EMISSIONS TAXES:

With fixed emission taxes, the policy condition necessary for the EKC is violated. When taxes do not increase over time, no incentive is provided to use a cleaner

[10] Grossman and Krueger, 1991

technology or to shift to the cleaner sector as income increases. Looking at equation (16), we see that both negative pressures drop off. The time path of emissions should exhibit a pattern of monotonic increase as shown in the diagram. While it is possible to attain the long term pollution by setting the fixed tax at the long term optimum, this imposes unnecessary burden in the early stages of development when the economy does not value the disutility of pollution very strongly. (Refer to Diagram 1.4)

I look again at the decomposition into scale, composition and intensity effects (Refer to Diagram 1.5). The scale of production grows unabated as there is no stronger restraining force in the later periods. As the inputs used in the dirty industry grow and taxes remain unchanged, this encourages production in the dirty sector. As the prices of the commodities go up, this reduces the real value of the fixed taxes. So the profit maximizing producers are encouraged to use increasingly dirty techniques. All three effects contribute positively to environmental degradation, making the overall sum of these effects even larger.

The income-pollution relation is found to be monotonic and unlike the EKC shape. However rich the economy becomes, or however important its position is with respect to the world economy, pollution will not decline with rising income if the governing body does not implement pollution taxes to reflect the growing disutility valuation of the residents. With fixed emissions taxes, the steady state capital is defined uniquely where the marginal payment to capital equals the rate of time preference. Hence we see in the diagram 1.6 that the steady state emission is set uniquely irrespective of the income level that the economy attains.

4C. EMISSIONS TAXES THAT INCREASE WITH GROWTH OF THE ECONOMY, BUT NOT SUFFICIENTLY

The efficient emissions policy derived in the theoretical model is where the rising environmental taxes exactly reflect the increasing valuation of pollution disutility. This efficient tax is a special case that satisfies the necessary policy condition for EKC- that environmental taxes should rise with increasing income. If taxes are lower that the optimum, the height of the inverted U is much higher (Refer to diagram 1.7). This additional pollution contribution arises because of all three scale, intensity and composition effects. Producers are interested in holding a larger capital stock as the tax payments are low, which increases the scale of production. As taxes are below the socially optimum, the intensity of emission is high. Low taxes also reduce the pressure to move to a cleaner composition of production. However, this is not the socially best outcome. Hence, an inverted U shaped income-environment relation from the time series data of an economy is not enough to infer that the economy is on the socially optimal trajectory. There exists scope for improvement in environmental policy to improve the outcome.

On the other extreme, we can imagine an environmental regime that wishes to avoid the hump altogether and sets stronger environmental taxes. This can achieve the environmental quality to be monotonically improving with rising income but by sacrificing growth. The implications of growth, environmental outcome, home and foreign welfare corresponding to different types of policy regimes are tabulated below.

Emission Policy	K$\|_{Steady}$	C$\|_{Steady}$	Z$\|_{Steady}$	Income-emission relation during transition	W$\|_{Steady}$
$\tau_t = \gamma\sqrt{P_t C_t}$	5115.6	345	249.96	Monotonically rising	-3.39
$\tau_t = \gamma P_t C_t$ Socially optimum policy in this model	397	16.23	26.76	EKC	2.63
$\tau_t = \gamma (P_t C_t)^{2.5}$	113.56	4	5.34	Monotonically declining	1.26

Table 1.2: Growth-environment tradeoff for different policy regimes with benchmark parameter values

As the first row of the above table shows, environmental policies that increase with per capita income may be weak enough never to overwhelm the growth in capital, resulting in a monotonically rising income-emissions relation. This allows higher returns to capital and hence growth to a higher steady state consumption (345) and capital stock (5115.6). The environment policy regime might be strict to result in a continuously improving environmental quality as income increases. Though this might appear desirable, one has to realize that the environmental quality (5.34) is achieved at the cost of a lower growth and a lower achievable consumption (4.0). Hence, the environmental policy that the social planner chooses reflects a trade off between consumption and environment. The EKC shape arises in only a range of environmental policies where the growth in scale initially dominates and then is gradually dominated by the cleaner composition and lower intensity effects stimulated by stricter environmental policy.

4D. ABSOLUTE SIZE OF THE ECONOMIES AT THE START OF TRADE:

When the economies under consideration are already close to their steady state (refer to Diagram 1.8), the second necessary condition for the EKC is violated. The growth of pollution is a positive function of capital. If the trading countries at the beginning of trade already have sufficient capital between them, the rate of further capital accumulation will be slow. The pollution reducing effect of rising taxes dominates, resulting in the downward segment of the EKC. Whether one will see the inverted shape under trade depends solely on whether the countries have passed the hump during their autarkic growth.

4E. SOURCES OF COMPARATIVE ADVANTAGE CAUSED BY DIFFERENCE IN ENDOWMENTS:

I consider other sources of comparative advantage by allowing the two economies to have different endowments of land ($\overline{L}$). For two economies with the same income levels at the beginning of trade, this means that the economy with a larger $\overline{L}$ has a smaller endowment of capital. The steady state versions of equations (10)-(13) form a self contained system defining the capital stock employed in each economy and the value of consumption in each economy. Thus a different endowment of the immobile endowment does not influence either the value of consumption or the level of capital employed in each economy. This also implies that the steady state environmental taxes are the same as before in both economies. To get an insight about the effect of difference in endowment, I assume that the total world endowment of $\overline{L}+\overline{L^*}$ is as before, but the allocation is different across the two economies (refer to diagram 1.9). The economy with the larger endowment of $\overline{L}$ will produce a greater world share of X_t and will experience a worse environmental outcome for the same income levels.

Having considered the impact of environmental policy on the observed income-environment relation, I consider how international trade affects the income-environment relation for any given environmental policy regime.

4F. TWO TRADING ECONOMIES IDENTICAL IN ALL RESPECTS, BUT STARTING TRADE AT DIFFERENT INCOME LEVELS:

If the foreign economy is at an earlier point of its growth path than the home economy at the beginning of trade, its marginal valuation of disutility is lower than at home at every point in time. Hence the foreign economy accepts home capital allowing the home economy to enjoy better environmental conditions (refer to diagram 1.10). As the gains from investment are shared across the economies due to mobile capital, home still enjoys income from its assets employed abroad. Assuming emission taxes to be efficiently set resulting in the intertemporal EKC relation, international trade shifts the EKC down for the richer partner than what would have been possible under autarkic growth. The consumption growth is locked in the same ratio as can be seen by comparing equations (8) and (10). So the developing foreign economy exports goods to the home, while the home economy finances its commodity consumption through capital flows to the foreign economy. At the steady state, the rich home will be willing to grow more than what it would willing when trading with an equal partner. This additional growth is desirable as it is financed out of overseas investment at no pollution cost to self.

The poorer trading partner though values pollution less on account of being poorer. However it ends up at a lower steady state income because it cannot appropriate the entire gains from the capital employed domestically. (Refer to diagram 1.11.)

Moreover, the additional dirtiness that will be associated for it to produce a percentage increase in world income makes it not worthwhile.

To appreciate fully the causes underlying the change in the levels of environmental outcome, it will be interesting to once again look at the factors underlying the shift. For any given level of income, the efficient taxes are unique. Hence the profit maximizing emission intensity will be the same with and without trade for every level of income. Diagram 1.12 shows that trade with a poor South reduces the scale of production in North. A large volume of the North-owned capital is located in the South. The North produces less at home, but can buy the dirty commodity from South using the payments on Northern capital employed in South. Hence North can finance the same consumption bundle at a lower pollution cost to self which is the effect of reduction in scale of production. Additionally, Northern producers now also have a stronger incentive to concentrate on the production of the cleaner commodity using the domestically located labor.

For the South, the converse is true. While the scale of production goes up, a part of the value of production is remitted to the capital owners of the North. The South ends up producing more and selling to North. The composition of production is also more biased toward the dirty sector because South takes on a big share of production of the commodity that uses internationally mobile capital. This is also reflected in the composition of the Southern production being more biased toward the dirty commodity.

Emission Policy	Size (s) of Home economy	Shape of Income-emission relation during transition	$K\|_{Steady}$	$C\|_{Steady}$	$Z\|_{Steady}$	$W\|_{Steady}$
$\tau_t = \gamma P_t C_t$	Autarky s=1	EKC	397	26.76	16.24	2.63
$\tau_t = \gamma P_t C_t$	s=0.56	EKC	143	30.96	6.59	3.17
$\tau_t = \gamma P_t C_t$	s=0.44	EKC	681.88	24.77	95.48	-0.61

Table 1.3: Impact of trade on EKC outcomes for different sized home economy

While the classical sources of comparative advantage provide gains from trade for both trading partners, the welfare effects arising solely due to environmental policies and capital flows shows that the poorer economy loses both in consumption and in environmental quality in free trade compared to the autarky situation. The consumption loss for the poor home reflected in the above table is caused by FDI which reduces the marginal returns to domestic capital. Other sources of potential gains from FDI in the form of employment generation, linkage effects, and knowledge transfer are not present in this model. The environmental costs of FDI reflected in the above table are relevant. It indicates that in the open economy scenario, the efficient environmental policy should also consider the impact it has on the flow of international capital. This however would lead to strategic interaction which I have considered elsewhere.[11]

The above discussion shows that though the income-pollution shape still shows the traditional EKC shape, the implications are widely different for two economies having different relative income but follow identical environmental policy.

[11] Please see my second essay "The welfare synergy in bundling international environmental agreements with international trade treaties"

Another comparative analysis is considered where countries are of equal size but have different values of pollution disutility parameter. Please refer to appendix 1F for detailed exposition of this scenario.

Having looked at scenarios where an economy is continuously either in autarky or in trade, I turn my attention to the situation where an economy makes a transition from autarky to trade.

4G. TRANSITION FROM AUTARKY TO TRADE:

The transition from an autarky income-environment relation to an open-economy income-environment relation generates a jump in income and environmental quality. International capital flows from an economy with a large capital stock to a small economy with a small capital stock. Also, the income of the economy experiencing capital outflows goes up during this transition because the domestically owned capital earns higher returns abroad. For the economy with the smaller domestic stock of capital, the inflow of capital causes worsening of environmental quality. The growth in income will also be slower because the returns to domestic capital decline due to inflow of foreign capital.

In the real world this shift is observed over a period of time in the form of dismantling of export-import tariffs or removal of capital flow restriction. I have shown that for the EKC relation to emerge in the inter-temporal growth path of an economy, a very precarious condition between growth in endowments and growth in taxes has to be satisfied and in most general situations of environmental policy such a relationship may not emerge. The changes in environmental quality and income due to movement toward freer trade will cause the cross country panel data to exhibit an income-environment relation that is not generated due to efficient environmental policy (Refer to diagram 1.13). Data from economies that are undergoing gradual transition from autarky to trade will behave in the manner described and the observed income-environment relation will reflect the EKC pattern although it does not hold for the individual economies.

The next three comparative dynamics looks at the impact on EKC of a one-time improvement in technology, an increase in world demand for the commodity the country has comparative advantage in, and a situation when an economy fulfilling the necessary condition EKC might experience a worse environmental outcome compared to its poorer trade partner.

4H. DYNAMIC IMPACT OF CLEANER TECHNOLOGY:

At every time point, there are two opposite forces acting within an economy. One is to have more capital to sustain current consumption and to accumulate capital for future production and consumption. The other is the dislike for capital due to the accompanying pollution. When a country comes in possession of a cleaner technology, in the early stages, the reduced emission per unit might trigger such a rate of capital accumulation that overall level of pollution is actually higher (refer to diagram 1.14). In the long term capital accumulation slows down. Then not only does the cleaner technique effect dominate, but the country can grow further due to the already accumulated capital.

4I. EFFECT OF PRICE RISE

Since the price of the dirtier good has been normalized to unity, an increase in demand for the relatively clean good X would increase the relative price of X, and lower the real pollution tax for that sector. As the emission coefficient is very small for this industry, the price rise has a small effect. However, this indicates that if prices of a commodity increase, the countries specializing in that product will see higher pollution compared to other economies (refer to diagram 1.15).

4J. RICH HOME IMPLEMENTING SUBOPTIMAL TAXES:

When the change in environmental policy is not strong enough to reflect the high value of disutility of the rich economy, then the tables might be turned in terms of environmental outcome. Suppose the home economy starts trading with a foreign economy which is at an early stage of growth and has an efficient environmental policy regime in place. Then in the initial periods, the tax might be less in the foreign economy causing it to accept home capital similar to the previous scenario. However, with growth the taxes in the foreign economy rise efficiently. If the taxes at home do not respond sufficiently to home income growth, then it is possible that at a later stage, the foreign tax is higher than that at home (refer to diagram 1.16). At this stage home would accept a larger share of world capital compared to the poorer but stricter foreign economy. The EKC of home instead of consistently lying below that of the poor foreign economy would intersect and rise above that of the foreign economy. This once more emphasizes the idea that high income in the absence of proper policy is not sufficient to attain optimal income-environment outcomes.

Even when stricter environmental policies retard production and income, the capital stock might grow in order to sustain this production under the stricter and hence less productive regime.[12] This accumulation of capital might give an illusion of growth although production and consumption have gone down.

It is interesting to see the above results in light of the convergence literature. In the present model, in addition to the level of capital, the emissions taxes are another determinant of the marginal productivity of capital. The level of taxes again depends on the income level of the country. A poorer country has a lower tax and an even higher marginal product of capital compared to the same level of capital in a rich country. Hence, at the steady states, though the effective marginal productivities are equalized, the levels of capital stock do not converge. Since the poorer countries end up employing a larger share of world capital, trade is not balanced. The poorer country exports the dirty good while the cleaner countries provide (export) factor inputs which are clean. There is no further incentive towards convergence.

4K. LESS TARGETED EMISSION TAXES:

For the scenario of less-targeted environmental policy described in section 3d and the optimum capital taxation derived, the numerical simulation result is presented below. For model parameters and starting conditions identical with the targeted taxation, the diagram below shows the relation between nominal income and emissions for the non targeted situation.

The inverted U shaped relation looks similar to before (refer to diagram 1.17). However, a comparison of the targeted and less targeted scenarios in diagram 1.18

[12] Please see appendix 1E for more details

reveals that the less targeted tax is too strict and strongly restricts the employment of capital, pollution and growth of national income.

To explain the results depicted in diagram 1.18, it is important to realize that the emission taxes calculated in the targeted and the less targeted scenarios are pure environmental policies in the sense that they take the pattern of trade as given. The emissions policies are not used either to alter the pattern of trade or to change the income of the economy in a beggar-thy-neighbor strategy. Thus these policies can be labeled as short-sighted in the sense that they do not take into account their effect for international trade and domestic income. This becomes strongly apparent during the comparison of targeted and less targeted environmental taxes. The optimal environmental taxes derived purely on environmental disutility consideration above reduce the income levels greatly in the non-targeted set-up because it discourages capital accumulation and also international capital flows. The environmental tax is till optimal for the resulting level of capital and income in the sense that given the level of income and pattern of trade, the optimum level of tax provides greater welfare than others taxation levels. For targeted emission taxes, the same force drives the trade outcomes to be so widely different for the two economies with different initial relative incomes. While setting emissions taxes neither economy takes into account that the emission taxes will affect the volume of capital flows, and hence production and income. For a model where the government weighs the implications of an environmental policy for trade and income, refer to the second essay. The growth aspects are abstracted in that model to focus on the interaction of trade and environmental policies.

5. U.S. EMISSION DATA INTERPRETED IN THE LIGHT OF THE MODEL

U.S emissions data for Ammonia, Sulphur Dioxide, Carbon-monoxide, Nitrogen-oxide, Particulate-material and Volatile-organic-compounds are available from US-EPA for the years 1990 and 1996-2001, at the 4 digit SIC level[13]. Integration of this data with domestic production data for those years makes it possible to create the decomposition US emission pattern to make it comparable with the predictions of the model[14].

I use the following technique for decomposition:

$Z = \sum_i Z_i$ where i represents industry at SIC4 level.

$$\text{or, } Z = \sum_i \frac{Z_i}{Y_i}\frac{Y_i}{Y}Y$$

$$\text{or, } dZ = Y\sum_i \frac{Y_i}{Y} d(\frac{Z_i}{Y_i}) + Y\sum_i \frac{Z_i}{Y_i} d(\frac{Y_i}{Y}) + d(Y)\sum_i \frac{Z_i}{Y_i}\frac{Y_i}{Y}$$

Discrete approximation:

$$Z_t - Z_0 = Y_0 \sum_i \frac{Y_{i0}}{Y_0}(\frac{Z_{it}}{Y_{it}} - \frac{Z_{i0}}{Y_{i0}}) + Y_0 \sum_i \frac{Z_{i0}}{Y_{i0}}(\frac{Y_{it}}{Y_t} - \frac{Y_{i0}}{Y_0}) + (Y_t - Y_0)\sum_i \frac{Z_{i0}}{Y_{i0}}\frac{Y_{i0}}{Y_0}$$

Change in emission in yr t wrt base year 0	Change in intensity	Change in composition	Change in scale

In diagram 1.19, 1990 is used as the initial period and changes are calculated relative to 1990. The sum of the available emissions is used as an index of environmental quality. The aggregate emission is seen to remain more or less constant over this time period. While this in itself does not seem very spectacular, decomposing this change in

[13] Provided by Thomas McMullen, USEPA in private email correspondence.
[14] This is the NBER productivity data extended till 2002. Provided by Wayne Gray in email correspondence.

emissions into changes occurring due to change in scale, change in composition and change in intensity reveals interesting insights about the prevailing environmental standards and about trade patterns. Over this period growth of the economy, captured by the scale effect, would have led to dramatic increases in emissions if it there had not been significant improvements in intensity as well as a shift out of dirty industries. This makes it evident that in addition to exogenous causes, the effective emission standards across the economy have become stricter over time providing incentive to profit maximizing producers to use cleaner methods. The composition of domestic production has moved towards a cleaner mix of products which reinforce the inference that the strictness of the environmental regime has increased over this time. The negative contribution of the composition change effect is however less than that due to the change in intensity effects.

The decomposition pattern predicted by the theoretical model (Section 4A, Pg 27) is found to be consistent with the actual decomposition of US emission. We can infer that US emissions standards have increased with income which is a necessary characteristic of efficient policy regime. Whether it was exactly efficient or not depends on the more complicated question of consumer valuation of actual valuation social cost of these emissions.

6. CONCLUSIONS:

The present analysis shows that during growth of individual economies a stricter environmental standard with growth of the economy is a necessary condition for the inverted-U shaped relation between income and emissions to emerge. This is because the higher taxes at greater economic prosperity encourages profit-maximizing producers to adopt cleaner technologies, and provides impetus to move to cleaner sectors. For trading economies, the differences in the trade pattern cause shifts in the inverted-U shape, but do not violate the overall shape of the relation.

One cannot rely solely on higher incomes as a remedy for environmental degradation issues. When emission tax policies do not respond or respond weakly to consumer disutility, pollution shows no sign of decreasing at higher income levels. Sufficiently high fixed taxes may make the fixed-tax steady state outcomes consistent with the steady-state under optimal tax or even avoid the hump shape altogether. However the environmental policy embodies the desired tradeoff between growth and environmental outcome and too-strict environmental policy imposes unnecessary restrictions on growth.

In a trading economy framework, identical efficient policy regimes will not deliver identical environmental outcomes to economies that have different trade and capital flow patterns. For an example, the same environmental policy in China would result in a different income-environment outcome depending on whether China is trading with USA or if it is trading with poorer economies in Africa. For two economies that begin international trade starting at different points in their growth path, the implications are very different. In absence of other sources of comparative advantage caused by difference in factor endowments, the smaller economy will accept foreign capital and will experience a worse environmental outcome than its more developed partner. The developed economy will be able to invest its capital abroad and use the returns on this capital to buy dirty commodities. Using the earlier example, China at any given income level will have a worse environmental outcome than USA at historically same levels of per-capita income. This is because the developed nation will have the opportunity to delegate the production of dirtier sectors to the developing economies, but when the same developing economies achieve a higher level of income they will not have the opportunity to delegate the dirtier sectors to some other economy unless they manage to find a further less developed economy. This result highlights the fact that predictions for individual economies using analyses based on a cross section of countries might be misleading.

Transition of economies from autarky to trade would cause capital to flow from developed to less developed economies. This causes the income-environment relation for a cross section of countries to exhibit EKC relation though it may not be true for the individual economies.

Additional factors that affect the relationship of environmental outcomes and income are pollution disutility awareness, price changes in the sectors that the country has comparative advantage in, and the technology of production and abatement. If an economy implements a cleaner technology, the effect might not be evident in the short horizon. With prevailing emission tax structure, the scale of production might go up to such an extent that it overwhelms the cleaner effect. In the longer horizon, the effect of the lower intensity will dominate and the economy will also be able to sustain a higher income level due to lower expenditure on abatement and a higher acceptable capital stock at home.

The dynamic model developed in this paper can be used to analyze the differences in scale of production, composition mix and technology used. It uncovers the environmental standards prevailing in the economy as well as effect of international trade on environmental quality. Using these dimensions the model can predict income-environment relationship that the economy can expect to experience if the environmental policy, trade pattern or one or more of the other components change.

The decomposition of US emissions is analyzed in the light of the model. Simultaneous movement toward lower emission intensity and cleaner sectors during 1990-2001 indicates that the US emissions policy was becoming stricter for this time, which is a necessary condition for efficient policy as defined in this model.

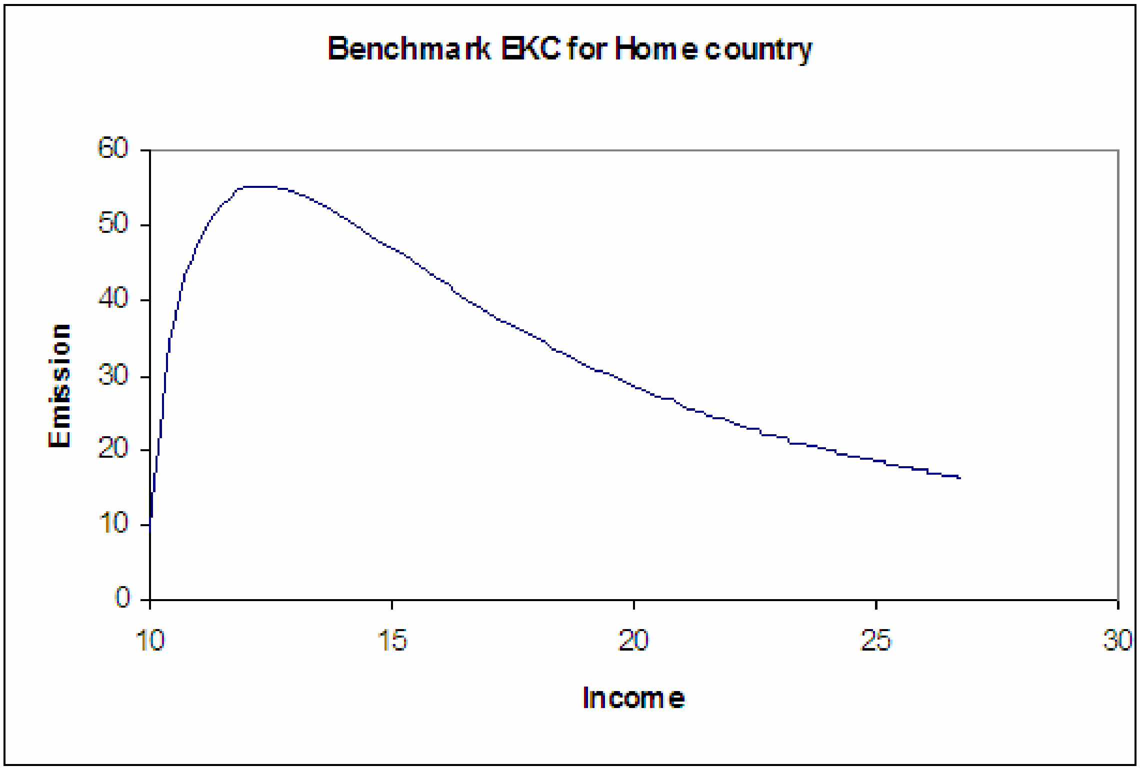

Diagram 1.2: Benchmark Environmental Kuznets curve for home country

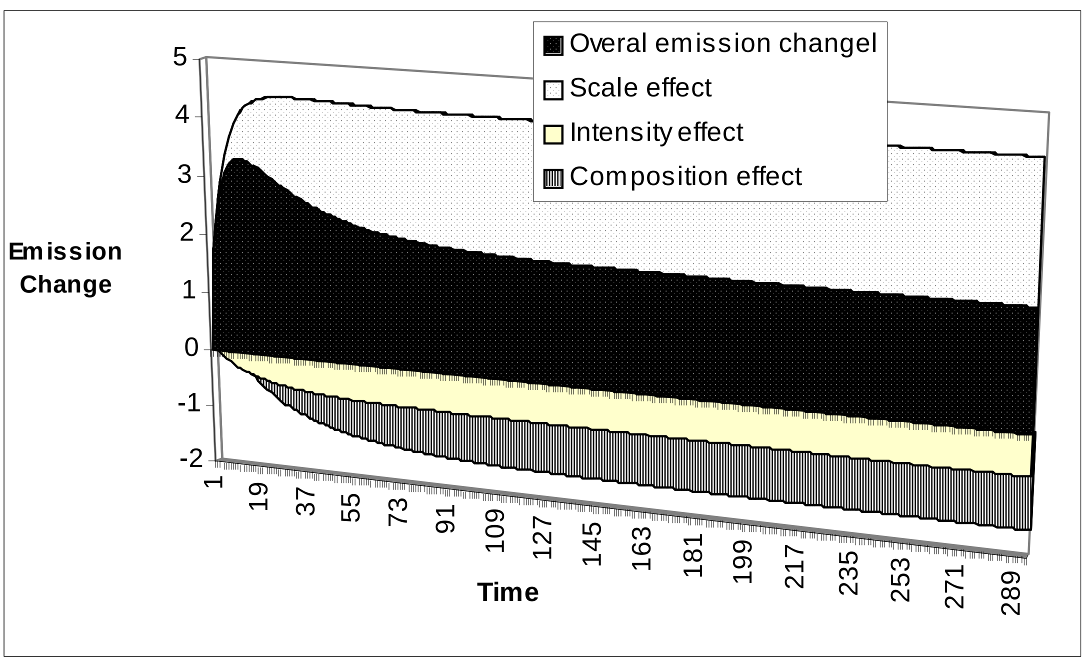

Diagram 1.3: Decomposition of aggregate emissions into underlying components

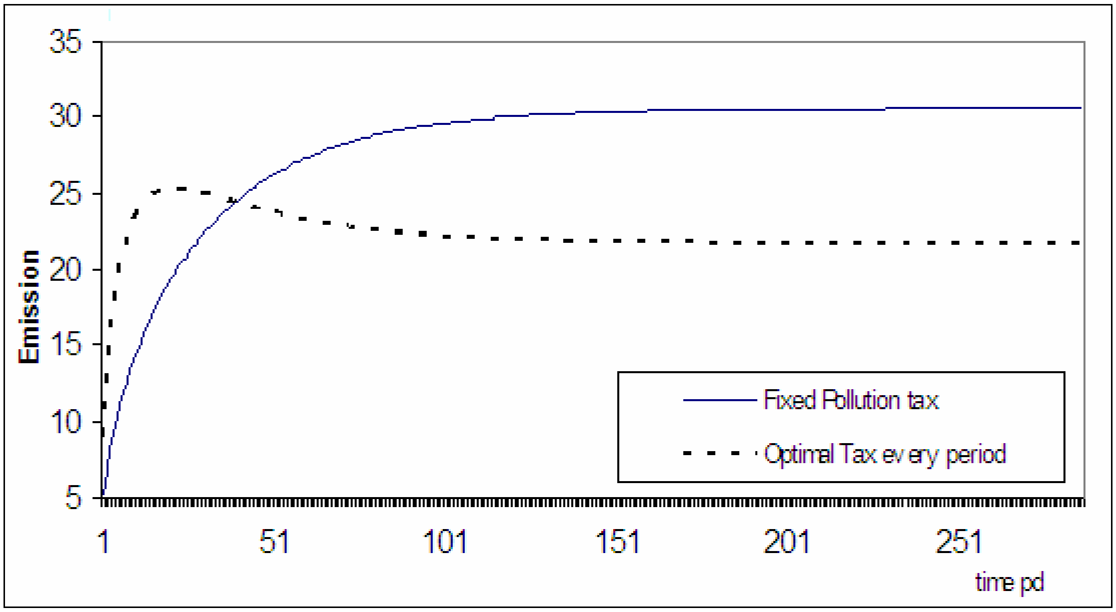

Diagram 1.4: Emissions under increasing and fixed emissions taxes

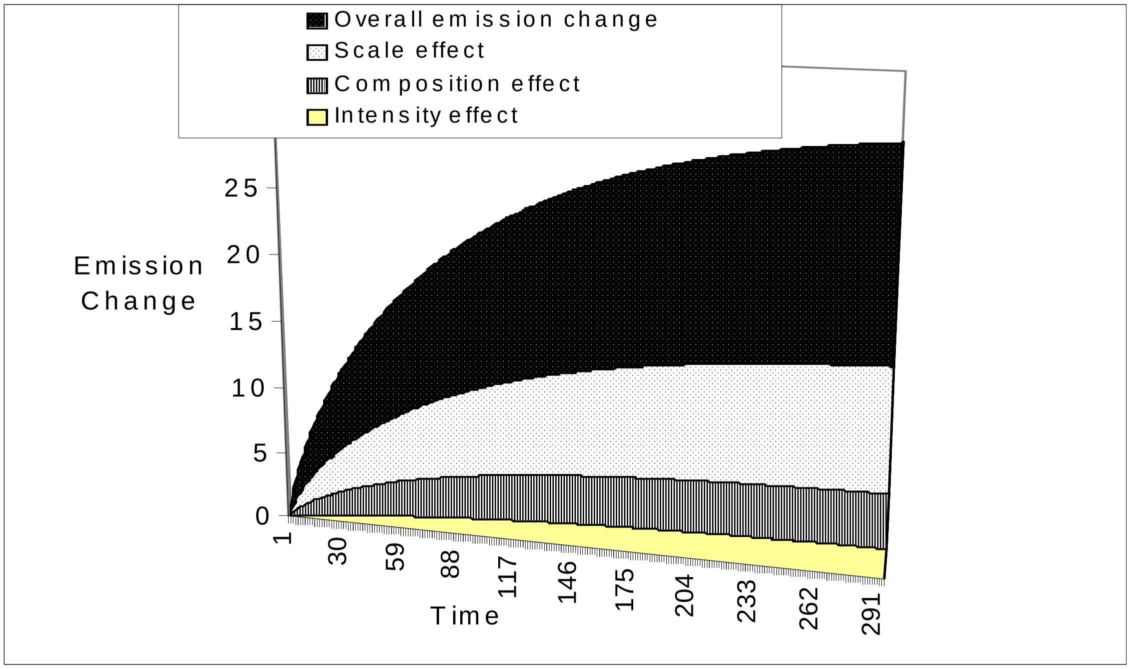

Diagram 1.5: Decomposition of aggregate emissions into underlying components for fixed emission taxes

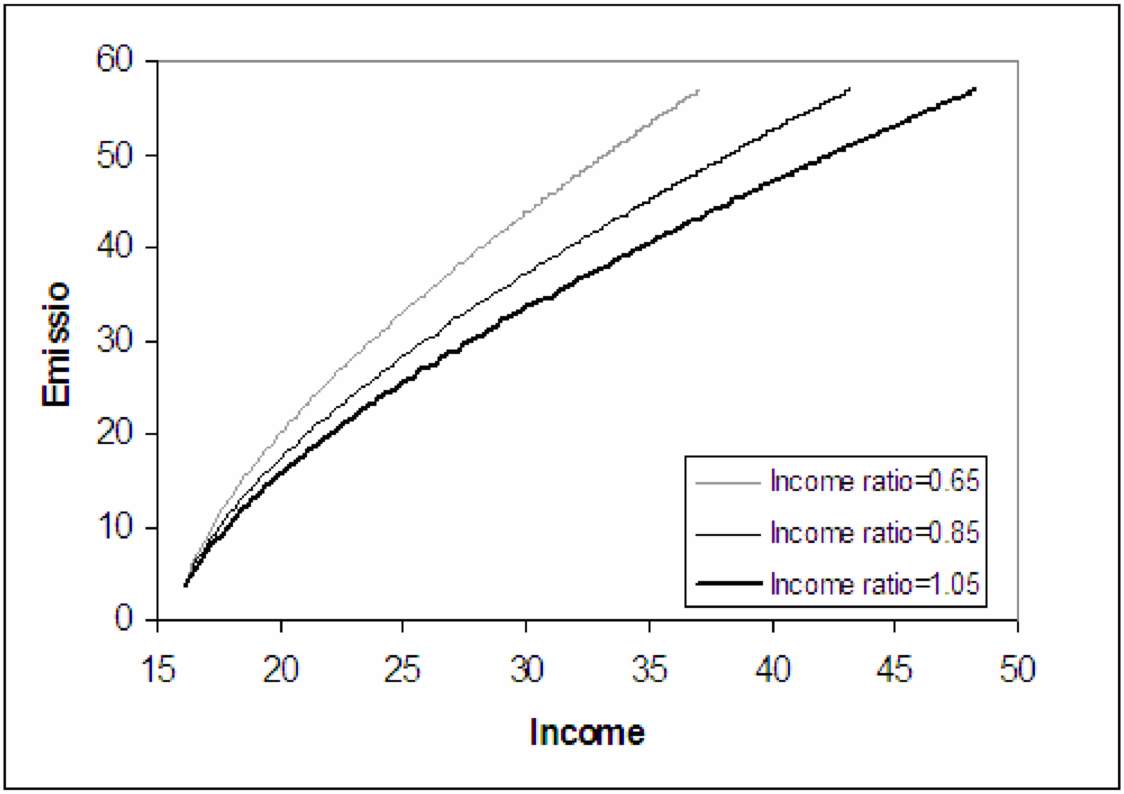

Diagram 1.6: Income emission time path under fixed emission taxes with different relative incomes

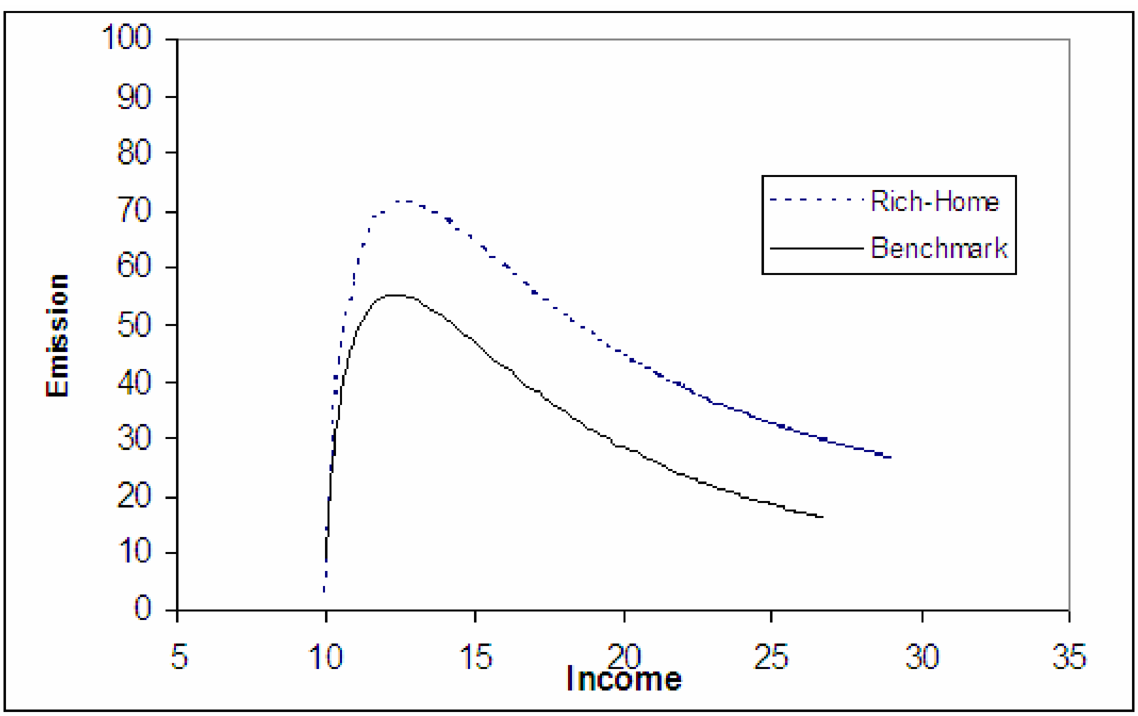

Diagram 1.7: Income-emission relation when emission taxes are rising insufficiently

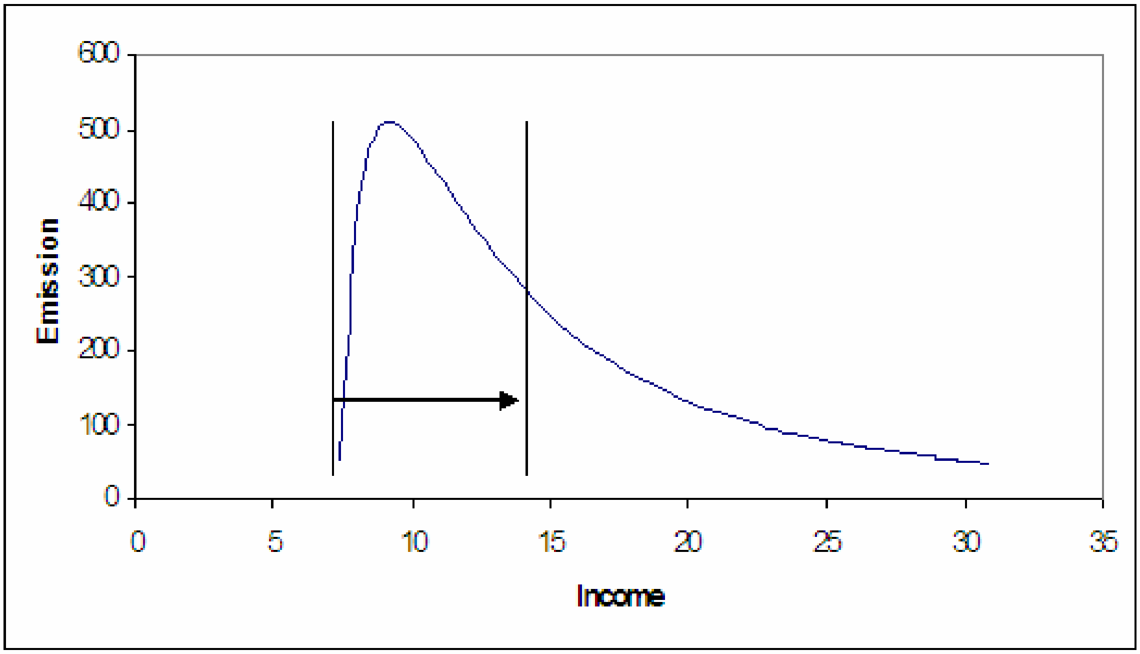

Diagram 1.8: Income-emission relation for economies with different absolute values of initial income

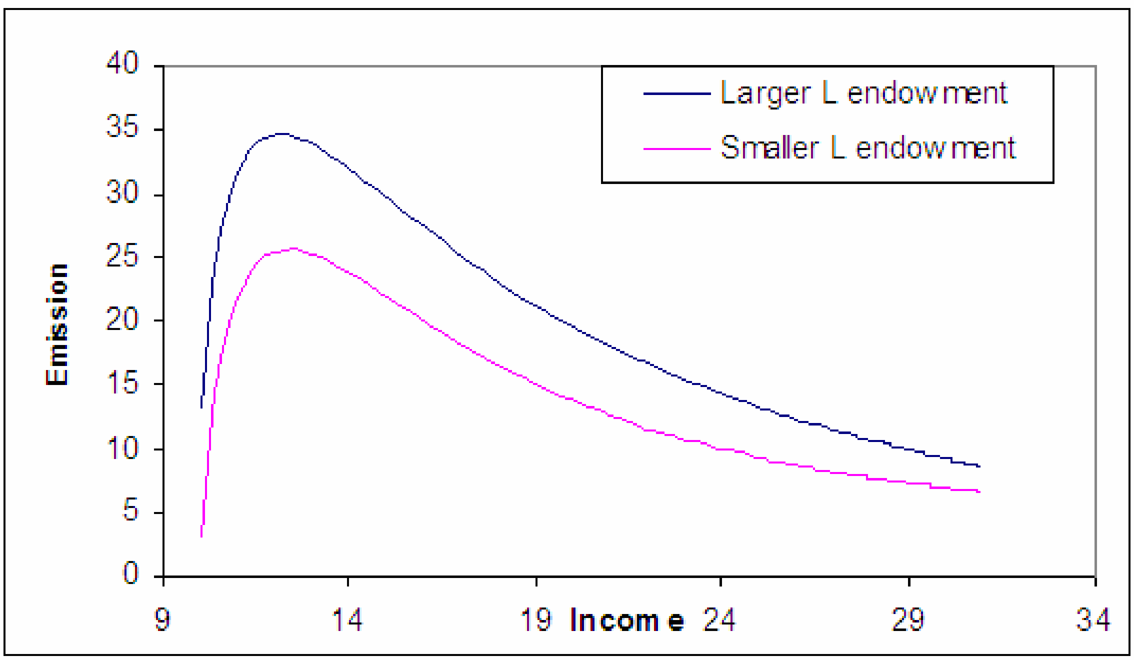

Diagram 1.9: Income-emission relation under different physical endowments

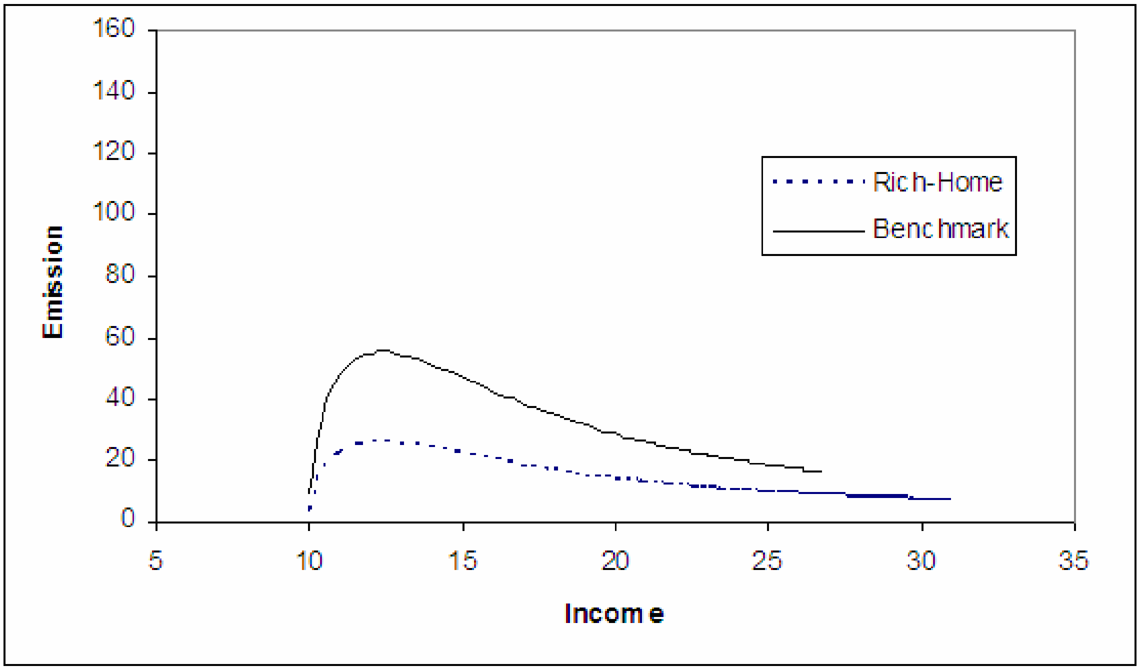

Diagram 1.10: Income-emission relation for economy with relative income high compared to the trading partner

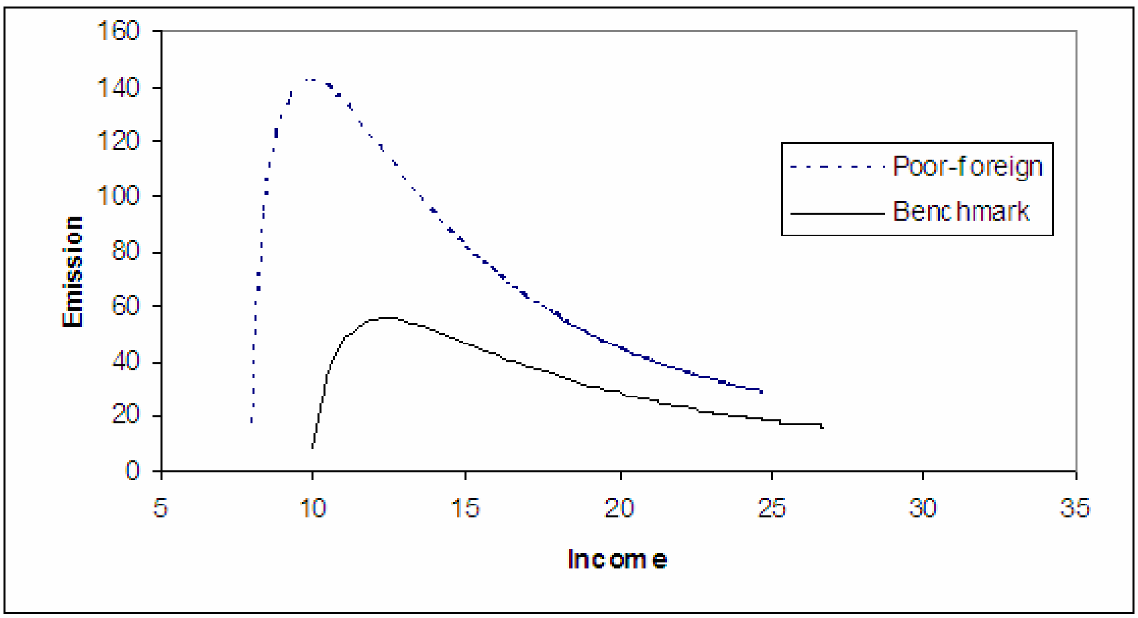

Diagram 1.11: Income-emission relation for economy with relative income low compared to the trading partner

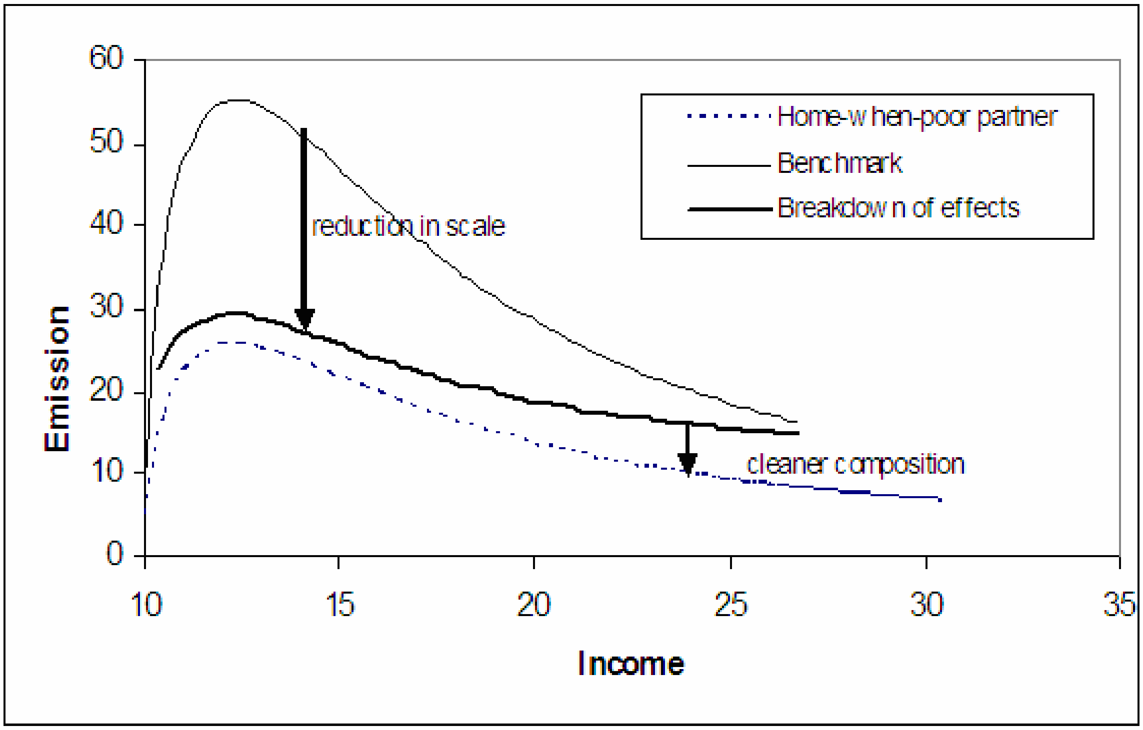

Diagram 1.12: Break down of emissions for economy with relative income low compared to the trading partner

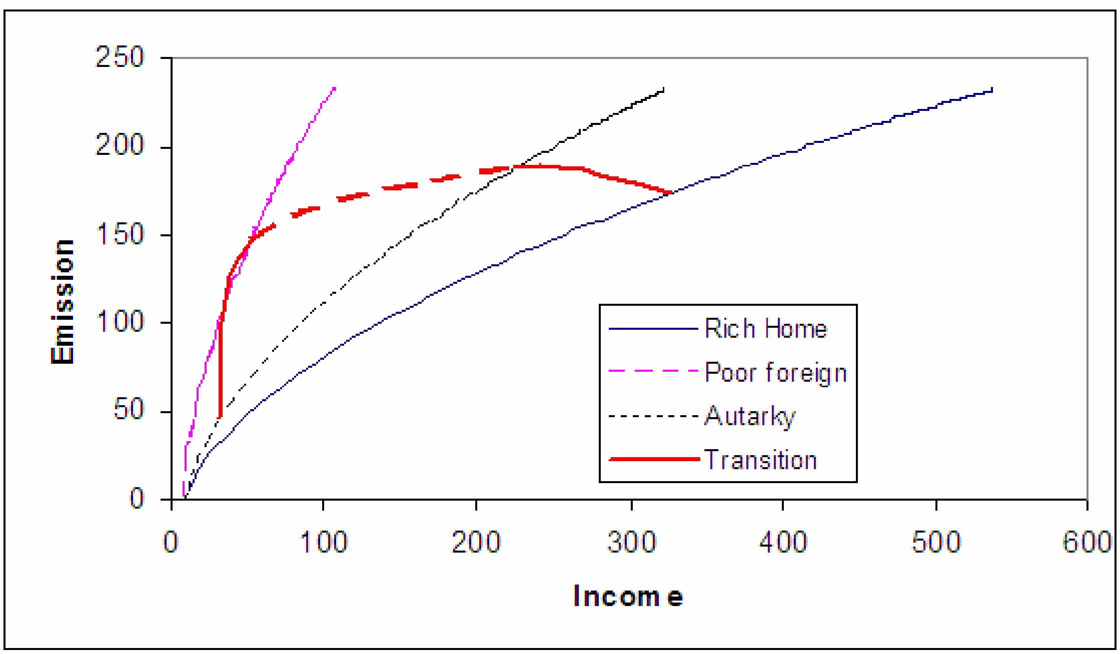

Diagram 1.13: Transition from autarky to trade

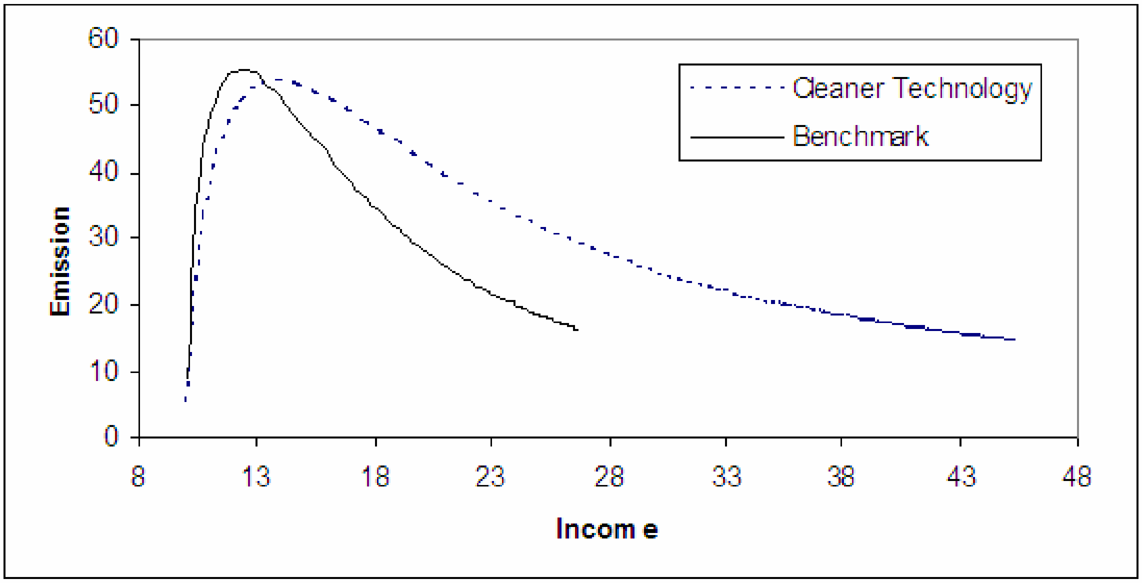

Diagram 1.14: Dynamic impact of cleaner technology

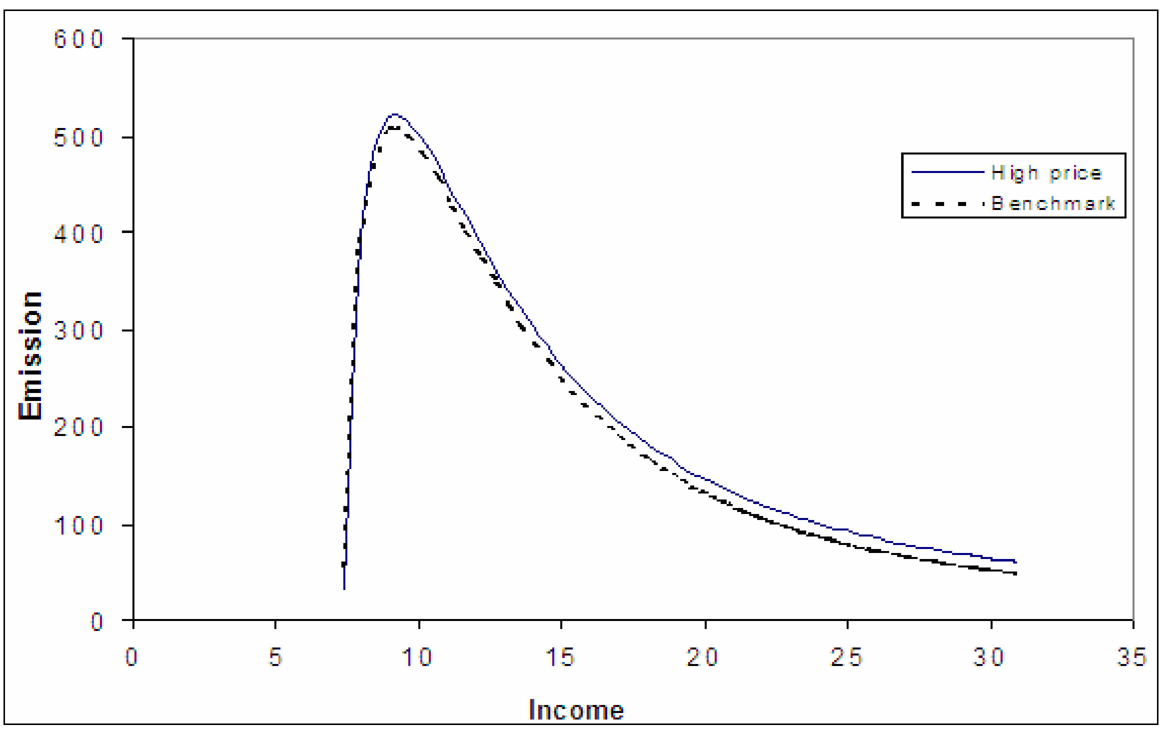

Diagram 1.15: Effect of price rise

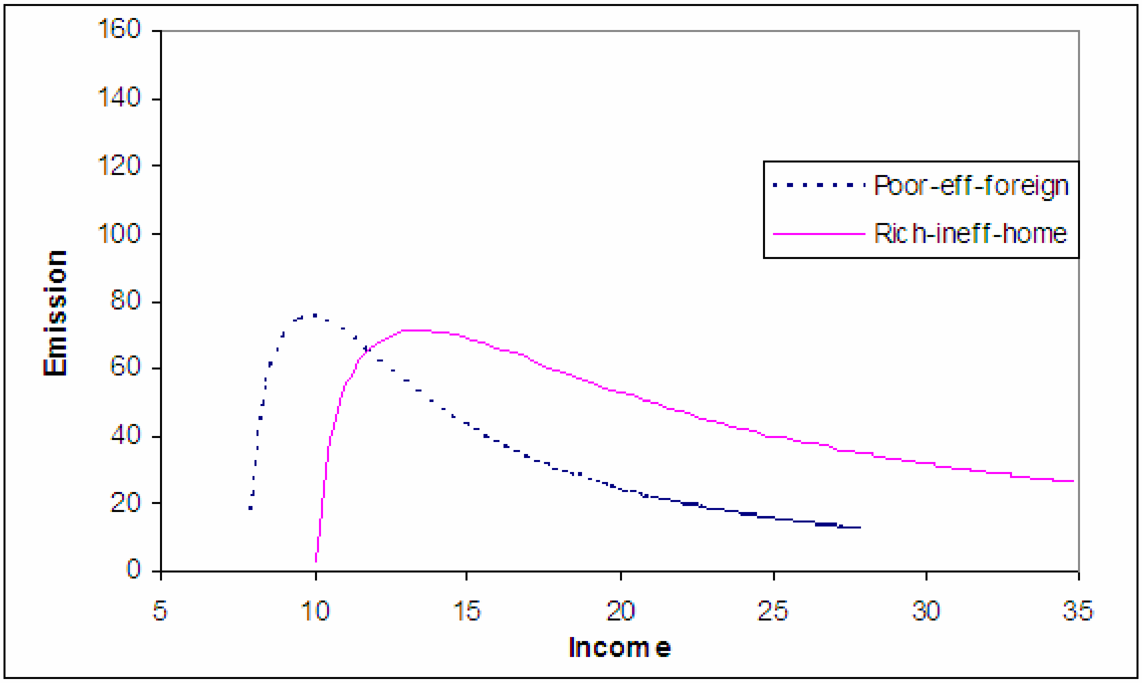

Diagram 1.16: Rich home economy implementing suboptimal taxes

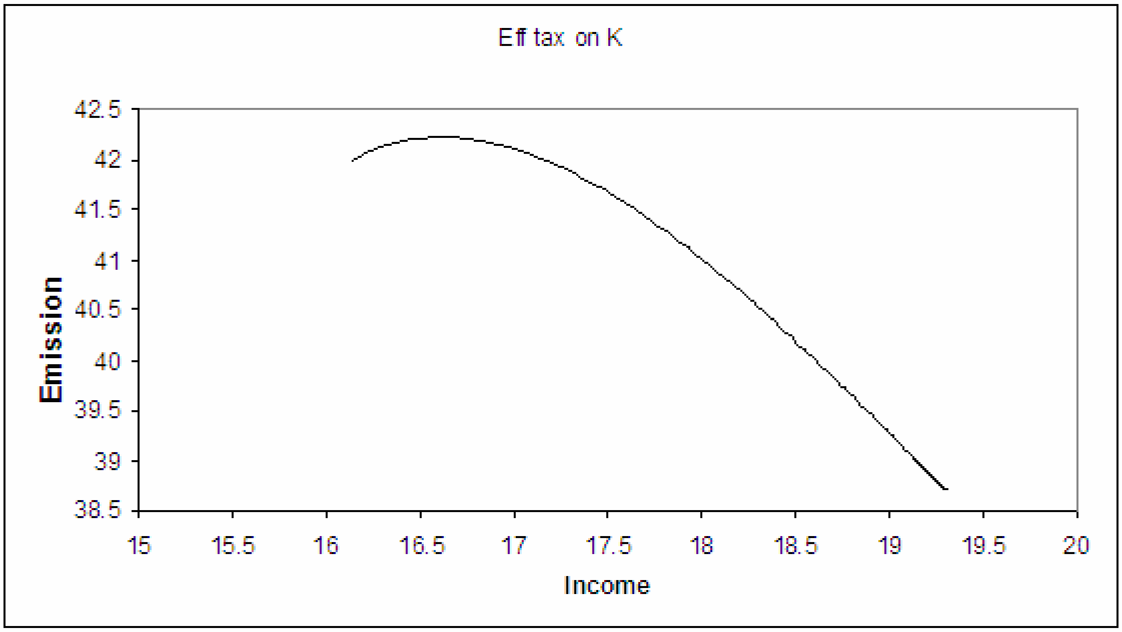

Diagram 1.17: Relation between Pollution and Income with less targeted but efficiently calculated pollution taxes

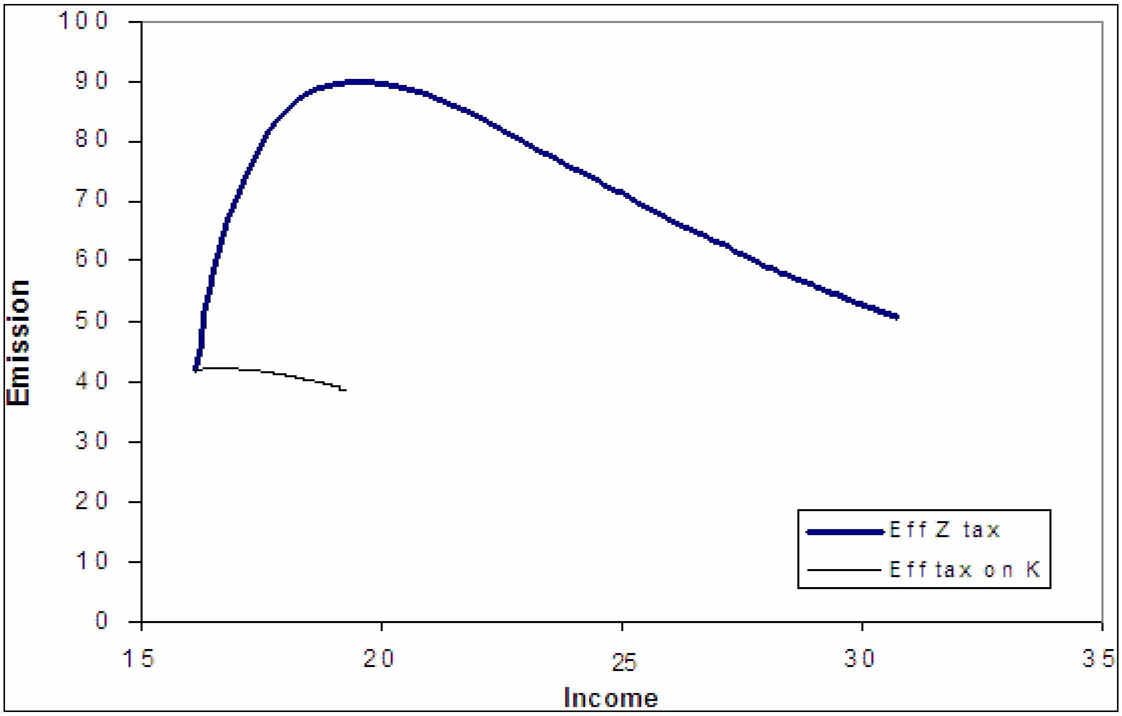

Diagram 1.18: Comparison of tax on emissions and tax on capital

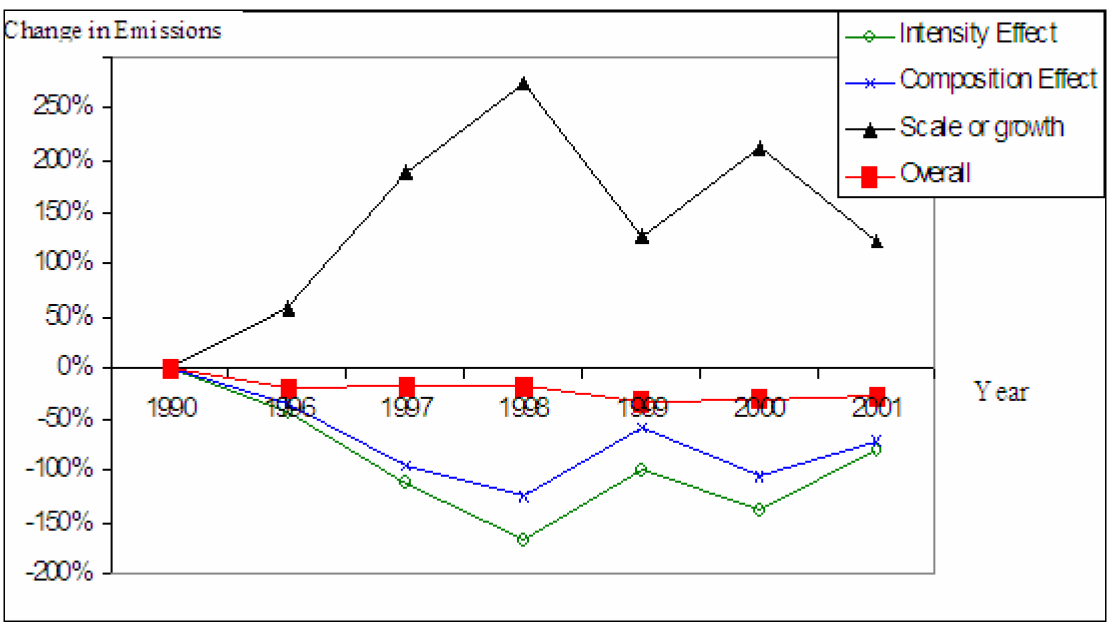

Diagram 1.19: Decomposition of U.S. emissions

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CHAPTER 3

THE WELFARE SYNERGY IN BUNDLING INTERNATIONAL ENVIRONMENTAL AGREEMENTS WITH INTERNATIONAL TRADE TREATIES

1. INTRODUCTION:

Co-operation in trade policy improves upon unilateral policy undertaken by trading countries and often helps the economies to move closer to a free trade outcome. On the other hand, it is also accepted that trade agreements like NAFTA would not have been possible if the negotiating parties had not consented to certain environmental side agreements. I examine whether simultaneous negotiation of environmental agreements will improve the welfare outcomes trade-policy agreements. The analysis will also examine whether Pareto superior equilibria exist where both trade partners benefit from environment and trade agreements compared to negotiation only of trade policy agreement. In the process, issues regarding when environmental policies may be used as disguised trade policy and when such a trade-off will not exist, are also laid out. The diagram lays out the motivation of this paper more clearly.

In game theoretic terms, this paper adds negotiation of joint environmental standards as a new arm to the trade-agreement game. I address two questions. First, can adding the environmental dimension make the co-operative outcome even better than trade-only negotiation (i.e. is $Ucc>Uc$)? Second, can environmental negotiation help move countries closer to free trade (i.e. is $t*c<tc$)?

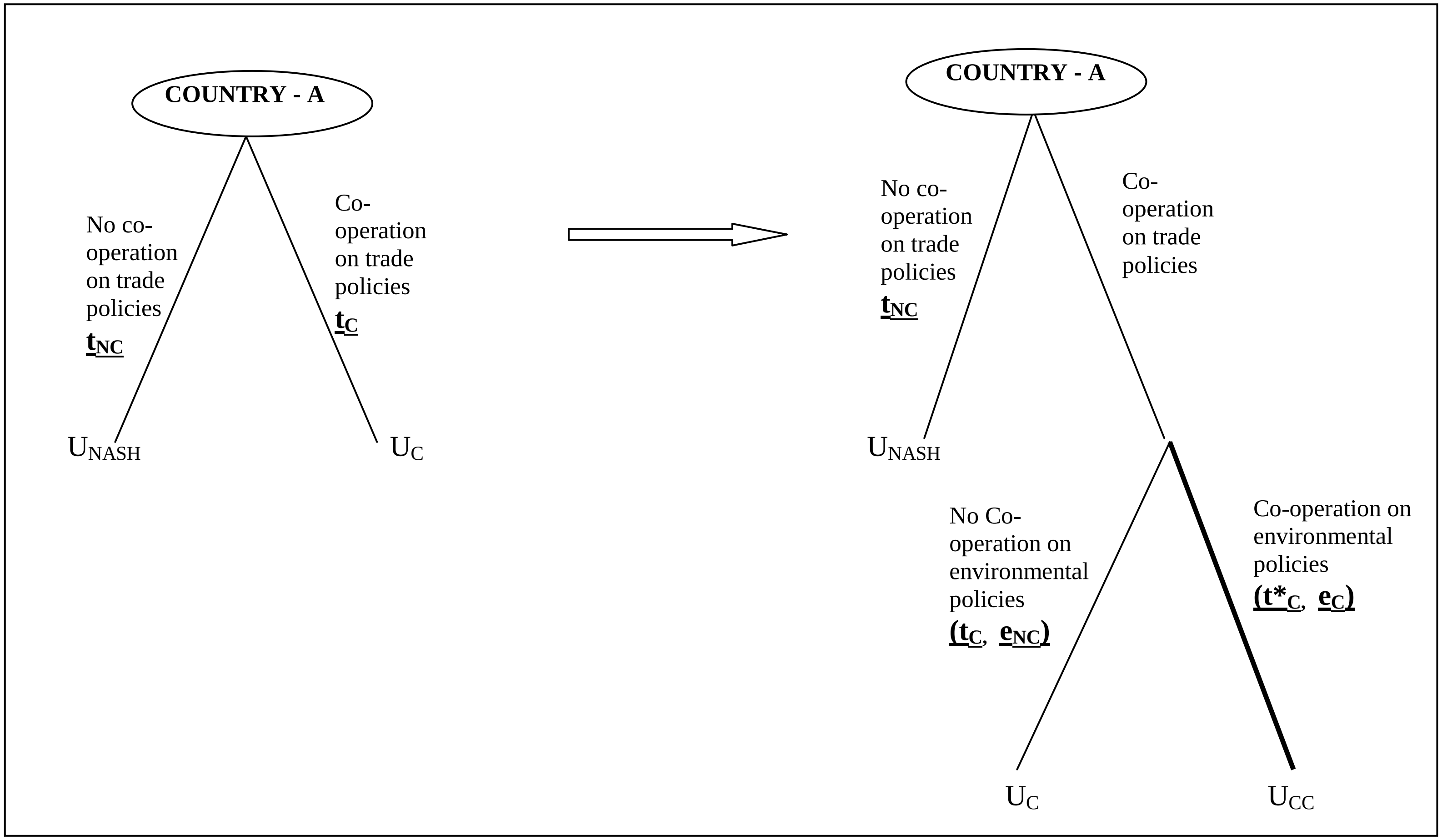

Diagram 2.1: Game theoretic representation of existing literature and current model

2. LITERATURE REVIEW:

Ludema and Wooton (1994) consider cross border externalities and trade liberalization. In a static game setup the authors show that there are two instruments available to the governments- trade tariff and abatement expenditure. However they consider co-ordination only on the trade frontier. By comparing Nash outcome with free trade outcome, they show that co-ordination on the trade frontier embodies domestic adjustment of the environmental policy.

Lisandro, Perroni, Whalley and Wigle (1997) consider a simple interaction of trade and environmental policies when South owns the environmental asset on which North places a huge existence value. In a static game setup they show that when an environmental agreement is linked to trade agreement, the South can use the environmental agreements to leverage for trade concessions.

Regibeau and Gallegos (2004) consider strategic use of trade policies for environmental motives. The government uses import tariff to protect firms from competition and encourage firms to encourage a cleaner but costly technology. In this case, free trade and zero tariffs encourage greater volume of production in the world but using dirtier processes. One of their results is similar to that of this model: Countries with tight WTO commitments have relatively dirtier production while those with a great deal of discretion in trade policy have cleaner production techniques.

Strategic interaction across governments on the environmental policy dimension is a key feature of the article by Elbers and Withagen(2004). They consider mobile labor that is attracted by higher real wages arising due to lax environmental regulations. The mobile workforce is simultaneously deterred by higher disutility of pollution. In this setup, governments choose the environmental tax fully cognizant of the effect such policy will have on the world prices and attractiveness to mobile factors. The authors define environmental dumping as the difference between the non-cooperative Nash taxes and the cooperative solution, an interpretation relevant for my results too.

Copeland and Taylor (2000) examine environmental agreements in a free trade regime. They compare the efficiency implications of various emissions reduction rules and contrast the free trade outcomes with autarkic outcomes. However, under trade they consider only the free trade situation and not an interaction of trade and environmental policies.

Barrett (1994) considers self enforcing international environmental agreements. The self enforcement property of the cooperative outcomes is sustained due to the infinitely repeated game framework where any deviation carries a threat and no scope of renegotiation. He numerically solves his models and finds that when the number of countries that shares the resource is large, the gains from cooperation are low. Rubio and Ulph (2004) revisit Barrett's analysis. Using additional Kuhn-Tucker constraints for non-negativity of emissions, they find that key results of the original paper are robust.

Bagwell and Staiger (1997, 2002) explain international trade agreements in a simple game theoretic framework. They show that while GATTs provisions essentially target a specific level of market access, such a commitment might provide incentives for the governments to distort their environmental or labor policies. However, the logic of GATT provisions aims at solving inefficiencies by suitably designed trade policies.

Esty (2001) provides a descriptive analysis of the trade environmental interaction.

Maggi (1999) considers trade policy, co-operation and role of multilateral institutions in a very elegant framework of repeated games between symmetric countries. I use the general framework of this model. In addition to import tariff, I include environmental standards as an additional dimension of international negotiation.

3. THEORETICAL MODEL:

The model looks at local pollutants that are emitted during the production process. Examples may include chemicals released into water or particulate matter released into air. It seems more likely that trading partners would be concerned with global pollutants as it affects all consumers, and would wish to make agreements regarding those. There is no direct environmental motive behind an environmental agreement for local pollutants. International environmental negotiations regarding local pollutants will be prompted by the indirect gains and losses in international trade that these environmental standards entail. Local pollutants being independent of direct concern to consumers in foreign countries provides a clearer and interesting case of the link between international trade and environmental agreements.

I consider two goods and two countries: home and foreign. Both countries have endowments of both goods. However, each country has a larger endowment of one commodity, and a smaller endowment of the other. Lower case variable are used for the home economy and upper case variables for the foreign economy. “x” and “y” are the endowments of the two commodities for the home economy while “X” and “Y” are the corresponding endowments for the foreign economy. “e” and “f” are the emission levels for the home economy in the x and y markets while “EE” and “F” are the corresponding emissions by the foreign economy. Home has a larger relative endowment of x and exports x while importing y. It sets import tariff "t" in the y market. The foreign economy sets import tariff "T" for imports in the x market.

To incorporate the environmental issues in the standard framework, I assume that in the absence of any abatement effort, every unit of "x" is associated with "m" units of pollution. If the extent of abatement is "a", then it is assumed that a proportional amount θa of the endowment is used up in the abatement activity, leaving x(1-θa) for consumption purposes. The corresponding per-unit emission level is defined as e=k*(m-a), where k is some multiplicative constant. The government chooses emission level "e" based on welfare maximization. The abatement activity decreases the pollution disutility, reduces the amount that the sellers have available to sell in the markets and increases the price of a commodity by making it scarcer.

I look at import tariffs as the instrument of international trade policy. Similar to Maggi (1999), I abstract from other instruments like export taxes and import subsidies.

The price that exporters receive is the price at which they sell in the import market minus the tariff they have to pay.

$p_{ex}=p_{im}-t$

In addition, the government of each country chooses the level of emission standards for its production processes. I do not assume that the governments of each country are restricted to choosing an identical emission standard for both sectors.

The demand for each good is given by $d(p)=\alpha-\beta p$, where p is the domestically prevailing price.

The demand however is also affected by the disutility caused by the emissions.

Instead of assuming an a-priori relation of disutility and prices, I allow the government to intervene in creating a market. The government sets the pollution standards by taking into consideration the marginal social benefit of reducing the last unit of pollution, and the marginal cost of abatement for the last unit of emission.

The home economy exports x at the price p_x, imports Y from country B at $p_y = P_Y + t$ where t is the import tariff imposed by home. The foreign economy imports X at price $P_X = p_x + T$ where T is the import tariff rate imposed by the foreign economy.

The market clearing condition for commodity X yields pricing functions.

$$(\alpha - \beta p_X) + (\alpha - \beta P_X) = x(1 - m + e) + X(1 - m + EE)$$

or, $$p_X = \frac{2\alpha - x(1 - m + e) + X(1 - m + EE)}{2\beta} - \frac{T}{2} \qquad (1)$$

Similarly $$P_X = \frac{2\alpha - x(1 - m + e) + X(1 - m + EE)}{2\beta} + \frac{T}{2} \qquad (2)$$

A weighted sum of consumer surplus and producer surplus is used as an indicator of social welfare[15].

---

[15] This is a close approximation of the social welfare:

$$u(x_1(p_1)) = \int_0^{x1} u'(t)dt - p_1 x_1(p_1) + p_1 x_1(p_1)$$

When the inverse demand function is defined by relative price without referring to income as in a quasilinear welfare function, the above expression can be approximated by:

$$u(x_1(p_1)) \approx \{\int_0^{x1} p_1(t)dt - p_1 x_1(p_1)\} + p_1 x_1(p_1)$$

Under the assumption of zero marginal costs, producer surplus is the term outside parentheses on the right hand side.

or, $u(x_1(p_1)) \approx CS + PS$

This assumption of zero marginal cost is valid in the present model with endowments. The approximation may be less valid in situation where the marginal costs of production are significant.

Use of consumer and producer surplus is useful in the current model because not all of domestic production is consumed domestically and not all of domestic consumption is produced domestically. Also, it allows me to analyze a situation where the policy maker puts different weights on consumer and producer surplus

The welfare of home economy from good X consists of the consumer surplus from consuming X and the consumer disutility from the emissions associated with the production of X and the producers surplus or profits from selling X in the domestic and foreign market.

$$u_X = [\frac{(\alpha - \beta p_x)^2}{2\beta} - \gamma ex] + w p_x x.(1 - m + e) \qquad (3)$$

where γ is the consumer disutility associated with every unit of emission and w is the weight of the producers welfare in the social welfare function

The welfare to the foreign economy from good X consists of the tariff revenue collected on the quantity imported in addition to the other components. The domestically prevailing prices are the import prices and the domestic producers of this commodity sell only in the domestic market.

$$U_X = \frac{(\alpha - \beta(p_X + T))^2}{2\beta} - \gamma ex + w(p_X + T)X(1 - m + EE) + T\{\alpha - \beta(p_X + T) - X(1 - m + EE)\} \qquad (4)$$

Note that the social welfare function is allowed to have a different weight "w" for producer surplus compared to the consumer surplus. The motivation for the differential weights given to welfare of producers and consumers is rooted in a political-economy logic that the production sector might be able to form organized interest groups that can offer political contributions, which politicians value for their potential use in coming elections or otherwise. Helpman and Grossman (1994)[16] show that such incentives may *"induce the government to behave as if it were maximizing a social welfare function that weights different members of the society differently, with individuals represented by a lobby group receiving a weight 1+a and those so not represented receiving a smaller weight of a."* Goldberg and Maggi (1999) [17] empirically test whether different interest groups do have different weights in the welfare function that the government uses to choose policy. They confirm this and further postulate that the weights are much larger than what may be justified by direct contributions, indicating that there might be more reasons for the government's preferential treatment of certain lobby groups. The formulation of the government's welfare function with differential weights encompasses the more commonly used scenario where both consumers and producers have the same weight as a special case. This allows us to handle a wider spectrum of welfare functions for government maximization.

To compare this model with the more standard models with only tariffs, I keep emissions level fixed and examine the properties of the welfare function. The relationship between foreign tariff and domestic welfare is found to be as follows:

$$\frac{du_x}{dT} = \{w.x.e - (\alpha - \beta.p_x)\}\frac{dp_x}{dT} \tag{5}$$

where $\frac{dp_x}{dT} = -\frac{1}{2} < 0$

$w \geq 1$ implies that domestic welfare is unambiguously decreasing in foreign tariffs. This becomes clear when we note that x.e is the effective supply of the

[16] "Protection for Sale", The American Economic Review > Vol. 84, No. 4 (Sep., 1994), pp. 833-850

[17] "Protection for Sale: An Empirical Investigation",The American Economic Review > Vol. 89, No. 5 (Dec., 1999), pp. 1135-1155

commodity and $(\alpha - \beta.p_x)$ is the domestic demand. As good x is the export commodity of the home country, $x.e > (\alpha - \beta.p_x)$. Hence $w \geq 1$ satisfies the condition $\frac{du_x}{dT}<0$

The relation between domestic tariff and domestic welfare for good y is as below:

$$\frac{du_y}{dt} = [\{(A - B.p_y) - y.f\} - \{(A - B.p_y) - w.y.f - tB\}\frac{dp_y}{dt}]$$

>0 ? >0

An increase in domestic tariff has costs and benefits associated with it. The direct benefit of a higher import tariff is the greater tariff revenue earned. The volume of imports reflects the marginal gain and is the first term on the right hand of the above expression. Higher import tariffs also raise domestic prices – this reduces consumer surplus and increases producer surplus. High tariff-induced high domestic price also reduce the volume imported and has a secondary negative impact on welfare. These three welfare gains and losses caused by a tariff induced domestic price rise are included in the term inside parentheses. The non co-operative tariff is set where the marginal benefits equal the marginal costs of a tariff increase, i.e. $\frac{du_y}{dt}$=0. I use the functional values of the first-derivatives to figure out the optimal tariff condition.

$$\frac{du_y}{dt} = \frac{1}{4}(-3Bt + (-3 + 2w)f.Y + F.Y)$$

The non co-operative tariff is set such that $\frac{du_y}{dt}$==0 and implies

$$t = \frac{(1 + f - n)(-3 + 2w)y + (1 + F - NN)Y}{3B} \qquad (6)$$

If w<1.5, an increase in the import-competing endowment y causes import tariff rate to go down. This is because larger domestic endowments imply that the import tariff induced lowering of domestic prices has a lower marginal gain for the consumers. Conversely if w>1.5, the producers have a stronger weight. Then as effective endowment of the import-competing good goes up, welfare-maximizing tariff on imports will go up because the producers are better able to meet the domestic demand and hence non-co-operative welfare maximization implies stronger protection from foreign competition.

For t lower than optimal, $\frac{du_y}{dt} > 0$ domestic welfare increases as domestic tariffs rise till a certain level, and then starts declining. The best response domestic tariff is positive.

I find that the second order conditions for convexity of the function are satisfied.

$$\frac{d^2u_y}{dt^2} = B(\frac{1}{2})^2 - 2B.\frac{1}{2} < 0$$

$$\frac{d^2u_x}{dT^2} = \beta.\frac{dp_x}{dT}\frac{dp_x}{dT} > 0$$

$$\begin{vmatrix} \frac{d^2u}{dt^2} & 0 \\ 0 & \frac{d^2u}{dT^2} \end{vmatrix} < 0 \qquad (7)$$

Having shown that with fixed emissions, the welfare functions have the standard features, I move on to analyze the scenario where the emissions are best responses to the tariffs, which is the spirit of the current model. The best response emissions are derived from the first order conditions of welfare maximization.

Best response for e: $\frac{\partial u}{\partial e} = 0$, or $e|_{br} = br(EE, T)$

Best response for f : $\frac{\partial u}{\partial f} = 0$, or $f\,|_{br} = br(F,t)$

$$\frac{de\,|_{br}}{dT} = \frac{(-\beta)(2-7w+6w^2)}{2wx(3w-1)} = \frac{(-\beta)(2w-1)(3w-2)}{2wx(3w-1)} < 0 \text{ as long as } w>2/3 \qquad (8)$$

As long as producer surplus does not have a very small weight in the welfare function, increases in foreign tariffs will be met by a weaker domestic emissions standard, to allow the domestic producers remain competitive.

$$\frac{df\,|_{br}}{dt} = \frac{B(2-9w+6w^2)}{2wy(3w-1)} = \frac{6B(w-7.37)(w-1.63)}{2wy(3w-1)} > 0 \text{ when } w<1.63 \text{ or } w>7.37 \qquad (9)$$

For w<1.63, the import competing sector is supported by a higher tariffs on imports coupled with a strict emissions standard. Lower tariffs on imports are traded off against allowing higher emissions.

2/3<w<1.63 is the range in which the best response of export emission-standard is negatively related to foreign tariff and import-competing emission-standard best response is positively related to domestic tariff.

Consider the relation of welfare with tariff in the scenario where emissions standards are chosen as best-responses. For w>2/3, domestic prices of exports are falling in foreign tariffs ($\frac{dp_x}{dT}$ <0) and domestic prices of imports are rising in domestic tariffs ($\frac{dp_y}{dt}$ >0)[18].

$$\frac{du_x}{dT} = \underbrace{\{w.x.e-(\alpha-\beta.p_x)\}}_{>0}\underbrace{\frac{dp_x}{dT}}_{<0} + \underbrace{(wp_x-\gamma)}_{>0}.x.\underbrace{\frac{de}{dT}}_{<0} \qquad <0 \qquad (10)$$

[18] Refer to appendix 2 for a proof of this

Equation (10) shows that domestic welfare is unambiguously declining in the foreign tariff. The relation between domestic tariff and domestic welfare is as below:

$$\frac{du_y}{dt} = [\{(A - B.p_y) - y.f\} - \{(A - B.p_y) - w.y.f - tB\}\frac{dp_y}{dt}] + (wp_y - \gamma - t)y\frac{df}{dt}$$

>0 ? >0 >0 >0

The non-cooperative domestic tariff rate is set to maximize domestic welfare: $\frac{du_y}{dt}=0$

Plugging back the functional values of the first-derivatives mentioned at the beginning of derivations into this condition yields:

$$B\gamma(-2+9w-6w^2)+2p_y w(2-6w+3w^2)+w(-3Aw+f(2-6w+3w^2)y = \frac{B}{9}t(w-\frac{1}{3})(w-\frac{2}{3}) \quad (11)$$

The coefficient on t on the right hand side is positive if w>2/3. When the weight to producer surplus is greater the 2/3, import-tariffs lower than the solution implies $\frac{du_y}{dt} > 0$. Hence domestic welfare is increasing in domestic tariffs till a certain level, and declining after the domestic tariff has exceeded the optimum level.

$$\frac{d^2u_y}{dt^2} = \frac{B(8-60w+156w^2-153w^3+36w^4)}{4(1-3w)^2 w} \quad (12)$$

$\frac{d^2u_y}{dt^2} < 0$ for 0.56<w<2.96

$$\frac{d^2u_x}{dT^2} = (w.x.\frac{de}{dT} + \beta.\frac{dp_x}{dT})\frac{dp_x}{dT} + w\frac{dp_x}{dT}\frac{de}{dT} \quad \mathbf{>0}$$

<0 <0 <0 <0 <0

$$\begin{vmatrix} \frac{d^2u}{dt^2} & 0 \\ 0 & \frac{d^2u}{dT^2} \end{vmatrix} < 0 \quad (13)$$

$2/3<w<1.63$ is the range within which all the conditions are satisfied. When this condition is satisfied, the welfare function satisfies all standard properties. The permissible range for the weight on producer surplus encompasses the commonly used case $w=1$.

The diagram below illustrates graphically the above mathematical conditions. The isowelfare functions for the two economies are drawn in the home and foreign tariff plane. Holding the partner’s tariff level fixed, each economy’s welfare increases in domestic tariff till a certain level and declines beyond that. The loci of the welfare maximizing domestic tariff traces out the best response tariff of each economy. The diagram also reveals that holding the domestic tariff level fixed, the welfare of each economy is unambiguously declining in the partner economy’s tariff level.

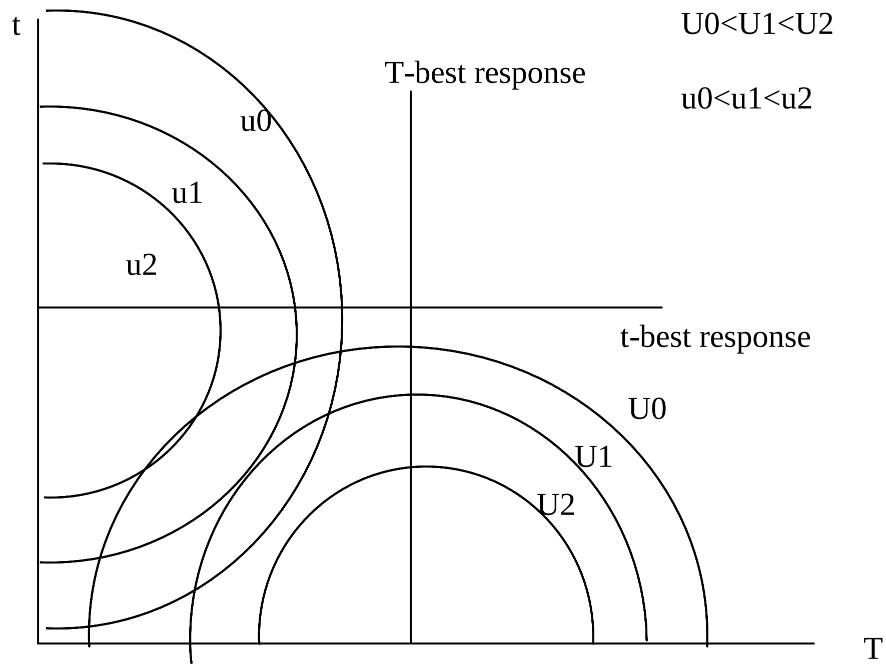

Diagram 2.2: Iso-welfare functions and best response tariff function in the domestic and foreign tariff plane

In the absence of any co-operation, each government unilaterally chooses the values of the three policy instruments using the best response function, which unilaterally maximize the social welfare function for the economy.

The model conforms to the beggar-thy-neighbor literature because as seen from equations (5) and (10), increased tariffs hurt the trade partner and helps the home country. Each economy non-co-operatively will choose a positive tariff as revealed in equations (6) and (11) to maximize welfare. This welfare maximization involves extraction of tariff revenue, lowering domestic prices that benefit domestic consumers and protecting the domestic producers against foreign competition. All these gains to domestic welfare are at the cost of foreign welfare. Thus each economy behaves in a “beggar-thy-neighbor” manner under non-cooperation. This beggar-thy-neighbor behavior under non-cooperation is key to the possibility of cooperation. Cooperation is sustained when welfare loss caused by alteration of non-cooperative domestic strategies is traded off against welfare gains as foreign policy shifts from non-cooperative strategies.

While equations (5),(6), (10), (11) show the "beggar-thy-neighbor" behavior with respect to tariff, the following section explores whether similar incentives prevail in the setting of export-emission standards. The relation between foreign welfare and domestic export emissions at the non-cooperative solution is given by equation (14).

$$\frac{\partial U}{\partial e} = (-1)\frac{(w-1)X(w\alpha - \beta\gamma)}{\beta(3w-1)} \tag{14}$$

Equation (14) implies that as long as a country has some endowment amount 'X' of a commodity, and as long as producers get more weight in the planners welfare function than consumers (w>1), the economy would gain from its trade partner having a stricter environmental standard than what is chosen non-cooperatively. However, if producers get a lower weight (w<1), or if the country has a negligible endowment of the commodity ($X \to 0$), then the country is a net importer of the good and would prefer the exporter to implement a lower environmental standard, because the domestic consumers would gain from this. The non-cooperative emission level that an economy chooses by accounting for disutility of consumers and competitiveness of producers is welfare maximizing for the domestic economy but welfare reducing for the trading partner. Hence this is also consistent with the "beggar-thy-neighbor" situation.

As illustrated above, a reduction in import tariffs and a tightening of emissions standards benefits an economy if the changes are made by the foreign economy, but reduces welfare if the changes are required domestically. This indicates that there exists scope for joint co-operation where welfare losses to self from a domestic policy change are more than compensated by welfare gains caused by foreign policy change.

4. TRADE NEGOTIATION:

When cooperation occurs only on the import tariffs the countries no longer choose their tariff rates according to the best response functions but according to the negotiated tariff rates. However each country still chooses emissions standards as best response to the co-operative tariff. This makes the welfare function of each country solely a function of the prevailing tariff rates as shown in the derivation of expression (15).

$u = u_X + u_Y$

or, $u = u_X(e, EE, T) + u_Y(f, F, t)$

or, $u = u_X(e|_{br}(T), EE|_{br}(T), T) + u_Y(f|_{br}(t), F|_{br}(T), T)$

or, $u(t,T) = u_X(T) + u_Y(t)$ (15)

The diagram 2.2 illustrates the iso-welfare curves which are of combinations of (t, T) that result in a given welfare level for an economy.

A cooperative equilibrium that is different from the Nash equilibrium is sustainable if there are multiple periods to be considered so that a deviation in one period would be followed by retaliation in subsequent periods. The range of such sustainable co-operative equilibria is such that the discounted loss from future retaliation outweighs the gain from deviation in a single period. The incentive compatibility constraint is the locus where the gains just equalize the loss. If a country deviates in one period, then its trade partner gets to know in the subsequent period and reverts back to the Nash choice for all future periods as that is its best response strategy.

$$ic : u_D(T_C) - u_C(t_C, T_C) = \frac{\delta}{1-\delta}(u_C(t_C, T_C) - u_N) \quad (16)$$

where δ is the discount rate

u_C is the welfare to the home country under cooperation, u_D is the welfare to home from deviation when the foreign country still fulfills its commitment because it does not realize the deviation of its opponent. Hence $u_D - u_C$ is the one-period gain from deviation. u_N is the welfare to the home country when both parties have reverted back to Nash strategies. Thus the right-hand side is the discounted loss from future punishment. The Nash welfare is a function only of the parameters of the model and hence is constant. The cooperative welfare for the home country is a function of the cooperative strategies of home and foreign countries. The best deviation tariff for home depends only on the cooperative choices that the foreign economy still adheres to.

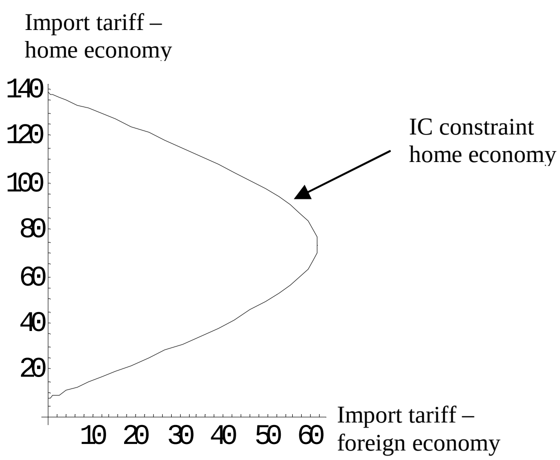

Diagram 2.3: Incentive compatibility constraint for the home economy for trade-only negotiation

Since tariffs are non-negative by assumption, the incentive-compatibility constraints (ICCs) of both countries are binding at the cooperative equilibrium.

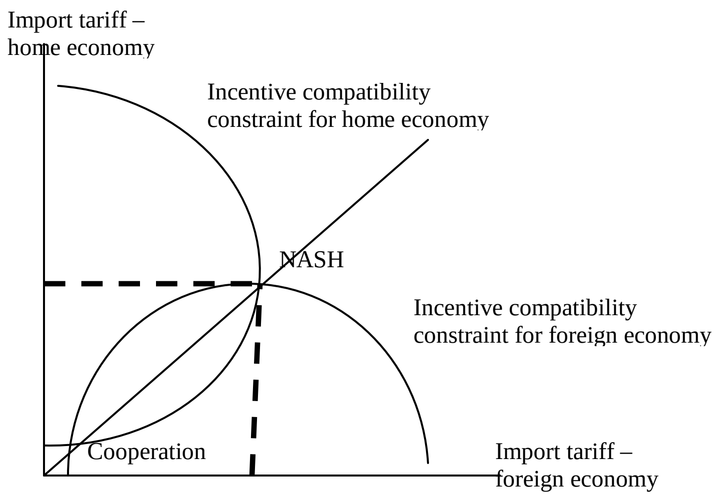

Diagram 2.4: Non-cooperative and trade-negotiation outcomes

The ICCs of the two countries must hold with equality both at the cooperative equilibrium as well as at the Nash equilibrium. The ICCs intersect at two points. Solution of the equations shows the intersection further away from the origin is the Nash solution and the intersection closer to the origin is the tariff-cooperation solution. The tariff under trade co-operation is lower than the unilateral maximization or Nash outcome. In terms of the welfare, cooperation helps attain higher welfare compared to Nash. This can be seen in the diagram below by noting that the cooperation attains an isowelfare locus that is closer to the vertical axis compared to the Nash isowelfare function.

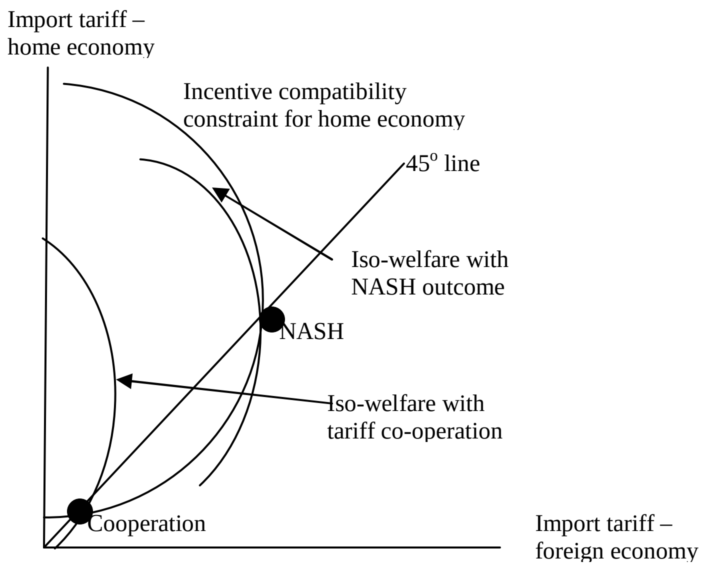

Diagram 2.5: Wefare levels associated with on-cooperative and trade-negotiation outcomes

The fact that trade policy cooperation improves welfare has been demonstrated by various researchers, though without accounting for environmental responses as modeled in this section. However a more interesting question is whether incorporation of emissions standards within the purview of international negotiation has the possibility of improving the welfare outcomes further. The numerical values for welfare improvement are tabulated later for a comparison of non-cooperative outcome, tariff cooperation and tariff-and-emission cooperation.

5. TRADE AND ENVIRONMENTAL NEGOTIATION:

A country might wish that its imports meet a certain environmental standard of production. For example, a country might not wish to import fish from a country that catches fish by an inexpensive method that causes large damage to the ecological system within the country of production. However, it is unlikely that the standards would be subject to international scrutiny if the country has a small industry that produces and caters only to the domestic market and causes local damage. So even with international agreement, I allow flexibility to the countries to choose the environmental standards for the import-competing industry using a best-response behavior. The following diagram depicts the idea that the environmental policy for the import-competing-sector is chosen as a best response to the negotiated tariffs and the export emission standards. The shaded plane represents the best response of the import competing sectors emissions as a function of import tariffs and export emissions. For an {import tariff, export emission} combination, the unique import-competing-best-response-emissions can be read off from the shaded plane.

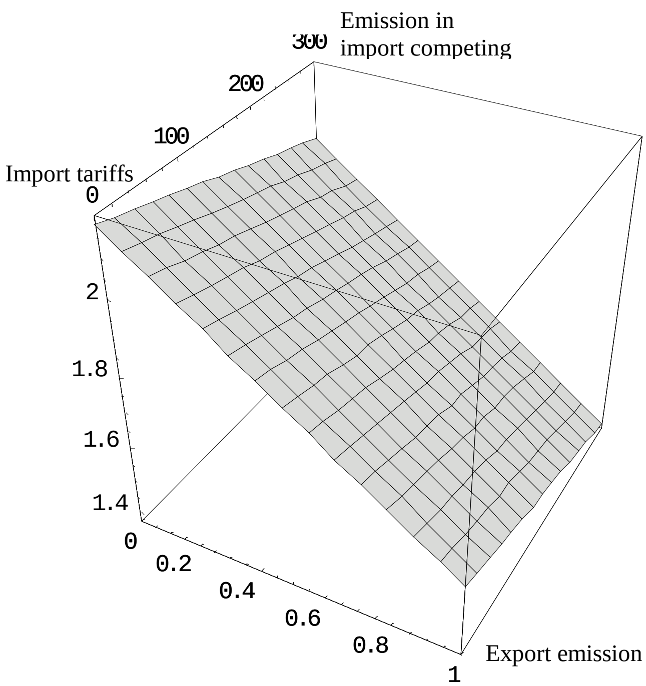

Diagram 2.6: Emissions in the import competing sector as a best response to import tariffs and emissions of export sector

Substituting out import-competing-sector-emissions with the use of the best response function the welfare of a country now is a reduced-form function of the negotiated tariff rates as well as negotiated export emission standards.

The following diagram shows the welfare map for the home country, holding the import tariff 't' of the home country and export emission 'F' of the trading partner at fixed levels. The diagram reveals that domestic welfare increases in domestic import tariff till a certain level of the tariff and declines thereafter. The same is true for the export emissions choice[19]. This is consistent with the best response tariff choice and best response export emission policies. If the trading partner were to keep its policies unchanged, then the economy could have attained maximum welfare denoted by the central iso-welfare locus by implementing its best response policies.

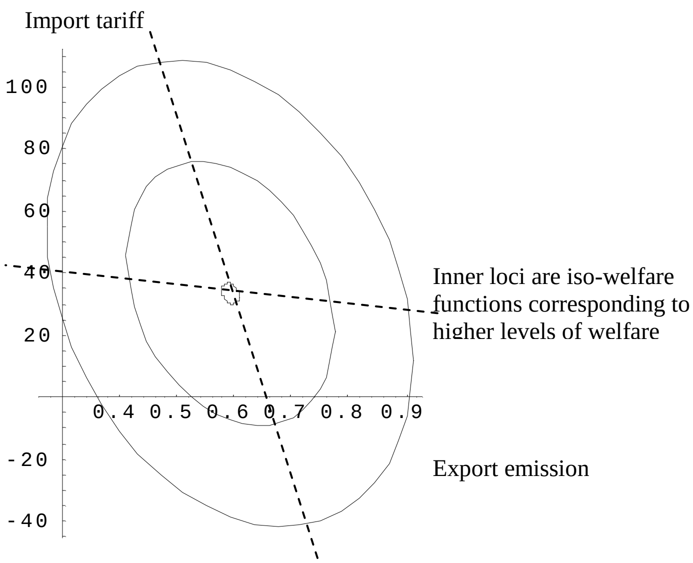

Diagram 2.7: Isowelfare functions relevant for trade-and-environment negotiation

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19 $\frac{dt}{de}\Big|_{isowelfare} = (-1)\frac{\partial u/\partial e}{\partial u/\partial t}$ <0 for ($e<e_{br}$, $t<t_{br}$) and ($e>e_{br}$, $t>t_{br}$)

>0 for ($e<e_{br}$, $t>t_{br}$) and ($e>e_{br}$, $t<t_{br}$)

Consider an infinitely repeated game. Let (e_C, f_C, t_C) denote the policy values that can be sustained with co-operation for home. The corresponding values for the foreign economy are (EE_C, F_C, T_C).

Welfare from co-operation is denoted by: $u_C = u_{XC}(e_C, EE_C, T_C) + u_{YC}(f_C, F_C, t_C)$

These levels are sustainable if, on deviation, the loss is greater than the gains. In the first period of deviation, the trade partner continues to satisfy the co-operative policies oblivious to the defection by the other, while the deviator gains by choosing the policy values that would be best response to the trade partner's co-operative policies. In the next period, everyone gets to know of this deviation and all respond in the best-response manner to the opponents, ending up in the Nash equilibrium for the periods thereafter.

Let us consider the problem of the home country. The international agreements are made on import tariffs 't' that the home country imposes on its imports of good Y, and on the environmental standard 'e' for the good X that the country exports. The country always gets to choose 'f' as its best response to the prevailing situation. I denote the single period deviation values by (e_D, f_D, t_D). Since the welfare has been modeled such that it is separable in the goods, each country just needs to consider the market in which it is deviating, to decide on its best response. While choosing the deviation on the environmental policy of its exports, the home economy takes the policies of the foreign economy at the co-operative levels. Since the trade partner will get to know about the deviation in the next period, if home decides to deviate it will deviate in both markets simultaneously because the punishments would follow in both markets.

In market X, home country chooses, $e_D = br(EE_C, T_C)$ (17)

In market Y, home deviates on the import tariffs it imposes. In market Y, home also adjusts its own domestic emissions in best response to its own tariff deviation:

$$t_D = br(f_D, F_C) \quad (18)$$

$$f_D = br(t_D, F_C) \quad (19)$$

This pair of equations can thus be solved just in terms of the trading partner's co-operative commitments. $t_D = t_D(F_C)$, $f_D = f_D(F_C)$ (20)

The associated welfare from deviating is named as before.

Using equations (17) and (20), I can rewrite the welfare from deviation in terms of the co-operative values of the policies.

$$u_D = u_{XD}(e_D, EE_C, T_C) + u_{YD}(f_D, F_C, t_D) \quad (21)$$

or, $u_D = u_{XD}(e_D(EE_C, T_C), EE_C, T_C) + u_{YD}(f_D(F_C), F_C, t_D(F_C))$

$$u_D = u_{XD}(EE_C, T_C) + u_{YD}(F_C)$$

Further, we need to recognize that the foreign economy chooses the environmental strategy EE_C on the domestic production of its import commodity X in best response to what it believes is the state of the market.

or, $u_D = u_{XD}(EE_C(e_C, T_C), T_C) + u_{YD}(F_C)$

or, $u_D = u_{XD}(e_C, T_C) + u_{YD}(F_C)$ (22)

Thus gains from deviating

$$g = u_D - u_N \quad (23)$$

The Nash solution is defined by the parameters of the model. Hence the gains from deviating can be thought to be a function only of the co-operative levels of policy. The loss associated with this deviation: $L^{A} = \frac{\delta}{1-\delta}\{(u_{XC} + u_{YC}) - (u_{XN} + u_{YN})\}$ (24)

where δ <1 is the rate at which the next period is valued in comparison to the current period. The loss from deviating is thus also a function only of the co-operative levels of policy.

A co-operative equilibrium is sustainable if it is incentive compatible, i.e. there should not be incentive to deviate. The loss from deviation should equal or outweigh the gains from deviation.

$ic \quad : g \quad \leq l$

or, $(u_{XD} + u_{YD}) - (u_{XN} + u_{YN}) \leq \frac{\delta}{1-\delta}\{(u_{XC} + u_{YC}) - (u_{XN} + u_{YN})\}$ (25)

The incentive compatibility constraint is a function of the co-operative levels of policy. Unlike in the only tariff situation, there are now two choice variables for every country and only one constraint. So the constraint itself is not sufficient to solve for the equilibrium. To select among the several possibilities that are incentive compatible, it is reasonable to assume that the countries will pick policy combination that maximizes the welfare of individual countries.

$$Max_{e_C, t_C} u_C = u_{XC}(e_C, EE_C|_{br}(e_C, T_C), T_C) + u_{YC}(f_C|_{br}(F_C, t_C), F_C, t_C)$$

subject to: $ic = 0$ and $IC = 0$

This implies choosing the point where the welfare function with co-operation is tangent to the incentive compatibility constraint.

$$\frac{\partial u_C / \partial e_C}{\partial u_C / \partial t_C} = \frac{\partial ic / \partial e_C}{\partial ic / \partial t_C} \qquad (26)$$

Equations (25), (26) and their foreign economy counterparts together determine the sustainable welfare maximizing co-operative policy choice. The table below provides the strategies chosen and welfare outcomes for a specific parameterization of the model.

	Nash	Co-operation only on import tariffs	Cooperation on import tariff and export emissions
Welfare level	0.37228	0.372298 (+0.005%)*	0.372625 (+0.093%)*
Import tariff	0.0804	0.0201	0.0655509
Export Emissions	0.5147	0.53778	0.232952

Parameters: x=Y=1.5, y=X=1, α=1, β=1, m=1, γ=0.01, ρ=0.99, w=1.25

* Percentage increase in welfare over Nash welfare level.

Table 2.1: Comparison of non-cooperation, only trade and trade-and-environment negotiation outcomes

The diagram below reflects these outcomes. Under symmetric equilibria, the iso-welfare loci of a country are drawn under the restriction that the values of the two choice variables for the foreign country is same as that for the home country at all points in the {import tariff, export emission} plane.

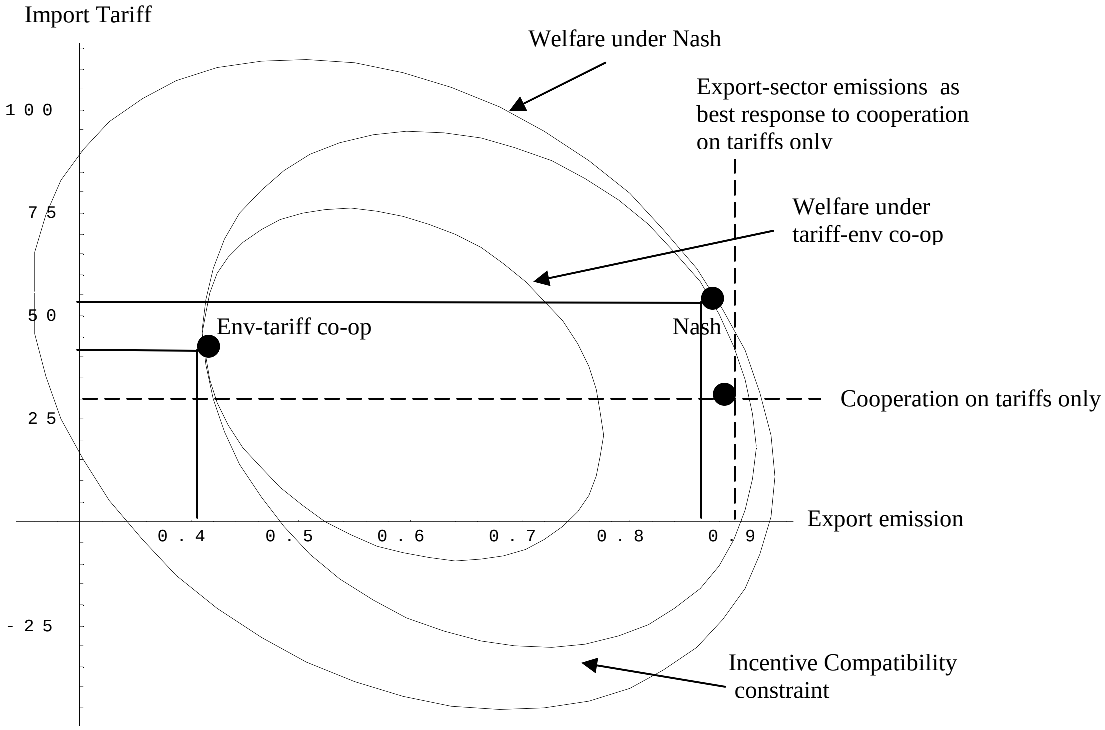

Diagram 2.8: Comparison of outcomes under non-cooperation, only-trade negotiation and trade-and-environment negotiation

For the only-tariff-cooperation solution the tangency condition is not relevant. The co-operative tariff solution and the corresponding best response export-sector emission are indicated in the diagram in the form of dashed lines. The {import-tariff, export-sector emission} combination lies within the iso-welfare function represent the Nash welfare level. This implies that cooperation on tariffs-only improves welfare relative to no-cooperation. Also the cooperative tariff level is lower than the non-cooperated tariff level but the environmental degradation is worse with the tariff-only agreement.

Compared to the Nash outcome, the tariffs are lower, emissions are lower and welfare is higher for each country when there is co-operation on the tariffs and environmental standards. The model indicates that co-operation on both frontiers improves welfare greatly as shown by the corresponding iso-welfare function being more towards the center. However, the tariff-only cooperation was able to attain larger cuts in tariffs compared to tariff-environment co-operation. The reason for this is that, left to their own devices, each country chooses a more polluting emission level in export commodity production and hence is willing to be more flexible on tariff cuts. However, when emissions are also part of the negotiation, stricter emissions requirements make the countries less willing to cut tariffs. This result is consistent with the findings of Regibeau and Gallegos (2004).They find that countries with tight WTO commitments have relatively dirty production while those with a great deal of discretion in trade policy have a clean production.

6. ASYMMETRIC ECONOMIES:

For symmetric economies, the demand function was derived from maximization of consumer surplus $\frac{\alpha}{\beta}x_c - \frac{x_c{}^2}{2\beta} - p_x x_c$ because the symmetry assumption automatically led to balanced trade outcomes. However, balanced trade requirements have to be explicitly taken into account when analyzing asymmetric economies.

$$(\frac{\alpha}{\beta}x_c - \frac{x_c{}^2}{2\beta} - p_x x_c) + (\frac{A}{B}y_c - \frac{y_c{}^2}{2B} - p_y y_c) + \lambda_1(p_x x(1-a) + p_y y(1-b) - p_x x_c - p_y y_c)$$

This leads to the demand functions having the form: $\alpha - (\lambda_1\beta).p_x = x_c, \quad A - (\lambda_1 B).p_y = y_c$ where the values of the Lagrange multipliers enter into defining the demand functions. The Lagrange multipliers differ by country. So there are two new variables in the system λ_1, λ_2 that need to be solved and one new equation: either one of the budget constraints or the balanced trade equation that was not explicitly considered before (the second budget equation is redundant by the Walras law). Hence, unlike in the Maggi model, the absolute prices of the two commodities cannot be solved. Only the relative price can be solved, which is consistent with standard trade models. Inserting the demand equations for the quantities consumes, the budget equation for the home economy can be written as:

$$p_x x(1-a) + p_y y(1-b) = p_x(\alpha - (\lambda_1 \beta).p_x) + p_y(A - (\lambda_1 B).p_y)$$

or, $$\lambda_1 = \frac{p_x \alpha + p_y A - (p_x x(1-a) + p_y y(1-b))}{(p_x{}^2 \beta + p_y{}^2 B)}$$

A similar solution exists for λ_2.

Plugging back the solutions for the quantities consumed, relative prices and the Lagrange multipliers into the social welfare function, I find it to be a function of the effective endowments as shown by expression (27).

$$u = \frac{(\alpha - (\lambda_1 \beta).p_x)^2}{2.\lambda_1 \beta} + \frac{(A - (\lambda_1 B).p_y)^2}{2.\lambda_1 \beta} + w\{p_x x(1-a) + p_y y(1-b)\} + t\{A - (\lambda_1 B).p_y - y(1-b)\} - \gamma_1 e^* x - \gamma_2 f^* y \qquad (27)$$

Maximization of the welfare function entails specific effective endowments. As the physical endowments of an economy changes, the economy will change its emissions levels to attain the target effective endowments. Larger absolute sizes of the economies in terms of physical endowments do not change the equilibrium outcomes.

An economy with more endowments can be rich which is associated with high aggregate pollution. It can reduce its emissions which also simultaneously reduces effective endowment. The equilibrium represents the optimal tradeoff between emissions and income.

7. GLOBAL POLLUTANTS:

If the emissions have an impact beyond the local economy, it would affect the results. Columns 2 and 3 present results for a global pollutant, with column 3 embodying a greater degree of international spillover. Column 1 is the case of zero spillover (or local pollutant) and provides the benchmark for comparison. “g” represents the degree of international effect of a pollutant.

	g=0	g=0.01	g=0.02
Welfare under non-cooperation	0.37228	0.361664	0.351047
Import tariff under non cooperation	0.0804	0.0804	0.0804
Export Emissions under non cooperation	0.5147	0.5147	0.5147
Welfare under only trade negotiation	0.372298	0.361674	0.351052
Import tariff under only trade negotiation	0.0201	0.03439	0.0486766
Export emissions under only trade negotiation	0.53778	0.532324	0.526869
Welfare under trade and environment negotiation	0.372625	0.362119	0.351633
Import tariff under trade and environment negotiation	0.0655509	0.0766432	0.0873372
Export emissions under trade and environment negotiation	0.232952	0.190567	0.147253

Table 2.2: Comparison of outcomes for local and global pollutants

When economies choose their actions non-cooperatively, international spillovers do not influence their domestic choices. This results in the non-cooperative strategies with local and global pollutants to be identical. However, the welfare level decreases because the emission choice of each economy affects other economies more strongly as the global effect get stronger. This indicates that given any opportunity of co-operation, every economy will more strongly try to influence the emission level of the partner economy, greater the global spillover effect. Tariff co-operation is consistent with this prediction. For pollutants of more global nature, the tariff cut is smaller and the best response emissions level is lower. Negotiating on tariffs, the countries do not push for very large tariff cuts because they realize that it would be accompanied by greater emissions which is undesirable by the trading partner. In the situation of tariff-and-emission co-operation, stronger global impact implies the economies agree to lower emissions level though it requires a higher co-operative tariff level to sustain it. Compared to non-cooperative outcomes, the emission level goes up when economies negotiate only on tariffs and emission level is held down when it is explicitly included in the negotiation similar to local pollutants. As lower emissions have a higher tariff tradeoff, the tariff cuts possible with emission-and-tariff negotiation is less than under the only tariff negotiation.

8. CONCLUSION:

This repeated game model shows that a joint negotiation on tariffs and environmental standards improve welfare compared to negotiating a trade treaty only. If the policymaker has a higher weight on producer welfare relative to consumer welfare, then compared to non-cooperation, trade-and-environment cooperation improves environmental standard while only trade negotiation will deteriorate the environmental quality. In this model, larger physical endowments result in high income and high pollution. The optimal tradeoff between income and emissions result in an optimal effective endowment which is independent of the actual physical endowments of an economy. Comparison of global pollutants with local pollutants shows that non cooperative behavior is same in both scenarios. Under cooperation, economies push toward stricter emissions standards for pollutants with more global impacts, though this comes at a cost of a smaller tariff reduction.

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CHAPTER 4

THE POLLUTION HAVEN DISGUISED IN FACTOR INTENSITIES

1. INTRODUCTION:

The pollution-haven hypothesis states that, ceteris paribus, production of dirty goods shifts to countries with weaker environmental standards. This is because strict environmental quality requirements increase the cost of production of dirty goods and put these countries at a comparative disadvantage. There exists a vast empirical literature studying the pollution-haven hypothesis. Though the idea is intuitively appealing, empirical evidence has eluded researchers for a long while. These studies mainly use cross-section data from poor countries with weak environmental standards and developed countries with strict environmental standards. Country-specific factor endowments are included to control for the Hecksher-Ohlin-Vanek (henceforth HOV) basis for trade. However the evidence is at best mixed and the sign of the coefficient is often found to be opposite of the expected direction. Only recently, studies using panel data have been able to find significant pollution-haven coefficients though the estimates are still suspected to be too small compared to anticipated true effects of abatement costs. The theoretical framework that the empirical literature refers to is the marginal-cost consideration: environmental strictness affects the marginal cost. With trade, the equalization of price leads to equalization of marginal cost and hence a reallocation of the dirty good to the environmentally slack countries. I start with the inspection of the theoretical model to uncover whether the apparently simple marginal cost consideration is obscuring a larger picture.

HOV hypothesis predicts pattern of trade based on factor endowments. The pollution haven hypothesis predicts that stricter countries should produce fewer of the dirty goods. This paper looks at the interaction of the abatement effects with the factor endowment effects. I find that whether the effect of stricter environmental regime on production is similar or opposite to the traditional pollution-haven effect depends critically on the factor intensity of the dirty good under consideration. In the process, the model also shows that different abatement standards lead to deviation from factor price equalization of physical inputs.

2. LITERATURE REVIEW:

Tobey (1990) uses a cross-sectional Heckscher-Ohlin model to study trade patterns in five highly polluting sectors. He finds that if one controls for differences in resource endowments, differences in regulatory stringency have no measurable effect on international trade patterns in these industries. The study consists of five cross-section regressions (one for each sector) of net exports on characteristics of 23 countries. The measure of environmental stringency is an ordinal ranking of countries based on a 1976 UNCTAD survey where questionnaires were sent to national officials in developed and developing countries.

Brunnermeier and Levinson (2004) surveys and critiques the large literature on the pollution-haven. The literature is largely empirical in nature. Based on the type of the dependent variable, the survey classifies the literature into three segments: those that explain the location choice of firms, those that analyze the level of production of dirty vs. clean goods, and those that examine the international movement of inputs mainly capital. In this essay, I build a theoretical model and empirically test an approach that addresses the second question: the influence of environmental standards on production pattern.

Levinson and Taylor (2004) use panel data of US trade with Mexico and with Canada in two equations, control for endogeneity of pollution abatement costs and unobserved industry characteristics. They find that industries which faced large increases in abatement cost were also the ones that had a greater increase in import volume indicating that these industries had shifted abroad.

Malatu, Florax and Withagen (2004) provide an empirical investigation of the effect of tighter environmental regulation. They claim that firm characteristics influence the impact of a stricter regulation. They state that output from industries that have lower fixed costs and higher labor intensity are likely to show a stronger impact of stricter regulation. They do not refer to a theoretical framework to validate their claim. My theoretical model shows that while it is true that impact of regulation should differ by industry characteristics, there is a more involved pattern than the simple rule of thumb that they claim. Their empirical result is somewhat mixed. While they find evidence that the impact of regulation varies across industries, the signs on the coefficients are often paradoxical. My paper may be thought of as a further step to find consistent and meaningful differences across industries.

Javorcik and Wei (2004) examine sensitivity of FDI to cross-industry differences in regulatory impact. Using a sample of 143 firms they find that the sign and significance level of the two pollution haven terms present in their estimation models varies across specifications. While the coefficient for host country's environmental stringency is significant and negative, the coefficient on an interaction term of host country stringency with industry level dirtiness is neither significant nor uniformly signed. These results indicate that while FDI is deterred by tight environmental standards, the effect of this for dirty versus clean industries is not different. Hence, their analysis, given the way it has been formulated, does not provide support for the pollution haven hypothesis.

Cole and Elliott (2005) mention factor intensity of dirty industries in their study of outbound FDI from USA. They assume dirty industries are capital intensive and in their regression equation they treat the dirtiness indicator and the capital intensity as two separate variables. They interpret the positive coefficients on the dirtiness indicator and on the capital-intensity variable as evidence for pollution haven effect. While the significant coefficient on dirtiness indicator supports pollution haven hypothesis, the coefficient on capital intensity may arise because capital intensive sectors would attract more capital.

3. THEORETICAL MODEL:

Starting with the basic HOV model, I include pollution and abatement considerations. I find implications of this model using the hat-algebra mathematical technique popularized by Jones (1965) in his mathematical exposition of magnification effects.

I start with a 2X2 HOV framework. The two inputs are capital and labor. The two goods are X, the clean good and Y the dirty good. The production of the dirty good necessitates some abatement effort as dictated by the exogenously given state of environmental stringency. Let A denote the level of abatement activity being undertaken.

Full employment relations:

$K = a_{YK}Y + a_{XK}X + a_{AK}A$ where *a*'s are the input coefficients

$L = a_{YL}Y + a_{XL}X + a_{AL}A$

The environmental strictness policy determines that every unit of Y is to be accompanied by "e" units of abatement activity A. Then A=e*Y. Using this, I rewrite the full employment conditions.

(1) $K = (a_{YK} + e * a_{AK})Y + a_{XK}X$

(2) $L = (a_{YL} + e * a_{AL})Y + a_{XL}X$

In order to sell at the international prices, the producers of Y have to consider the abatement expenditure in addition to the direct production expenditure.

(3) $p = a_{YK}r + a_{YL}w + e(a_{AK}r + a_{AL}w)$

(4) $1 = a_{XK}r + a_{XL}w$ where p is the price of Y relative to X

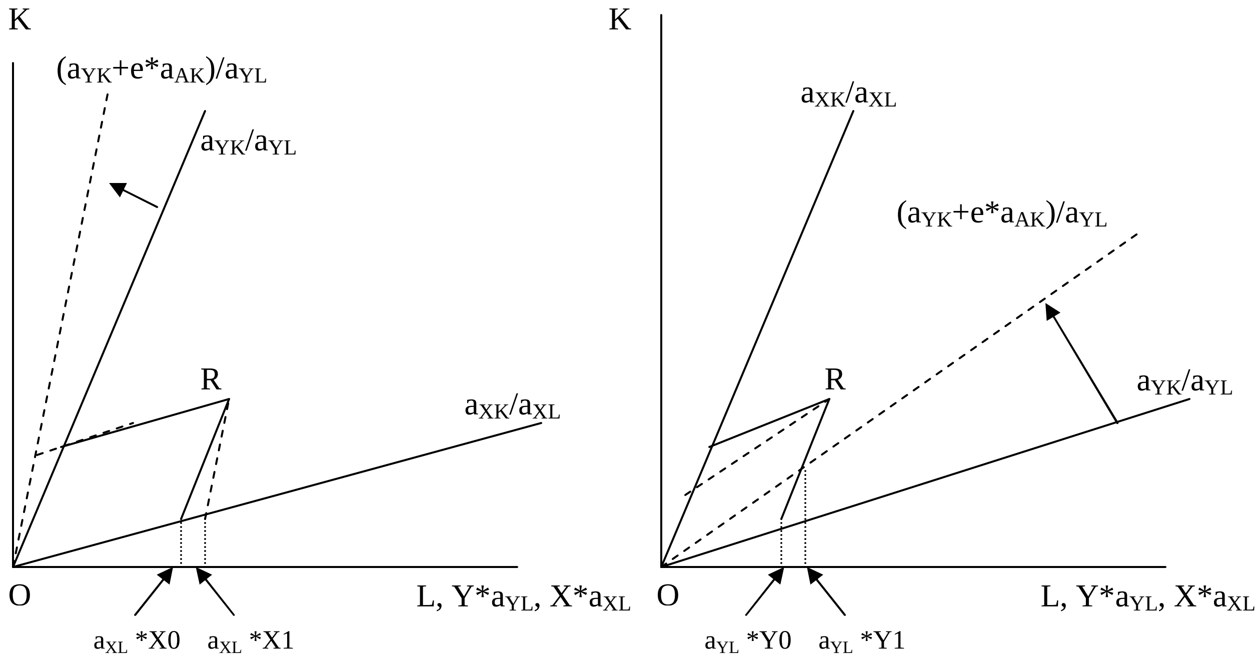

Diagram 3.1: Effect of abatement activity on production, with different factor intensity of abatement activity

In the two panels of Diagram 3.1, R is the endowment point. The dashed line captures the relative factor intensity of the vector sum Y+eA. The diagram depicts the case where the abatement technology A uses only K. The above two panels roughly describe the different cases I am trying to show mathematically.

Panel 1: If the dirty industry Y is more K intensive than X, then stricter abatement results in an increased production of the clean good which also implies a lower production of the dirty good given a fixed endowment of labor.

Panel 2: Instead if the dirty industry Y is more L intensive than X (the rays indicating the production activities X and Y are reversed) then stricter abatement results in increased production of the dirty good and a decreased production of the clean good.

For the purpose of intuitive motivation, several simplifications are embodied in the above diagram. For example the factor prices and hence the production rays before and after abatement are kept unchanged and abatement is assumed to be solely capital using. A mathematical approach allows for a more comprehensive analysis. Equations (1) –(4) above are relevant for the mathematical exposition.

Define input coefficients *b* to be the sum of the production and associated abatement activity input coefficient of Y.

$b_{YK} = (a_{YK} + e * a_{AK})$

$b_{YL} = (a_{YL} + e * a_{AL})$

The equations (1)-(4) are rewritten as:

(1.0) $K = b_{YK} Y + a_{XK} X$

(2.0) $L = b_{YL} Y + a_{XL} X$

(3.0) $p = b_{YK} r + b_{YL} w$

(4.0) $1 = a_{XK} r + a_{XL} w$

Then the percentage-change form equations are identical to the four fundamental equations of HO framework from Jones (1965):

(1.1) $$\lambda_{YL} \hat{Y} + \lambda_{XL} \hat{X} = \hat{L} - \{\lambda_{YL} \hat{b}_{YL} + \lambda_{XL} \hat{a}_{XL}\}$$

(2.1) $$\lambda_{YK} \hat{Y} + \lambda_{XK} \hat{X} = \hat{K} - \{\lambda_{YK} \hat{b}_{YK} + \lambda_{XK} \hat{a}_{XK}\}$$

(3.1) $$\theta_{YL} \hat{w} + \theta_{YK} \hat{r} = \hat{p} - \{\theta_{YL} \hat{b}_{YL} + \theta_{YK} \hat{b}_{YK}\}$$

(4.1) $$\theta_{XL} \hat{w} + \theta_{XK} \hat{r} = -\{\theta_{XL} \hat{a}_{XL} + \theta_{XK} \hat{a}_{XK}\}$$

θ_{ij} is the share of expenditure on j-th input in the i-th sector. λ_{ij} is the share of industry i's use of input j. The $\theta_{ij}, \lambda_{ij}$ in the above equations differ from the standard HOV equations in the sense that the matrices comprise of b_{ij} which are sum of the production abatement coefficients for Y instead of only the production coefficients a_{ij} .

To derive the effect of abatement standards, it becomes important to break the newly defined variables into their underlying components.

$$\hat{b}_{YL} = \frac{db_{YL}}{b_{YL}} = \frac{d(a_{YL} + ea_{AL})}{a_{YL} + ea_{AL}}$$

$$= \frac{(da_{YL} + e * da_{AL}) + a_{AL} * de}{a_{YL} + ea_{AL}}$$

$$= \frac{(da_{YL} + e * da_{AL})}{a_{YL} + ea_{AL}} + \frac{a_{AL} * e}{a_{YL} + ea_{AL}} \frac{de}{e}$$

or, $\hat{b}_{YL} = \hat{\alpha}_{YL} + s_{AL}\hat{e}$

$s_{AL} \equiv \dfrac{e * a_{AL}}{a_{YL} + ea_{AL}}$ is abatement's share in total expenditure on labor for Y

$\hat{\alpha}_{YL}$ reflects the partial change in $\hat{b}_{YL}$ only due to factor price changes and not the part caused by the exogenous $\hat{e}$

Similarly $\hat{b}_{YK} = \hat{\alpha}_{YK} + s_{AK}\hat{e}$ where $s_{AK} \equiv \dfrac{e * a_{AK}}{a_{YK} + ea_{AK}}$

I rewrite equations (3.1) in terms of these components:

(3.1') $$\theta_{YL}\hat{w} + \theta_{YK}\hat{r} = \hat{p} - \{\theta_{YL}(\hat{\alpha}_{YL} + s_{AL}\hat{e}) + \theta_{YK}(\hat{\alpha}_{YK} + s_{AK}\hat{e})\}$$

There is no corresponding version for equation (4.1) as the X industry is a clean sector without any abatement requirements.

The cost minimizing envelope condition ensures that the slope of isocost equals the slope of isoquant.

$$\frac{(da_{YL} + e * da_{AL})}{(da_{YK} + e * da_{AK})} = \frac{-r}{w}$$

or, $\frac{(da_{YL} + e * da_{AL})}{(a_{YL} + e * a_{AL})} \frac{w * (a_{YL} + e * a_{AL})}{p} + \frac{(da_{YK} + e * da_{AK})}{(a_{YK} + e * a_{AK})} \frac{r * (a_{YK} + e * a_{AK})}{p} = 0$

(5.1) $$\theta_{YL} \hat{\alpha}_{YL} + \theta_{YK} \hat{\alpha}_{YK} = 0$$

(6.1) $$\theta_{XL} \hat{a}_{XL} + \theta_{XK} \hat{a}_{XK} = 0$$

I use the cost minimizing conditions (5.1) and (6.1) in equations (3.1') and (4.1), to derive equations (5.2) and (6.2). While (4.1) reduces to the standard form, the exogenous changes $\hat{e}$ do not disappear from the RHS of (3.1').

4. EFFECT ON INPUT PRICES:

To emphasize the effect of change in strictness $\hat{e}$, I abstract from the change in relative prices ($\hat{p}$ =0). This is equivalent to a small-country scenario where any change in production at home does not affect world prices. [20]

(5.2) $$\theta_{YL} \hat{w} + \theta_{YK} \hat{r} = -\{\theta_{YL} s_{AL} + \theta_{YK} s_{AK}\} \hat{e}$$

(6.2) $$\theta_{XL} \hat{w} + \theta_{XK} \hat{r} = 0$$

[20] This assumption is not a necessary part of any of the results and can be brought back in without any complication.

$$\text{or, } \begin{bmatrix} \theta_{YL} & \theta_{YK} \\ \theta_{XL} & \theta_{XK} \end{bmatrix} \begin{bmatrix} \hat{w} \\ \hat{r} \end{bmatrix} = \begin{bmatrix} -\{\theta_{YL} s_{AL} + \theta_{YK} s_{AK}\} \\ 0 \end{bmatrix} \hat{e}$$

The abatement activity causes differences between the factor intensity of production of Y versus the gross input requirement, defined as input required for production as well as abatement for Y. However, I assume that this gross input requirement does not change the factor intensity ranking of Y with respect to X.

(7.1)
$$(\hat{w} - \hat{r}) = \frac{-\{\theta_{YL} s_{AL} + \theta_{YK} s_{AK}\}}{|\theta|} \hat{e}$$

If Y is K intensive, then $|\theta|$ is negative and $(\hat{w} - \hat{r}) > 0$

The changes in the absolute prices are provided in equations (7.2) and (7.3):

(7.2)
$$\hat{w} = \frac{-\theta_{XK} \{\theta_{ZL} s_{AL} + \theta_{ZK} s_{AK}\}}{|\theta|} \hat{e},$$

(7.3)
$$\hat{r} = \frac{\theta_{ZK} \{\theta_{ZL} s_{AL} + \theta_{ZK} s_{AK}\}}{|\theta|} \hat{e}$$

If dirty good Y is K intensive, then $|\theta| < 0$, $\hat{w} > 0$, $\hat{r} < 0$ with increased strictness $\hat{e} > 0$

If dirty good Y is L intensive, then $|\theta| > 0$, $\hat{w} < 0$, $\hat{r} > 0$ with increased strictness $\hat{e} > 0$

These mathematical results illustrate that starting with the original factor prices an increased abatement requirement raises the cost of production of the dirty good. For an unchanged world price p, and the economy still producing both goods, the input prices need to change to accommodate this additional component. If the dirty good is K-intensive, then the price of capital goes down. Simultaneously the price of labor goes up in order to keep the total cost for the labor-intensive clean good unchanged. If the dirty good is L-intensive, then the additional abatement cost requires the price of labor to fall.

The price of capital rises in order for the costs of the clean good to remain equal to the unchanged prices.

In the international trade context with factors immobile across countries, the above factor price changes imply that the factor prices for the physical inputs capital and labor are not equalized across countries. Referring back to the standard H.O.V. model it is easy to identify that this happens because the assumption of identical technology across countries fails here. Although the production technology for X,Y and abatement is assumed to be the same, the cost of production of Y is essentially a weighted sum of the direct production cost of Y and the indirect abatement cost. Since the weights vary across countries based on the exogenous environmental standards, the overall production technique for Y is different across countries.

Comparing with the Kenen-Conway concept of “improved endowment” (see Conway 1997), the current model has an almost parallel concept of “effective endowment” which is defined as the amount of endowments effectively available for actual production purposes. Hence subtracting out the endowments used for abatement use from the total physical endowments defines the effective endowments.

To make the point clear, let us use the following matrix notations:

X: production vector

V: physical endowment vector

VS: effective endowment vector

P: vector of price of final goods

H: Technology matrix of producing the final goods

A: vector of the quantities of the two inputs used for abatement purposes

WS: Vector of the prices of the effective endowments

In this scenario, the vector of prices of the effective endowments (WS) is the same as the vector of prices (W) of the physical endowments. VS=V-eAX where e denotes the level of strictness and HX=VS

The parallel result that the prices of the effective endowments are equalized does not follow through here because unlike the Kenen model where the third commodity is non-traded good, in this model the abatement activity is embodied in the traded dirty good. This is similar to difference in production technology across two countries being embodied in the cost of producing a same homogenous good. So the price of Y must cover the cost of the entire bundle.

$H^T W \neq P$

Instead $(H+eA)^T W=P$

This re-emphasizes the fact that a difference in the technology of production drives the difference in input prices.

5. CHANGE IN PRODUCTION:

The elasticity of substitution between labor and capital in the X and Y sector is defined as in the Jones derivation.

$$\sigma_X = \frac{\hat{a}_{XK} - \hat{a}_{XL}}{\hat{w} - \hat{r}}; \sigma_Y = \frac{\hat{\alpha}_{YK} - \hat{\alpha}_{YL}}{\hat{w} - \hat{r}}$$

Change in output from equations (1.1) and (2.1):

(8.1)
$$\begin{bmatrix} \lambda_{YL} & \lambda_{XL} \\ \lambda_{YK} & \lambda_{XK} \end{bmatrix} \begin{bmatrix} \hat{Y} \\ \hat{X} \end{bmatrix} = \begin{bmatrix} \hat{L} - (\lambda_{YL}\hat{b}_{YL} + \lambda_{XL}\hat{a}_{XL}) \\ \hat{K} - (\lambda_{YK}\hat{b}_{YK} + \lambda_{XK}\hat{a}_{XK}) \end{bmatrix}$$

The change in input requirement coefficient for the dirty industry Y is broken into the change in input requirement for production and for abatement.

$$\text{or,} \quad \begin{bmatrix} \lambda_{YL} & \lambda_{XL} \\ \lambda_{YK} & \lambda_{XK} \end{bmatrix} \begin{bmatrix} \hat{Y} \\ \hat{X} \end{bmatrix} = \begin{bmatrix} \hat{L} - \{\lambda_{YL} (\hat{\alpha}_{YL} + s_{AL} \hat{e}) + \lambda_{XL} \hat{a}_{XL}\} \\ \hat{K} - \{\lambda_{YK} (\hat{\alpha}_{YK} + s_{AK} \hat{e}) + \lambda_{XK} \hat{a}_{XK}\} \end{bmatrix}$$

$$\text{or,} \quad \begin{bmatrix} \lambda_{YL} & \lambda_{XL} \\ \lambda_{YK} & \lambda_{XK} \end{bmatrix} \begin{bmatrix} \hat{Y} \\ \hat{X} \end{bmatrix} = \begin{bmatrix} \hat{L} - (\lambda_{YL} \hat{\alpha}_{YL} + \lambda_{XL} \hat{a}_{XL}) - \lambda_{YL} s_{AL} \hat{e} \\ \hat{K} - (\lambda_{YK} \hat{\alpha}_{YK} + \lambda_{XK} \hat{a}_{XK}) - \lambda_{YK} s_{AK} \hat{e} \end{bmatrix}$$

The elasticity of substitution of the inputs allows me to substitute the change in input coefficients as functions of the input prices.

$$\text{(8.2)} \quad \begin{bmatrix} \lambda_{YL} & \lambda_{XL} \\ \lambda_{YK} & \lambda_{XK} \end{bmatrix} \begin{bmatrix} \hat{Y} \\ \hat{X} \end{bmatrix} = \begin{bmatrix} \hat{L} + \delta_L (\hat{w} - \hat{r}) - \lambda_{YL} s_{AL} \hat{e} \\ \hat{K} - \delta_K (\hat{w} - \hat{r}) - \lambda_{YK} s_{AK} \hat{e} \end{bmatrix}$$

$\delta_L \equiv \lambda_{LX} \theta_{KX} \sigma_X + \lambda_{LY} \theta_{KY} \sigma_Y$ and $\delta_K \equiv \lambda_{KX} \theta_{LX} \sigma_X + \lambda_{KY} \theta_{LY} \sigma_Y$ are the percent savings in factor use associated with one percent rise in relative factor price

Assuming fixed endowments, the above system reduces to (8.3).

$$\text{(8.3)} \quad \begin{bmatrix} \lambda_{YL} & \lambda_{XL} \\ \lambda_{YK} & \lambda_{XK} \end{bmatrix} \begin{bmatrix} \hat{Y} \\ \hat{X} \end{bmatrix} = \begin{bmatrix} \delta_L (\hat{w} - \hat{r}) - \lambda_{YL} s_{AL} \hat{e} \\ -\delta_K (\hat{w} - \hat{r}) - \lambda_{YK} s_{AK} \hat{e} \end{bmatrix}$$

I consider the change in relative production due to a change in abatement strictness in an economy.

$$\text{(9.1)} \quad (\hat{Y} - \hat{X}) = [\frac{(\lambda_{YK} s_{AK} - \lambda_{YL} s_{AL})}{|\lambda|} \hat{e} + \frac{(\delta_L + \delta_K)}{|\lambda|} (\hat{w} - \hat{r})]$$

To get an expression of the relative change in outputs solely as a function of the change in abatement strictness $\hat{e}$, I substitute out $(\hat{w}-\hat{r})$ in terms of $\hat{e}$ using equation (7.1):

(9.2) $$(\hat{Y}-\hat{X}) = [\frac{(\lambda_{YK}s_{AK} - \lambda_{YL}s_{AL})}{|\lambda|} - \sigma_S(\theta_{YL}s_{AL} + \theta_{YK}s_{AK})]\hat{e}$$

where $\sigma_S \equiv \frac{(\delta_L + \delta_K)}{|\lambda||\theta|}$.

The determinants $|\lambda|$ and $|\theta|$ have the same sign always, whether positive or negative. This implies $\sigma_S > 0$. Hence the second term is always negative. This implies that irrespective of the factor intensities of productions, an increase in strictness has a tendency to affect input prices which in turn indirectly increases the production of the clean good X relative to the production of the dirty good Y. This conforms to the traditional pollution haven production effect.

For example, if the dirty industry is K-intensive, we know from equations (7.2) and (7.3) that stricter abatement requirements will reduce the price of capital and increase the wage rate. This provides incentives to producers in both industries to move towards the cheaper capital and free up labor. This would encourage the production of the labor-intensive good which in this instance is the clean good and a reduction of the capital-intensive dirty good. On the other hand if the dirty industry is labor-intensive equations (7.2) and (7.3) indicate that the additional abatement requirement will reduce the wage rate and increase the price of capital. This provides incentive to producers in both industries to move towards the cheaper labor and free up capital. This in turn would encourage the production of the K-intensive good which in this case is the clean good and a reduction of the labor intensive dirty good. So in both cases we see that the change in input prices always encourages a decline in the production of the dirty good thus bolstering the traditional pollution haven type of outcome.

Now let us turn our attention to the first right-hand term in equation (9.2). If Y is K intensive then $|\lambda|$<0. The first term will be positive if:

$$\lambda_{YL} s_{AL} > \lambda_{YK} s_{AK}$$

or, $$\frac{Y * b_{YL}}{L} \frac{e * a_{AL}}{b_{YL}} > \frac{Y * b_{ZK}}{K} \frac{e * a_{AK}}{b_{YK}}$$

or, $$\frac{a_{AK}}{a_{AL}} < \frac{K}{L}$$

Thus, when the dirty good Y is K-intensive relative to the clean good X, if the K-intensity of the abatement activity is less(greater) than the overall K-abundance of the economy an increase in strictness will directly favor(deter) the relative production of the K-intensive dirty good. Alternately when the dirty good Y is L-intensive relative to the clean good X, if the K-intensity of the abatement activity is less(greater) than the overall K-abundance of the economy an increase in strictness will directly deter (favor) the relative production of the K-intensive dirty good. So we see that in two cases out of four, the direction of change in pattern of production is opposite to the traditionally held prediction- an increase in the abatement level in an economy may increase the share of the dirty good in the production.

Starting with the system (8.3) I now look at the absolute levels of production instead of the relative levels of production:

(10.1)
$$\hat{Y} = \frac{1}{|\lambda|}\begin{vmatrix} -\lambda_{YL}s_{AL} - \delta_L(\hat{w}-\hat{r}) & \lambda_{XL} \\ -\lambda_{YK}s_{AK} + \delta_K(\hat{w}-\hat{r}) & \lambda_{XK} \end{vmatrix}\hat{e}$$

(11.1)
$$\hat{X} = \frac{1}{|\lambda|}\begin{vmatrix} \lambda_{YL} & -\lambda_{YL}s_{AL} - \delta_L(\hat{w}-\hat{r}) \\ \lambda_{YK} & -\lambda_{YK}s_{AK} + \delta_K(\hat{w}-\hat{r}) \end{vmatrix}\hat{e}$$

To get a clearer idea of the above expressions, let us start with the effect on outputs in the absence of effects of factor price changes.

(12.1)
$$\hat{Y} = \frac{1}{|\lambda|}(\lambda_{YK}s_{AK} * \lambda_{XL} - \lambda_{YL}s_{AL} * \lambda_{XK})\hat{e}$$

(13.1)
$$\hat{X} = \frac{1}{|\lambda|}\lambda_{YL}\lambda_{YK}(s_{AL} - s_{AK})\hat{e}$$

On simplifying the expressions within the brackets, I find that if Y is relatively K intensive i.e., $|\lambda|$<0 then $\partial Y > 0$ *if* $\frac{a_{AK}}{a_{AL}} < \frac{a_{XK}}{a_{XL}}$; $\partial X > 0$ *if* $\frac{a_{AK}}{a_{AL}} > \frac{a_{YK}}{a_{YL}}$

Case 1: The abatement activity is more K intensive than Y, ie $\frac{a_{AK}}{a_{AL}} > \frac{a_{YK}}{a_{YL}} > \frac{a_{XK}}{a_{XL}}$

Outcome: $\partial X > 0, \partial Y < 0$ → The traditionally expected pollution haven result

Case 2: The abatement activity is less K intensive than X, ie $\frac{a_{YK}}{a_{YL}} > \frac{a_{XK}}{a_{XL}} > \frac{a_{AK}}{a_{AL}}$

Outcome: $\partial X < 0, \partial Y > 0$ → Opposite to the traditionally expected pollution haven result

Case 3: The K intensity of abatement activity is between that of Y and X, ie $\frac{a_{YK}}{a_{YL}} > \frac{a_{AK}}{a_{AL}} > \frac{a_{XK}}{a_{XL}}$

Outcome: $\partial X < 0, \partial Y < 0$

Next consider Y being relatively L intensive, i.e., $|\lambda|>0$. Then $\frac{a_{XK}}{a_{XL}} > \frac{a_{YK}}{a_{YL}} > \frac{a_{AK}}{a_{AL}}$ provides a traditional pollution haven direction of production change while $\frac{a_{AK}}{a_{AL}} > \frac{a_{XK}}{a_{XL}} > \frac{a_{YK}}{a_{YL}}$ moves the production in direction opposite to traditional pollution haven expectations i.e., toward a higher relative production of the dirty good.

To visualize the above results using real trade outcomes we can think of a labor abundant country that uses dirty technology in its export sector to compete in the world market. Suppose this country makes its abatement requirements stricter and the abatement investment requires mainly capital in the form of end-of-pipe abatement methods. This would make the scarce capital endowment even scarcer under the assumption of internationally immobile inputs, increasing the production of labor intensive dirty good in a Rybczynski type of effect. This would show up in the data as an apparent contradiction to the pollution haven expectation.

Expressions (10.2) and (11.2) are expressions for production change where the input price change has been incorporated.

$$(10.2)\ \hat{Y} = [\frac{1}{|\lambda|}\{\lambda_{XL} * \lambda_{YK} s_{AK} - \lambda_{XK} * \lambda_{YL} s_{AL}\} - \frac{1}{|\lambda||\theta|}\{(\theta_{YL} s_{AL} + \theta_{YK} s_{AK})(\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)\}]\,\hat{e}$$

$$(11.2)\ \hat{X} = [\frac{1}{|\lambda|}\{\lambda_{YK} * \lambda_{YL} s_{AL} - \lambda_{YL} * \lambda_{YK} s_{AK}\} + \frac{1}{|\lambda||\theta|}\{(\theta_{YL} s_{AL} + \theta_{YK} s_{AK})(\lambda_{YK}\delta_L + \lambda_{YL}\delta_K)\}]\,\hat{e}$$

Comparison of (10.2) with (12.1) shows that the second term on the right hand side reflects that changes in factor price further tend to decrease the production of the dirty good Y while comparison of (11.2) with (13.1) shows that changes in factor prices encourage an increase in X production, irrespective of the relative factor intensities of the two commodities. When the dirty industry and the abatement activity are intensive in the same input relative to the clean sector, the effective endowment effect strengthens the effect of the factor price movement, leading to the traditional pollution haven type of outcome. When the dirty industry and abatement activity have opposite factor intensities relative to the clean sector, the effective endowment effect opposes the effect of the factor price movement. The relative strength of the two effects determines whether the net effect will be consistent or opposite of the traditional pollution haven expectation.

The above analysis with mobile inputs demonstrates a reason why the pollution haven hypothesis has been difficult to justify. If the dirty exports of an economy are labor intensive in nature, then an increased environmental strictness, where abatement is largely capital intensive, could be reflected as the dirty industries contributing to a larger share of trade volume if the effective endowment effect dominates. The above analysis shows how such an outcome can be explained using standard theoretical tools.

6. NEGATIVE AGGREGATE INCOME EFFECT:

Although depending on the factor intensities, stricter abatement standard increases or decreases the production of dirty and clean goods, it should be unambiguous for a small economy that the aggregate income of the economy should go down as it chooses to move to the stronger abatement requirement. I check below whether this is true for the model.

$$dI = \hat{X} * X + p * \hat{Y} * Y$$

or, $dI = \hat{X}\{Yp * \frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}} \frac{|\lambda|}{|\theta|}\} + \hat{Y} * Yp$

The expressions for change in quantities from (10.2) and (11.2) are substituted into the change in income expression.

$$dI = \hat{e}Yp$$

$$[\{\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}}\frac{|\lambda|}{|\theta|}\}[\frac{1}{|\lambda|}\{\lambda_{YK}*\lambda_{YL}s_{AL}-\lambda_{YL}*\lambda_{YK}s_{AK}\}+\frac{\hat{1}}{|\lambda||\theta|}\{(\theta_{YL}s_{AL}+\theta_{YK}s_{AK})(\lambda_{YK}\delta_L+\lambda_{YL}\delta_K)\}]$$

$$+[\frac{1}{|\lambda|}\{\lambda_{XL}*\lambda_{YK}s_{AK}-\lambda_{XK}*\lambda_{YL}s_{AL}\}-\frac{1}{|\lambda||\theta|}\{(\theta_{YL}s_{AL}+\theta_{YK}s_{AK})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)\}]]$$

To find results from the above expression, I look at the effect of input-price change and the effect of effective-endowment-change, on income, separately.

Effect of environmental-strictness induced change in factor prices:

$$dI|_{input-price} = \hat{e}Yp\frac{1}{|\lambda||\theta|}*$$

$$[\{(\theta_{YL}s_{AL}+\theta_{YK}s_{AK})(\lambda_{YK}\delta_L+\lambda_{YL}\delta_K)\}\{\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}}\frac{|\lambda|}{|\theta|}\}-\{(\theta_{YL}s_{AL}+\theta_{YK}s_{AK})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)\}]$$

The right hand side of the above expression simplifies to zero[21]. This means that change in input prices does not have a net effect on aggregate income of the economy.

Reduction in effective endowments caused by stricter abatement standard, even in the absence of factor price changes, should be sufficient to reduce aggregate income. So I evaluate the change in income caused by effective endowment change terms.

$$dI|_{eff-endow} = \hat{e}Yp*\frac{1}{|\lambda|}[\{\lambda_{ZK}*\lambda_{ZL}s_{AL}-\lambda_{ZL}*\lambda_{ZK}s_{AK}\}\{\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}}\frac{|\lambda|}{|\theta|}\}+\{\lambda_{XL}*\lambda_{ZK}s_{AK}-\lambda_{XK}*\lambda_{ZL}s_{AL}\}]$$

The next logical step is to realize that the aggregate income should be reduced whether the abatement technology is only labor using, only capital using, or uses both. So I

[21] Please refer to appendix 3 for calculations

examine the change in effective-labor (i.e. coefficient on s_{AL}) and effective-capital endowment (i.e. coefficient on s_{AK}) terms separately. I find that aggregate income goes down whether abatement is capital-using or labor-using or both. Appendix 3 is devoted to the derivation and simplification of these results.

The above results show that change in effect endowments due to stricter abatement results in a net decline in aggregate income while the changes in factor prices influence the production of the dirty and clean sectors but they do not have any net effect on aggregate income.

7. EFFECT ON TRADE PATTERN:

If both consumption goods are normal goods, then the decline in aggregate income of the economy implies a reduced demand for both commodities. For the commodity that experiences an increased production and a reduced demand, the net exports will rise (or the net imports will fall if the commodity is an import commodity). The commodity that experiences a decrease both in production and consumption, experiences a greater decline in production compared to the decline in consumption. This results in larger import demand (or a smaller export supply).

8. TERMS OF TRADE EFFECT FOR A LARGE COUNTRY:

Given the altered demands by the economy in the world market as explained above, the trade prices would be affected if the economy is a large country. This is similar to the transfer problem where a country by transferring a part of its income, may face an improvement or deterioration of its terms of trade. In the current stricter-abatement scenario, the income of the economy declines not because it transfers its income but because it uses a part of its endowments for clean-up purposes.

When the production-change equation (10.2) and (11.2) predict that $\hat{X} > 0, \hat{Y} < 0$ in conformation with the traditional pollution haven prediction, then the income and trade changes as described in section 7 imply $\hat{p} > 0$.

Similarly when $\hat{X} < 0, \hat{Y} > 0$ in contradiction to the traditional pollution haven prediction, then $\hat{p} < 0$.

If both $\hat{X} < 0, \hat{Y} < 0$ then $\hat{p}$ >0 if decline in net demand for X is greater than decline in net demand for Y, i.e., (dI*$mpc_{|X}$ –dX) < (dI*$mpc_{|Y}$ –dY)

When $\hat{p} \neq 0$, the equation (3.1) retains its entire form $\theta_{YL}\hat{w} + \theta_{YK}\hat{r} = \hat{p} - \{\theta_{YL}\hat{b}_{YL} + \theta_{YK}\hat{b}_{YK}\}$. The price change term shows up in the factor-price-change equations

$$\begin{bmatrix} \theta_{YL} & \theta_{YK} \\ \theta_{XL} & \theta_{XK} \end{bmatrix} \begin{bmatrix} \hat{w} \\ \hat{r} \end{bmatrix} = \begin{bmatrix} -\{\theta_{YL}s_{AL} + \theta_{YK}s_{AK}\} \\ 0 \end{bmatrix} \hat{e} + \begin{bmatrix} \hat{p} \\ 0 \end{bmatrix}$$

and consequently in the change in production equations (10.1) and (11.1)

9. WASTE TRADING:

If the economy can trade waste, then an analysis of the factor intensities of the abatement process becomes redundant. Dirty industries sell wastes at a per-unit cost 'c' to the producers in that sector. Then the only difference between the current model and the HOV model would be that the returns to producers in the dirty Y sector would be 'p-c' instead of 'p'.

$$K = a_{YK} Y + a_{XK} X$$

$$L = a_{YL} Y + a_{XL} X$$

$$p - c = a_{YK} r + a_{YL} w$$

$$1 = a_{XK} r + a_{XL} w$$

The rest of the derivation of the model would be similar to the standard HOV model with the only difference of having to carry ‘p-c’ around instead of ‘p’. A movement to stricter standard would entail a larger cost ‘c’ which is similar to a lowering of net price. As effective endowments are unaffected, forces that drove the earlier results opposite to the traditional pollution haven expectations are absent. When the economy moves to a stricter regime, the net price received in the dirty sector goes down, leading to an effect similar to world prices going down in the HOV setup. The altered version for equation (9.2) is given by:

$$(\hat{Y} - \hat{X}) = [\sigma_S (\hat{p} - c)] \text{ where } \sigma_S \equiv \frac{(\delta_L + \delta_K)}{|\lambda||\theta|}$$

If world prices are unchanged $\hat{p} = 0$ and amount of pollutants goes up as the economy moves to the stricter regime, then the expression for change in relative production is given below.

$$(\hat{Y} - \hat{X}) = \sigma_S (-c\hat{e})$$

When the economy moves to a stricter regime, the cost for the dirty sector of selling its wastes goes up, reducing the relative production of the good as expected by the traditional pollution haven hypothesis. In the exceptional case where an economy can dump its pollutant in another economy without having to pay the destination economy any compensation, the movement to stricter environmental regime has no effect on cost and hence on production. The only result would be a larger volume of wastes dumped in the destination economy.

10. THEORY TO HYPOTHESES:

Having used the mobile-factors general equilibrium model to illustrate the nature of underlying forces, it is nevertheless important to realize that the real trade consists of more than the simple two good model and that inputs are completely mobile only in the long run. The N goods cases can be motivated by the use of a specific factor model which recognizes that in the short term, all factors are not perfectly mobile across industries. I assume that capital K_i in each sector is fixed in the short run and is the industry specific input. Labor L_i is assumed to be mobile across industries. This N good, N+1 factor model is more relevant for formulating empirically testable hypothesis.

Jones(1975) provides the mathematical framework for the N good, N+1 factor framework. I visualize the N-1 sectors as being dirty and the N-th sector as the clean X sector. I do not restrict the changes in capital endowments to equal zero. However, I assume that current capital stock change decisions are pre-determined variables.

$$X = \frac{K_X}{a_{KX}}$$

$$\text{or, } \hat{X} = \hat{K}_X - \hat{a}_{KX}$$

$$Y_i = \frac{K_i}{b_{Ki}}$$

$$\text{or, } \hat{Y}_i = \hat{K}_i - \hat{b}_{Ki} = \hat{K}_i - (\hat{\alpha}_{Ki} + \hat{e}_{Ki})$$

$\hat{e}_{Ki}$ is the change in capital used for abatement activity, per unit of output. Straightforward generalization of the 2X2 model would assert that abatement capital in all sectors goes up by the same proportion $\hat{e}$ of the sectoral abatement capital share s_{KAi} which remains unchanged before and after change in policy. This is too restrictive an assumption, necessitating the above more general approach.

$$\hat{Y}_i - \hat{X} = \hat{a}_{KX} - \hat{\alpha}_{Ki} + \hat{K}_i - \hat{K}_X - \hat{e}_{Ki} \quad (14.1)$$

The percentage change form of the price equation (15.1) takes a form similar to equation (5.2) from the 2X2 model. The only difference is that similar to change in abatement capital, change in abatement expenditure $\hat{e}_i$ across sectors is not restricted to be proportional $\hat{e}$ to pre-policy abatement expenditure s_i.

$$\theta_{Li}\hat{W}_i + \theta_{Ki}\hat{r}_i = \hat{p}_i - \hat{e}_i \quad (15.1)$$

Derivation of equation (15.1) makes use of the tangency of isocost and isoquant condition (15.2) identical to equation (5.1) in the 2X2 setup.

$$\theta_{Li}\hat{\alpha}_{Li} + \theta_{Ki}\hat{\alpha}_{Ki} = 0 \quad (15.2)$$

The elasticity of labor's marginal productivity curve in each industry is defined as

$$\gamma_{LX} = \frac{\hat{a}_{LX} - \hat{a}_{KX}}{\hat{W}_X - \hat{p}_X}, \; \gamma_{Li} = \frac{\hat{\alpha}_{Li} - \hat{\alpha}_{Ki}}{\hat{W}_i - (\hat{p}_i - \hat{e}_i)}$$

Explicit expressions for changes in the specific factor coefficients $\hat{a}_{KX}$ and $\hat{\alpha}_{Ki}$ are derived in the manner similar to the 2X2 model by eliminating $\hat{\alpha}_{Li}$ and $\hat{\alpha}_{LX}$ with the use of elasticities γ's.

(15.3) $$\hat{a}_{KX} = \gamma_{LX}\theta_{LX}(\hat{W}_X - \hat{p}_X)\,;\ \hat{\alpha}_{Ki} = \gamma_{Li}\theta_{Li}(\hat{W}_i - \hat{p}_i - \hat{e}_i)$$

Substituting (15.3) into (14.1) I get (14.2).

(14.2) $$\hat{Y}_i - \hat{X} = \gamma_{LX}\theta_{LX}(\hat{W}_X - \hat{p}_X) - \gamma_{Li}\theta_{Li}(\hat{W}_i - \hat{p}_i + \hat{e}_i) + \hat{K}_i - \hat{K}_X - \hat{e}_{KAi}$$

The different wage rates prevailing in different industries can be explained as every industry having a specific skill requirement of its workers. This skill is assumed to be industry specific and not transferable across industries. The demand for skill is exogenous to the model and depends on the technology of the industry. The workers in each industry are paid a premium for their skill. For example, if the chemical industry requires a chemical engineer, then while a decrease in wages might increase the demand for chemical engineers, the skill required of every engineer remains unchanged.

$$\Gamma_i = L_i * l_i$$

where L_i is the physical amount of labor, l_i is the skill level and Γ_i is the effective labor.

$W_i = w * w_i$

W_i is the actual wage rate paid to the workers. It comprises of two parts: w that reflects the payment to unskilled homogenous component, and w_i which are the mark-ups of the sector-specific wage.

The prevailing technology determines the demand for skill l_i. Hence w_i is determined by the supply of the skill. This supply depends on schooling and training, and hence like capital stock, is assumed to be predetermined. So while making a production decision, the producers take the skill premium they would have to pay (w_i) as given.

(14.3)

$$\hat{Y}_i - \hat{X} = \hat{w}(\gamma_{LX}\theta_{LX} - \gamma_{Li}\theta_{Li}) - \gamma_{LX}\theta_{LX}(\hat{p}_X - \hat{w}_X) + \gamma_{Li}\theta_{Li}(\hat{p}_i - \hat{w}_i - \hat{e}_i) - \hat{e}_{Ki} + \hat{K}_i - \hat{K}_X$$

In equation (14.3) $\hat{e}_{KAi}$ is the effective endowment effect similar to the 2X2 model. It says that if abatement is capital using, where capital stock is predetermined and sector-specific then an increase of environmental strictness reduces the effective amount of specific capital and hence production. Unlike in the 2X2 model, change in effective endowments does not lead to any unexpected results. As capital is sector specific, a decrease in effective endowment of capital has an unambiguous tendency to reduce the output of the sector.

The other term involving the abatement effect $\hat{e}_i$ in equation (14.3) again has factor intensity coefficient θ_{Li} attached to it. This term indicates that for a given elasticity of marginal productivity of labor and for a given change of sector level abatement expenditure, production in a labor-intensive sector will decline more in response to increase in environmental strictness compared to a specific-capital-intensive good. This happens because the capital-intensive good has a lower flexibility in responding to changes in policy that increase the marginal cost.

The first right-hand term in equation (14.3) is similar to the factor-price effect seen in the 2X2 model. This term involving price and wages reveal that while a given increase in wages will have a greater negative impact on sectors more dependant on labor, an equal increase in price will favor production in the labor intensive commodity as it has greater flexibility to respond.

By estimating equation (14.3) I plan to examine the impact of the US Clean Air amendment of 1990. By comparing domestic production before and after 1990, I test whether the pollution haven effect, in the new form that I have identified, was important in changing the production and hence trade pattern of the USA.

11. DATA AND ESTIMATION:

I consider a difference-in-difference approach to test the impact of Clean Air Act of 1990 using equation (14.3). I omit 1990-1991 as years of adjustment. 1988-1989 comprise my "before" and 1992-1993 comprise my "after" time periods. I use the NBER productivity database for quantities and prices of outputs and inputs at the SIC-4 digit level and the expenditure to abate air pollution, at SIC-4 level from U.S. Census Bureau's Current Industrial Reports: Pollution Abatement Costs and Expenditures, MA-200. In my exercise, the control group is those industries that have zero emission coefficient. Corrugated and solid fiber boxes (SIC- 2653) is taken as a representative of the clean sector due to smallest air emission per unit of production over several years The treatment group are those industries that have any positive emissions level.

Before is time period before 1990 Clean Air amendment.

After is the analysis period after 1990.

I take an average of the variables over two year 1988-1989 to define the "before" observation and an average over the two years 1992-1993 to define the "after" observation to smooth out year specific aberrations.

Regression is done in logs of the variables due the percentage form of the theoretical derivation. The terms in the regression results are interpreted with reference to the theoretical equation (14.3). The regressors are:

Price_effect: $\gamma_{Li}\theta_{Li}(\hat{p}_i - \hat{w}_i)$, Capital: $\hat{K}_i$, Eff_endow effect: $\hat{e}_{KAi}$, Interaction: $\gamma_{Li}\theta_{Li}\hat{e}_i$

Since not all dirty goods are traded, I identified traded goods using U.S. multilateral trade data.. Among 411 SICs at the 4 digit level for the year 1987, this process eliminated 63 SICs leaving the analysis with 348 SICs. The analysis based on these 348 SICs lead to very similar results to the complete sample. These results are presented on the third column of the table. As suggested by the theory, equality of coefficients is imposed for the price effect and interaction effect.

	No interaction term	With interaction term	Remove non traded SIC
Price_effect	0.181* (2.97)	0.182* (2.98)	0.162* (2.57)
Capital	0.5* (5.46)	0.5* (5.46)	0.54* (5.72)
Eff_endow	-0.025** (-1.90)	-0.025** (-1.90)	-0.023** (-1.73)
Interaction		-0.182* (-2.98)	-0.162* (-2.57)
Constant	0.020** (1.68)	0.021** (1.67)	0.012 (0.93)

* Significant at 5%, ** Significant at 10%

Table 3.1: Effect of environmental policy change on U.S. Domestic production SIC-4 for years 1988-89, 1992

The regression coefficients show the expected signs. The price effect has a positive effect on production of all industries. A one percent increase in price net of wage payments would increase production by 0.18% in an industry whose share of payments to labor equals one. However, given that the average labor share θ_{Li} is 0.11 across sectors, a one percent increase in price net of wage payments would increase production by 0.02% in the average industry. Capital stock had a positive effect on production of all industries with a 1% increase in sector specific capital stock increasing the quantity of production by approximately 0.5%. Dirtier industries requiring sector-specific investments show a reduction in production of 0.025% for every percentage point increase in abatement expenditure. This term is not significant at the 5% level, but is at the 10% level. The abatement expenditure and labor intensity interaction term again predicts that a 1% increase in abatement costs would decrease production by 0.02% in the average industry.

The traditional pollution haven hypothesis would consider the decreased production due to increased sector specific abatement investment cost as captured through the effective endowment effect. This would be found to be 0.025% and also not significant at the 5% level. Viewed in this way, pollution haven effect remains elusive. However, the highly significant coefficient on the interaction term adds another 0.02% reduction in production for every percent increase in abatement expenditure. The pollution-haven effect, in this modified guise, has a tangible effect of the 1990 Clean Air Amendment of USA.

In the absence of a-priori information about the elasticity of marginal product of labor in each sector, the elasticities have been assumed to be same for all sectors. The percentage change in capital expenditure for abatement has been approximated by the percentage change in overall abatement expenditure in each sector[22].

12. CONCLUSION:

The 2X2 theoretical model provides some interesting results regarding the pollution haven predictions. Depending on the factor-intensities of production and abatement, a stricter environmental regime may, in certain situations, favor the production of the dirty commodity which is unexpected in the traditional pollution haven hypothesis. For example, if a country specializes in dirty labor intensive commodities, and if abatement technology is capital intensive, then a tighter environmental standard would make capital scarcer, encouraging the production of the labor intensive dirty commodity.

While the above theoretical result is indicative of production patterns, a generalization to the N-commodity scenario provides results that depend on the relative importance of more-mobile and less-mobile inputs in the production of the various sectors. Dirtiness of sectors is not the only important determinant of the negative impact of a stricter environmental regime as is believed. For production in industries that are equally dirty, one that uses the mobile input more intensely will show the impact more strongly. This theoretical result is tested using US abatement expenditure and production data. The coefficient on this factor-intensity dependent pollution haven term is significant. This makes the total effect of a stricter environmental regime on dirty industries much larger than what is seen using only the traditional dirtiness indicator of

[22] The capital expenditure data are not very indicative of year specific inducements and abatement capital is often difficult to separate from production capital. For more detail refer to Levinson and Taylor 2004.

industries.

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APPENDIX 1A: COPELAND AND TAYLOR'S TECHNIQUE OF COMBINING PRODUCTION OF OUTPUT AND PRODUCTION OF EMISSIONS INTO A COBB-DOUGLAS FORM

In the absence of any abatement activity $Y=K^s$, $Z= K$

If θ is the fraction of resources spent for abatement activity, then the abatement technology is represented by the function $(1-\theta)^{1/\alpha}$

$\alpha<1$ implies increasing returns to scale abatement technology.

Output level with abatement activity: $Y=\{(1- \theta)K\}^s$

Emission level after abatement activity: $Z=(1-\theta)^{1/\alpha}K$

Elimination of θ between the above two production functions results in the Cobb Douglas form of production relation. $Y=Z^{\alpha s} K^{s- \alpha s}$

Note that for $\theta=0$, $Z=K>Y$

APPENDIX 1B: METHOD OF LINEARIZATION AND GETTING ON TO THE SADDLE PATH

The two variable two equation system demonstrates the technique used for the actual 7X7 system.

The system of difference equations is written in the following format.

$$A^* \begin{pmatrix} K_{t+1} \\ C_{t+1} \end{pmatrix} = D^* \begin{pmatrix} K_t \\ C_t \end{pmatrix}$$

The variables C_t and K_t may either be in levels or in deviations from mean format (obtained by Taylor approximation for a non-linear system).

$$\text{Or} \quad \begin{pmatrix} K_{t+1} \\ C_{t+1} \end{pmatrix} = A^{-1}D^* \begin{pmatrix} K_t \\ C_t \end{pmatrix}$$

The eigenvalues r_1 and r_2 for the system may be found as:

$$\text{Det } |A^{-1}D - r\, I| = 0$$

In case of a system with saddle path stability, one of the roots (say r_1) will be greater than one and the other (r_2) less than one.

The eigenvectors corresponding to the eigenvalues are found as:

$$(A^{-1}D - r\, I) * \begin{pmatrix} m \\ n \end{pmatrix} = 0$$

Let $(m_1 \;\; n_1)^T$ be the eigenvector corresponding to the root r_1 and $(m_2 \;\; n_2)^T$ be the eigenvector corresponding to r_2. (It is known, and has been verified, that $m_i = s_i n_i$ where s_i can be determined as a function of the elements of the matrix $A^{-1}D$ and the particular eigenvalue r_i)

The solution of a difference equation system of the above form is then given by:

$$\begin{pmatrix} K_t \\ C_t \end{pmatrix} = \begin{pmatrix} m_1 r_1^t + m_2 r_2^t \\ n_1 r_1^t + n_2 r_2^t \end{pmatrix}$$

For the system not to explode, m_1 and n_1 have to have zero coefficients.Then given that s_2 and r_2 are known from previous calculations, use of the initial conditions provides the value of n_2

$K_0 = m_2 r_2 = s_2 n_2 r_2$; $C_0 = n_2 r_2$

As a side-note, one can see the relation of the dynamics of the saddle path as a function of the stable eigenvalue:

$K_t = m_2 r_2^t$

$K_{t+1} = m_2 r_2^{t+1}$

Or $K_{t+1}/K_t = r_2$

Identical reasoning holds for C_t.

APPENDIX 1C: CAPITAL OWNED, CAPITAL EMPLOYED, BONDS, AND EARNINGS FROM ABROAD

For ease of understanding, let us consider a country that invests a part of its domestically owned capital abroad. (Since labor is assumed to be immobile, and since X commodity is produced only using labor, we need to worry only about capital and the production of Y)

$$P_t C_t + (\tilde{\tilde{K}}_{t+1} - \tilde{\tilde{K}}_t) + (\tilde{\tilde{B}}_{t+1} - \tilde{\tilde{B}}_t) = Y_t(K_t) + P_{Xt} X_t + r_t \tilde{\tilde{B}}_t + \textit{payment to } (\tilde{\tilde{K}}_t - K_t)$$

K_t is the amount that is employed in the country

and $\tilde{\tilde{K}}_t$ is the amount of capital owned by the economy, with $\tilde{\tilde{K}}_t > K_t$

$\tilde{\tilde{B}}_t$ is the amount of bonds held for the purpose of consumption smoothing.

In the first period when the economies open up to trade, we know exactly how much of the domestic capital locates abroad. In the subsequent periods there is no additional structural equation that determines the evolution of $\tilde{\tilde{K}}_t$ in relation to the other variables of the system. $\tilde{\tilde{K}}_t$ appears only in defining the budget equation. As we know and have seen above, bonds and capital get paid at the same rate r_t.

What has happened is that the two variables: amount of capital employed abroad $\tilde{\tilde{K}}_t - K_t$ and amount of bonds held $\tilde{\tilde{B}}_t$, are linearly dependant.

Let us define a new variable $B_t = \tilde{\tilde{B}}_t + (\tilde{\tilde{K}}_t - K_t)$. The summation of the two variables does not pose a contradiction in any part of the model because the payments to both these variables and the pollution effects (which is none) of both these variables are identical in every period.

The existing system of structural equations is then able to trace out the evolution of K_t and B_t. One only has to be careful in interpreting B_t because it is different from the way bonds are usually defined: ie for consumption smoothing purposes. The B_t here represents flow of domestic wealth to foreign nations for purpose of consumption smoothing and investments in production both of which earns returns at the rate r_t in the current period.

APPENDIX 1D: MODEL WITH NON-SPECIFIC INPUTS

When both capital and labor inputs may be used in both sectors, we have four additional variables that were not present before: the labor used in Y sector and the amount of capital used in X sector in the home country as well as the foreign country. In addition to the new Euler equation for capital stock in X sector, the system also has to ensure that the returns to each input is equalized across the two sectors. It is assumed that the inter-sectoral decision for labor can be made in the current period but the decision about capital stock is made in the previous period.

$$\sum_{t=0}^{\infty}\rho^t[\ln\{\frac{Y_t(K_t^Y,L_t^Y)+P_{Xt}X_t(K_t^X,L_t^X)+r_tB_t-(K_{t+1}^Y-K_t^Y)-(K_{t+1}^X-K_t^X)-(B_t-B_{t-1})}{P_t}\}$$
$$-\gamma\{Z_t^Y(K_t^Y,L_t^Y)+Z_t^X(K_t^X,L_t^X)\}]$$

First order condition with respect to K_{t+1}^Y:

$$\frac{1}{P_tC_t}=\rho\frac{1}{P_{t+1}C_{t+1}}\{\frac{\partial Y_{t+1}(K_{t+1}^Y,L_{t+1}^Y)}{\partial K_{t+1}^Y}+1-\gamma P_{t+1}C_{t+1}\frac{\partial Z_{t+1}^Y(K_{t+1}^Y,L_{t+1}^Y)}{\partial K_{t+1}^Y}\}$$

First order condition with respect to K_{t+1}^X:

$$\frac{1}{P_tC_t}=\rho\frac{1}{P_{t+1}C_{t+1}}\{P_{Xt+1}\frac{\partial X_{t+1}(K_{t+1}^X,L_{t+1}^X)}{\partial K_{t+1}^X}+1-\gamma P_{t+1}C_{t+1}\frac{\partial Z_{t+1}^X(K_{t+1}^X,L_{t+1}^X)}{\partial K_{t+1}^X}\}$$

F.O.C w.r.t. B_{t+1}:

$$\frac{1}{P_tC_t}=\rho\ [\frac{1}{P_{t+1}C_{t+1}}\{1+r_{t+1}\}]$$

As investors have the option either to invest in capital in X sector, capital in Y sector or in bonds, the returns across these options must be equalized every period.

$$r_{t+1}=Y'(K_{t+1}^Y)-\gamma P_{t+1}C_{t+1}Z'(K_{t+1}^Y)=P_{Xt+1}X'(K_{t+1}^X)-\gamma P_{t+1}C_{t+1}Z'(K_{t+1}^X)$$

or, $r_t=Y'(K_t^Y)(1-\gamma P_tC_t\frac{\alpha}{\tau_t})=X'(K_t^X)P_{Xt}(1-\gamma P_tC_t\frac{\beta}{\tau_t})$

Under the optimal pollution tax $\tau_t=\gamma P_tC_t$, the above relation reduces to

$$r_t=(1-\alpha)Y'(K_t^Y)=P_{Xt}(1-\beta)X'(K_t^X)$$

For labor market growth of labor is not a choice variable in this model. Thus for labor market to be in equilibrium it is sufficient that the value of marginal returns on labor is equalized across the two sectors every period. This equalization however occurs under the influence of pollution taxes in place, which ensures that optimal emissions calculations already affect the production function and the marginal product of labor.

Substitution of the market clearing condition $L_t^X = \overline{L} - L_t^Y$ into the intertemporal welfare function and consideration of the first order condition with respect to labor employed in any one of the sectors, provides the following equation.

$$\frac{\partial Y_t\ (K_t^Y, L_t^Y)}{\partial L_t^Y} - \gamma P_t C_t \frac{\partial Z_t^Y (K_t^Y, L_t^Y)}{\partial L_t^Y} = \frac{\partial X_t\ (K_t^X, L_t^X)}{\partial L_t^X} - \gamma P_t C_t \frac{\partial Z_t^X (K_t^X, L_t^X)}{\partial L_t^X}$$

With efficient pollution tax, the above equation reduces to:

$$w_t = (1-\alpha)Y'(L_t^Y) = P_{Xt}(1-\beta)X'(L_t^X)$$

In the absence of any abatement activity $Y=(K^{\mu} L^{1-\mu})^{s}$,$Z= K^{\mu} L^{1-\mu}$

Output level with abatement activity: $Y=\{(1-\theta)(K^{\mu} L^{1-\mu})\}^{s}$

Emission level after abatement activity: $Z=(1-\theta)^{1/\alpha}(K^{\mu} L^{1-\mu})$

Elimination of θ between the above two production functions results in the Cobb Douglas form of production relation. $Y=Z^{\alpha s} K^{s-\alpha s}$

The labor market and capital market equilibrium conditions can be combined to provide a relation between capital-labor ratios in the two sectors.

$$\frac{w_t}{r_t} = \frac{(1-\alpha)Y'(L_t^Y)}{(1-\alpha)Y'(K_t^Y)} = \frac{P_{Xt}(1-\beta)X'(L_t^X)}{P_{Xt}(1-\beta)X'(K_t^X)}$$

or, $\frac{Y'(L_t^Y)}{Y'(K_t^Y)} = \frac{X'(L_t^X)}{X'(K_t^X)} \rightarrow (\frac{K_t^Y}{L_t^Y}) = f(\frac{K_t^X}{L_t^X})$ under Cobb-Douglas production function.

Numerical Simulation:

Under constant returns to scale

$$\bar{r} = \frac{1}{\rho} - 1 \qquad (13)$$

Equations (8) and (10) reveal that in the integrated economy, the growth of consumption expenditure is identical in the two countries. Thus,

$$\frac{\overline{\overline{PC}}}{\overline{\overline{PC*}}} = \frac{Wealth_0}{Wealth_0^*} \tag{14}$$

$Wealth_0$, $Wealth_0^*$ are the value of the endowments of the home and foreign economy at the beginning of trade, valued at the international market prices.

$$\frac{1}{\rho} - 1 = (1-\alpha)\frac{\partial Y(K^Y, L^Y; \tau)}{\partial K^Y}$$

$$\frac{1}{\rho} - 1 = (1-\alpha)\frac{\partial(\frac{\alpha}{\gamma PC})^{\frac{\alpha}{1-\alpha}} K_Y{}^{\mu} L_Y{}^{1-\mu}}{\partial K_Y}$$

$$\frac{1}{\rho} - 1 = (1-\alpha)(\frac{\alpha}{\gamma PC})^{\frac{\alpha}{1-\alpha}} \mu \frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{K_Y} \tag{15}$$

$$\frac{1}{\rho} - 1 = (1-\alpha)(\frac{\alpha}{\gamma P*C*})^{\frac{\alpha}{1-\alpha}} \mu \frac{K_Y^{*}{}^{\mu} L_Y^{*}{}^{sy-\mu}}{K_Y^*} \tag{16}$$

$$\frac{1}{\rho} - 1 = P_X(1-\beta)\frac{\partial X(K^X, L^X; \tau)}{\partial K^X}$$

$$\frac{1}{\rho} - 1 = P_X(1-\beta)\frac{\partial(\frac{\beta P_X}{\gamma PC})^{\frac{\beta}{1-\beta}} K_X{}^{\eta} L_X{}^{1-\eta}}{\partial K_X}$$

$$\frac{1}{\rho} - 1 = (1-\beta)(P_X)^{\frac{1}{1-\beta}} (\frac{\beta}{\gamma PC})^{\frac{\beta}{1-\beta}} \eta \frac{K_X{}^{\eta} L_X{}^{1-\eta}}{K_X} \tag{15X}$$

$$\frac{1}{\rho} - 1 = (1-\beta)(P_X)^{\frac{1}{1-\beta}} (\frac{\beta}{\gamma P*C*})^{\frac{\beta}{1-\beta}} \eta \frac{K_X^{*}{}^{\eta} L_X^{*}{}^{1-\eta}}{K_X^*} \tag{16X}$$

$$(1-\alpha)\frac{\partial Y(K^Y, L^Y; \tau)}{\partial L^Y} = P_X(1-\beta)\frac{\partial X(K^X, L^X; \tau)}{\partial L^X}$$

$$(1-\alpha)(\frac{\alpha}{\gamma PC})^{\frac{\alpha}{1-\alpha}}(1-\mu)\frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{L_Y} = (1-\beta)(P_X)^{\frac{1}{1-\beta}}(\frac{\beta}{\gamma PC})^{\frac{\beta}{1-\beta}}(1-\eta)\frac{K_X{}^{\eta} L_X{}^{sx-\eta}}{L_X} \tag{17}$$

Dividing 17 by 18:

$$(\frac{\gamma^* PC^*}{\gamma PC})^{\frac{\alpha}{1-\alpha}} \frac{\frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{L_Y}}{\frac{K_Y^*{}^{\mu} L_Y^*{}^{sy-\mu}}{L_Y^*}} = (\frac{\gamma^* PC^*}{\gamma PC})^{\frac{\beta}{1-\beta}} \frac{\frac{K_X{}^{\eta} L_X{}^{sx-\eta}}{L_X}}{\frac{K_X^*{}^{\eta} L_X^*{}^{sx-\eta}}{L_X^*}} \tag{18'}$$

$$\overline{PC} = \overline{Y} + \overline{P_X}\,\overline{X} + \overline{r}\,\overline{B} \tag{19}$$

$$\overline{PC}^* = \overline{Y^*} + \overline{P_X}\,\overline{X^*} - \overline{r}\,\overline{B} \tag{20}$$

$$\overline{P_X}[\overline{X}(\overline{P},\overline{L}) + \overline{X}^*(\overline{P},\overline{L^*})] = \omega[\overline{PC} + \overline{PC}^*] \tag{21}$$

$$\overline{Y}(\overline{K}) + \overline{Y^*}(\overline{K^*}) = (1-\omega)(\overline{PC} + \overline{PC^*}) \tag{22}$$

While solving equation (13) - (20) for the steady state values, equations (14), (15), (16), (15X), (16X), (17), (18), (21), (22) form a self contained system for $\overline{PC^*}, \overline{PC}, \overline{K_X}, \overline{K_X^*}, \overline{K_Y}, \overline{K_Y^*}, \overline{L_X}, \overline{L_X^*}, \overline{P_X}$. Once these values are solved, (13), (19) and (20) provide the solutions for $\overline{P},\ \overline{r}\,\overline{B}$.

Actual solution process:

1) Create a grid of Ly from 0 to 1, Ky 1 to very large number.

First four equations create grid for PC, PC*, Ky*, Ly*

2) For each element, calculate PC using equation 15.

$$\frac{1}{\rho} - 1 = (1-\alpha)(\frac{\alpha}{\gamma PC})^{\frac{\alpha}{1-\alpha}} \mu \frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{K_Y} \tag{15}$$

3) Calculate PC* grid using equation 14.

$$\frac{\overline{PC}}{\overline{PC^*}} = \frac{Wealth_0}{Wealth_0^*} \tag{14}$$

4) Calculate the demand for Y, and the amount produced by home to get the grid of market clearing supply of Y from foreign country.

5) Use equation (22') and (16) to solve for Ky* and Ly* grid

$$(\frac{\alpha}{\gamma PC})^{\frac{\alpha}{1-\alpha}} K_Y{}^{\mu} L_Y{}^{sy-\mu} + (\frac{\alpha}{\gamma^* PC^*})^{\frac{\alpha}{1-\alpha}} K_Y^{*\,\mu} L_Y^{*\,sy-\mu} = (1-\omega)(\overline{PC} + \overline{PC^*}) \tag{22}$$

$$(\frac{\alpha}{\gamma^* PC^*})^{\frac{\alpha}{1-\alpha}} K_Y^{*\,\mu} L_Y^{*\,sy-\mu} = (1-\omega)(\overline{PC} + \overline{PC^*}) - (\frac{\alpha}{\gamma PC})^{\frac{\alpha}{1-\alpha}} K_Y{}^{\mu} L_Y{}^{sy-\mu} \tag{22'}$$

$$\frac{1}{\rho} - 1 = (1-\alpha)(\frac{\alpha}{\gamma PC^*})^{\frac{\alpha}{1-\alpha}} \mu \frac{K_Y^{*\,\mu} L_Y^{*\,sy-\mu}}{K_Y^*} \tag{16}$$

(22') divided by (16) provides Ky. Put that back into either (22') to solve for Ly*.

Next 3 equations create grid for Kx, Kx* and Px*. However, Px* is left for later.

6) Calculate aggregate demand for X.

$$(P_X)^{\frac{1}{1-\beta}} [(\frac{\beta}{\gamma PC})^{\frac{\beta}{1-\beta}} K_X{}^{\eta} L_X{}^{sx-\eta} + (\frac{\beta}{\gamma^* P^* C^*})^{\frac{\beta}{1-\beta}} K_X^{*\,\eta} L_X^{*\,sx-\eta}] = \omega[\overline{PC} + \overline{PC}^*] \tag{21}$$

$$\frac{1}{\rho} - 1 = (1-\beta)(P_X)^{\frac{1}{1-\beta}} (\frac{\beta}{\gamma PC})^{\frac{\beta}{1-\beta}} \eta \frac{K_X{}^{\eta} L_X{}^{sx-\eta}}{K_X} \tag{15X}$$

$$K_X \frac{\frac{1}{\rho} - 1}{(1-\beta)\eta} = (P_X)^{\frac{1}{1-\beta}} (\frac{\beta}{\gamma PC})^{\frac{\beta}{1-\beta}} K_X{}^{\eta} L_X{}^{sx-\eta} \tag{15X'}$$

$$\frac{1}{\rho} - 1 = (1-\beta)(P_X)^{\frac{1}{1-\beta}} (\frac{\beta}{\gamma P^* C^*})^{\frac{\beta}{1-\beta}} \eta \frac{K_X^{*\,\eta} L_X^{*\,sx-\eta}}{K_X^*} \tag{16X}$$

$$K_X^* \frac{\frac{1}{\rho} - 1}{(1-\beta)\eta} = (P_X)^{\frac{1}{1-\beta}} (\frac{\beta}{\gamma P^* C^*})^{\frac{\beta}{1-\beta}} K_X^{*\,\eta} L_X^{*\,sx-\eta} \tag{16X'}$$

Use (15X') and (16X') to rewrite equation (21)

$$\frac{\frac{1}{\rho} - 1}{(1-\beta)\eta} (K_X^* + K_X) = \omega[\overline{PC} + \overline{PC}^*] \tag{21'}$$

7) Also the already created grid of Ly and Ly* provides Lx and Lx* grid. So dividing equation (15X) by (16X) provides:

$$\left(\frac{K_X}{K_X^*}\right)^{1-\eta} = \left(\frac{\gamma^* PC^*}{\gamma PC}\right)^{\frac{\beta}{1-\beta}} \left(\frac{L_X}{L_X^*}\right)^{sx-\eta} \quad (1516)$$

Equation (21) provided sum of Kx, Kx* and equation (1516) provides ratio of these two. Hence the grid of Kx, Kx* is determined.

Next two equations are used to choose a single combination out of the grid.

Equation 17 says that wage in the two sectors for home country must be same. This equation is divided by the returns to capital in the two sectors of home country equations 15 and 15X.

$$(1-\alpha)\left(\frac{\alpha}{\gamma PC}\right)^{\frac{\alpha}{1-\alpha}} (sy-\mu)\frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{L_Y} = (1-\beta)(P_X)^{\frac{1}{1-\beta}} \left(\frac{\beta}{\gamma PC}\right)^{\frac{\beta}{1-\beta}} (sx-\eta)\frac{K_X{}^{\eta} L_X{}^{sx-\eta}}{L_X} \quad (17)$$

$$\frac{(1-\alpha)\left(\frac{\alpha}{\gamma PC}\right)^{\frac{\alpha}{1-\alpha}} (s-\mu)\frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{L_Y}}{(1-\alpha)\left(\frac{\alpha}{\gamma PC}\right)^{\frac{\alpha}{1-\alpha}} \mu\frac{K_Y{}^{\mu} L_Y{}^{sy-\mu}}{K_Y}} = \frac{(1-\beta)(P_X)^{\frac{1}{1-\beta}} \left(\frac{\beta}{\gamma PC}\right)^{\frac{\beta}{1-\beta}} (1-\eta)\frac{K_X{}^{\eta} L_X{}^{sx-\eta}}{L_X}}{(1-\beta)(P_X)^{\frac{1}{1-\beta}} \left(\frac{\beta}{\gamma PC}\right)^{\frac{\beta}{1-\beta}} \eta\frac{K_X{}^{\eta} L_X{}^{sx-\eta}}{K_X}}$$

$$\frac{(sy-\mu)}{\mu}\frac{K_Y}{L_Y} = \frac{(sx-\eta)}{\eta}\frac{K_X}{L_X}$$

$$\frac{K_Y}{L_Y} / \frac{K_X}{L_X} = \frac{\mu}{(sy-\mu)}\frac{(sx-\eta)}{\eta} \quad (17')$$

Similarly equation (18) in conjunction with previously used equations provides (18')

$$(1-\alpha)\left(\frac{\alpha}{\gamma P^* C^*}\right)^{\frac{\alpha}{1-\alpha}} (1-\mu)\frac{K_Y^{*\mu} L_Y^{*\,sy-\mu}}{L_Y^*} = (1-\beta)(P_X)^{\frac{1}{1-\beta}} \left(\frac{\beta}{\gamma P^* C^*}\right)^{\frac{\beta}{1-\beta}} (1-\eta)\frac{K_X^{*\,\eta} L_X^{*\,sx-\eta}}{L_X^*} \quad (18)$$

$$\frac{K_Y^*}{L_Y^*} / \frac{K_X^*}{L_X^*} = \frac{\mu}{(sy-\mu)}\frac{(sx-\eta)}{\eta} \quad (18')$$

Next the remaining variables: Px and B are solved.

Px : equation 21, 15X or 16X

r: equation 13: $\bar{r} = \frac{1}{\rho} - 1$

B: Equation 19 or 20: $\overline{PC} = \overline{Y} + \overline{P_X}\,\overline{X} + \bar{r}\bar{B}$

$$\overline{PC}* = \overline{Y*} + \overline{P_X}\,\overline{X*} - \bar{r}\bar{B}$$

APPENDIX 1E: SENSITIVITY OF RESULTS TO POLLUTION DISUTILITY PARAMETER

Capital accumulates as the difference between production and consumption in both the standard growth models as well as in the current one with pollution disutility. This is captured in equation (1). The corresponding zero investment locus is given by equation (2).

$$(K_{t+1} - K_t) + (1-\omega)P_t C_t = (K_t)^{\frac{sy-\alpha}{1-\alpha}} \left(\frac{\alpha}{\tau}\right)^{\frac{\alpha}{1-\alpha}} \qquad (1)$$

$$(K_{t+1} - K_t) = 0 \rightarrow (1-\omega)P_t C_t = (K_t)^{\frac{sy-\alpha}{1-\alpha}} \left(\frac{\alpha}{\tau}\right)^{\frac{\alpha}{1-\alpha}}$$

$$K_t = [(1-\omega)P_t C_t \left(\frac{\tau}{\alpha}\right)^{\frac{\alpha}{1-\alpha}}]^{\frac{1-\alpha}{sy-\alpha}} \qquad (2)$$

The consumption growth equation in the standard growth model is given by equation (3). Equation (4) is the corresponding zero consumption expenditure growth equation. This expression embodies the fact that consumption expenditure attains a steady level when the welfare cost of delaying the consumption by one period $\frac{1}{\rho}-1$ equals the payoff MP_K of doing so.

$$\frac{P_{t+1}C_{t+1}-P_tC_t}{P_tC_t}=\rho[1+(K_{t+1})^{\frac{sy-1}{1-\alpha}}\frac{sy-\alpha}{1-\alpha}(\frac{\alpha}{\tau})^{\frac{\alpha}{1-\alpha}}]-1 \qquad (3)$$

$$P_{t+1}C_{t+1}-P_tC_t=0\rightarrow\frac{1}{\rho}-1=(K_{t+1})^{\frac{sy-1}{1-\alpha}}\frac{sy-\alpha}{1-\alpha}(\frac{\alpha}{\tau})^{\frac{\alpha}{1-\alpha}} \qquad (4)$$

With pollution disutility there is an additional term to the above equations. This appears because though the welfare cost of delaying consumption by one period is unchanged, the payoff from investment has changed. The reward for investing is the additional production (MP_K) minus the disutility of pollution that is generated by using the unit of resource for future production instead of current consumption. This is reflected in equation (5) while the associated zero consumption-expenditure growth locus is represented by equation (6).

$$\frac{P_{t+1}C_{t+1}-P_tC_t}{P_tC_t}=\rho[1+(K_{t+1})^{\frac{sy-1}{1-\alpha}}\frac{sy-\alpha}{1-\alpha}(\frac{\alpha}{\tau})^{\frac{\alpha}{1-\alpha}}\{1-\gamma P_{t+1}C_{t+1}(\frac{\alpha}{\tau})\}]-1 \qquad (5)$$

$$P_{t+1}C_{t+1}-P_tC_t=0\rightarrow\frac{1}{\rho}-1=(K_{t+1})^{\frac{sy-1}{1-\alpha}}\frac{sy-\alpha}{1-\alpha}(\frac{\alpha}{\tau})^{\frac{\alpha}{1-\alpha}}\{1-\gamma P_{t+1}C_{t+1}(\frac{\alpha}{\tau})\}$$

$$[\frac{\frac{sy-\alpha}{1-\alpha}(\frac{\alpha}{\tau})^{\frac{\alpha}{1-\alpha}}\{1-\gamma P_{t+1}C_{t+1}(\frac{\alpha}{\tau})\}}{\frac{1}{\rho}-1}]^{\frac{1-\alpha}{1-sy}}=(K_{t+1}) \qquad (6)$$

Equation (1) is a positively sloped line in the consumption expenditure – capital plane as shown in Diagram 1. A higher abatement tax makes capital less productive.

Hence for any steady state level of capital stock, a lower value of consumption expenditure can be sustained as shown by a leftward shift of the curve.

The zero consumption-expenditure growth locus for the standard growth model is given by a horizontal locus in the consumption expenditure – capital plane. A higher abatement tax lowers the marginal productivity of capital and hence lowers the level of capital at which consumption expenditure remains steady. This is also represented in Diagram A1.

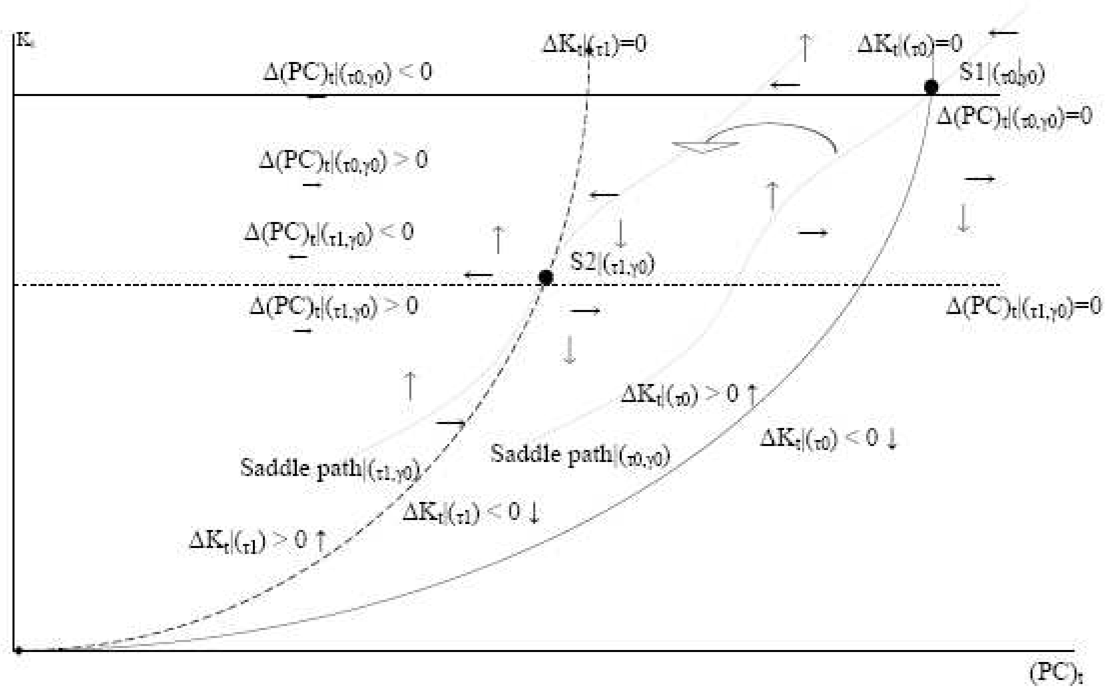

Diagram A1: Steady state consumption locus under different emission tax

When pollution disutility is an additional cost of productive capital, the level of capital at which consumption expenditure remains steady is a decreasing function of consumption expenditure. This happens because at higher consumption levels, pollution disutility is valued more strongly, making a lower capital stock desirable. This can be seen by comparing the solid lines in Diagram A2.

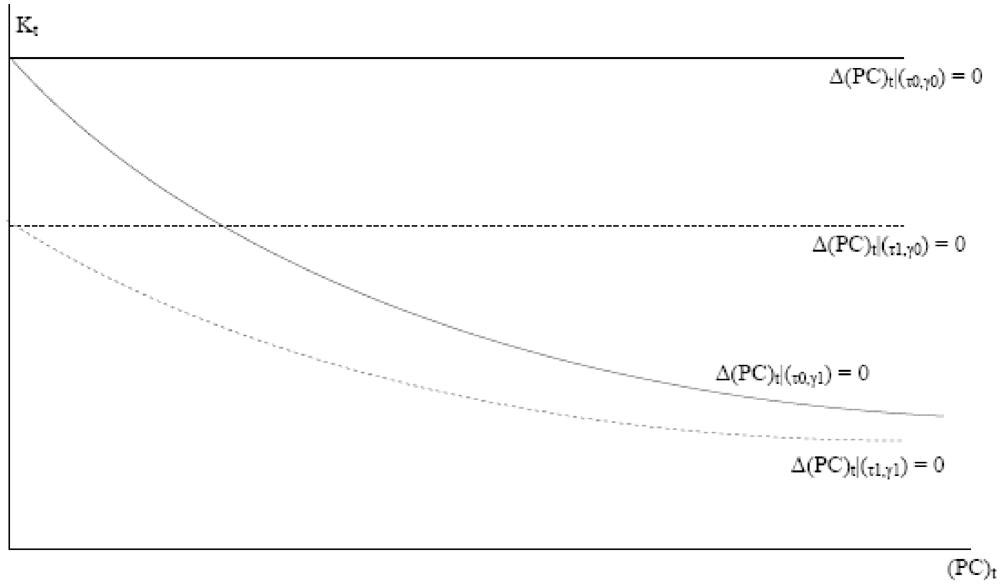

Diagram A2: Steady state consumption locus under different disutility parameters

A higher pollution tax has the previous dampening effect on the desired capital stock arising due to lowered productivity reasons. But the higher tax also lowers the pollution disutility and this difference is valued more strongly with higher consumption levels. This causes the gap between the desired capital stock in the high-tax low-tax scenarios to narrow at increasingly higher income. This is seen in Diagram 2.

For sufficiently high pollution disutility sensitivity (high γ), the loci for different pollution tax regimes might even intersect indicating that the decreased attractiveness of capital due lower productivity is more than offset by the increased attractiveness due to the cleaner technology used. This is depicted in Diagram 3.

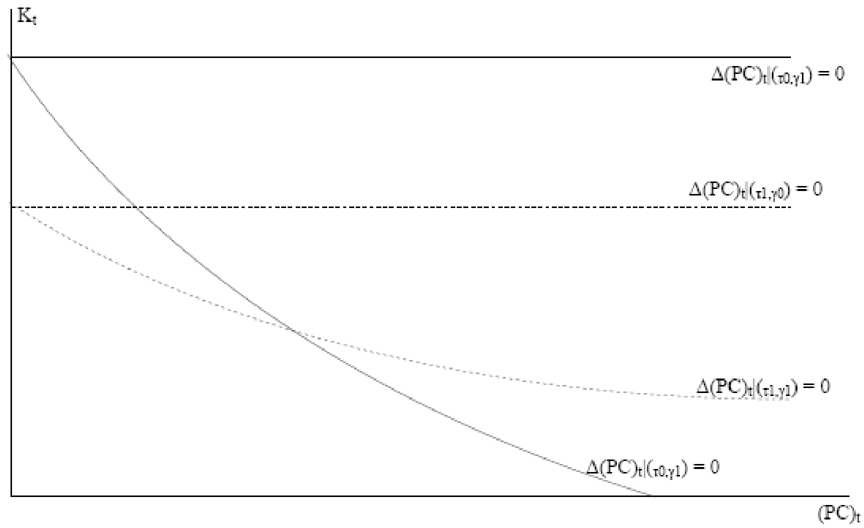

Diagram A3: Intersecting steady state consumption locus under different disutility parameters

The steady state of the system is at the intersection of the zero capital growth and zero consumption-expenditure growth loci. To predict the effect of higher pollution taxes on the steady state, one has to note that for the ΔK=0 locus higher tax rates has positive effect on steady state capital and a negative effect on the expenditure level. For the ΔPC=0 locus, higher tax rate has a negative impact on both steady capital and consumption expenditure levels. This is depicted in Diagram 4. The movement of the steady state solution depends on the direction of these two shifts. While the effect on the consumption expenditure is unambiguously negative, the outcome for capital depends on the relative strength of the two shifts.

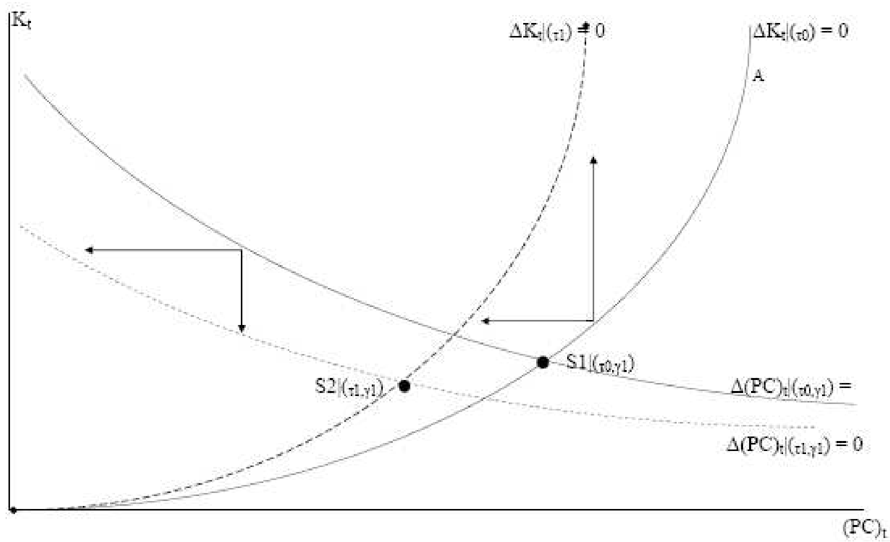

Diagram A4: Steady states equilibria under different disutility parameter values

The steady state capital stock might increase even without the intersection of same γ differential tax ΔPC=0 loci. This is depicted in Diagram A5. For increased γ, the ΔPC=0 loci shift down. However the distance between pairs of same γ different tax loci decreases as the clean technology associated with the higher tax is valued more with larger γ. Comparison of pairs of steady state (A,A'), (B,B'), (C,C'), (D,D') show that though in the standard growth models with γ =0, the steady state capital is low for a high pollution tax, this might be reversed as γ increases. This may happen even when the γ is not large enough for the same γ different tax ΔPC=0 loci to intersect.

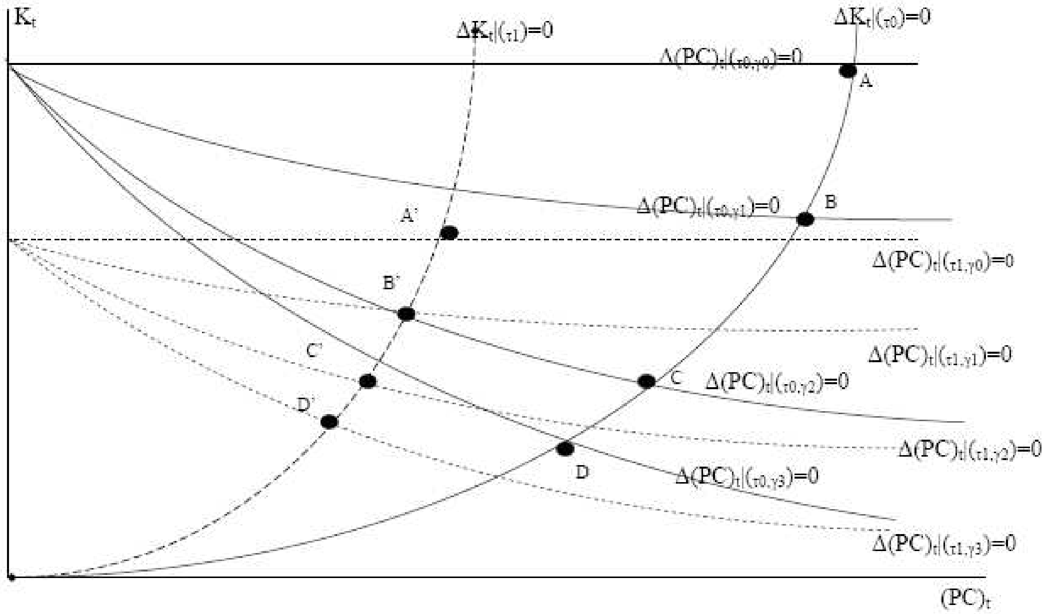

Diagram A5: Possibilities of steady states for different pollution disutility parameters

APPENDIX 1F: TWO TRADING ECONOMIES THAT ARE IDENTICAL IN ALL RESPECTS, EXCEPT IN RELATIVE VALUATION OF POLLUTION

From the perspective of the home country, the situation is almost similar to the one where the foreign economy was willing to accept international capital because it was poor. The home economy is not concerned whether the trade partner is willing to take in the dirty capital because it is poor, or because the partner cares less about domestic pollution.

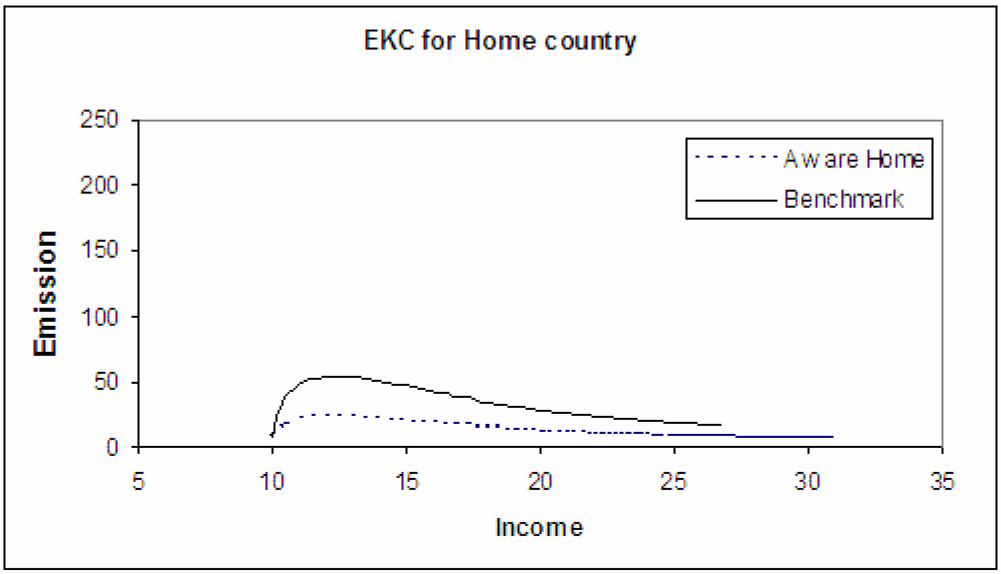

Diagram A6: Income-emission relation for a more aware economy

When we compare the foreign economy, the outcome is somewhat different than before. For one, it is has an equal share in all the productive resources wherever they may have been employed. This makes the final income of the foreign country to equal that of the home country.

Also as this foreign country is less concerned about domestic environmental conditions, it is willing to accept large volumes of capital, thus providing a much looser restrain on the growth of incomes of the world economy. For this reason, both countries end up at a higher income than possible otherwise.

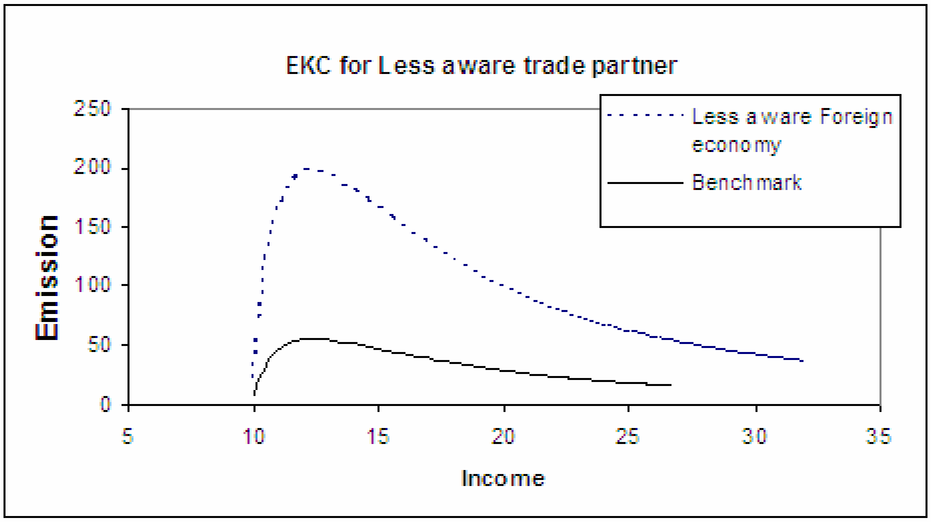

Diagram A7: Income-emission relation for a less aware economy

It is often the case that the poorer economies are also the ones that care less about environmental regulations, perhaps in the hope of encouraging domestic growth. So a combination of if we are to combine the last two scenarios, it would emerge that the richer and more aware home will experience a better environmental condition and higher income. The poorer and less environmentally responsible foreign economy will experience a worse environmental condition and will be able to increase its income compared to enforcing strict environmental policies. However, in this model, income in the foreign economy does not catch up with that of the home as in a perfectly integrated model. The home always shares the increased productivity of the environmentally less-strict foreign economy.

APPENDIX 2: RELATIONSHIP BETWEEN TARIFFS AND PRICES

$$p_x = \frac{2\alpha - x.e + X.EE}{2\beta} - \frac{T}{2}$$

$$\frac{dp_x}{dT} = \frac{(-1)}{2\beta}\{x\frac{de}{dT} + X\frac{dE}{dT}\} - \frac{1}{2}$$

$$\frac{dp_x}{dT} = \frac{(-1)}{2\beta}[x\frac{(-\beta)(2-7w+6w^2)}{2wx(3w-1)} + X\frac{\beta(2-9W+6W^2)}{2WX(3W-1)}] - \frac{1}{2}$$

$$\frac{dp_x}{dT} = \frac{(-1)}{2}[\frac{-(2-7w+6w^2)}{2w(3w-1)} + \frac{(2-9W+6W^2)}{2W(3W-1)}] - \frac{1}{2}$$

If w=W, ie if the weight that producers get relative to consumers is same in both economies, then the above term can be simplified.

$$\frac{dp_x}{dT} = \frac{(-1)}{2}[\frac{-(2-7w+6w^2)}{2w(3w-1)} + \frac{(2-9w+6w^2)}{2w(3w-1)}] - \frac{1}{2}$$

$$\frac{dp_x}{dT} = (-\frac{1}{2})[\frac{1}{2w(3w-1)}[-(2-7w+6w^2) + (2-9w+6w^2) + 1]$$

$$\frac{dp_x}{dT} < 0 \rightarrow [\frac{1}{2w(3w-1)}\{-(2-7w+6w^2) + (2-9w+6w^2)\} + 1] > 0$$

$$\{-(2-7w+6w^2) + (2-9w+6w^2)\} + 2w(3w-1) > 0$$

$$-2w + 2w(3w-1) > 0$$

$$(3w-1) > 1$$

$$w > 2/3$$

For w>2/3, domestic prices of exports are rising in foreign tariffs

$$p_y = \frac{2A - y.f + Y.F}{2B} + \frac{t}{2}$$

$$\frac{dp_y}{dt} = \frac{1}{2} - \frac{1}{2B}\{y\frac{df}{dt} + Y\frac{dF}{dt}\}$$

$$\frac{dp_y}{dt} = \frac{1}{2} - \frac{1}{2B}\{y\frac{B(2-9w+6w^2)}{2wy(3w-1)} + Y\frac{(-B)(2-7W+6W^2)}{2WY(3W-1)}\}$$

$$\frac{dp_y}{dt} = \frac{1}{2} - \frac{1}{2}\{\frac{(2-9w+6w^2)}{2w(3w-1)} - \frac{(2-7W+6W^2)}{2W(3W-1)}\}$$

The above expression can be simplified when w=W

$$\frac{dp_y}{dt} > 0 \rightarrow \frac{1}{2} - \frac{1}{2}\{\frac{(2-9w+6w^2)}{2w(3w-1)} - \frac{(2-7w+6w^2)}{2w(3w-1)}\} > 0$$

$$2w(3w-1) - \{(2-9w+6w^2) - (2-7w+6w^2)\} > 0$$

$$2w(3w-1) + 2w > 0$$

$$w > 0$$

For w>2/3, domestic prices of imports are rising in domestic tariffs.

APPENDIX 3: CHANGE IN INCOME DUE TO CHANGE IN INPUT PRICES

Looking at the terms within parentheses:

$$dI = Yp\frac{1}{|\lambda||\theta|}(\theta_{ZL}s_{AL} + \theta_{ZK}s_{AK})(\lambda_{ZK}\delta_L + \lambda_{ZL}\delta_K)\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}}\frac{|\lambda|}{|\theta|} - (\theta_{ZL}s_{AL} + \theta_{ZK}s_{AK})(\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)]$$

It is useful to look at the effect of abatement that is only labor using or only capital using.

If abatement uses both inputs, then the effect will be a combination of the two effects.

Coefficient of s_{AK} :

$$= \frac{1}{|\theta|}[(\lambda_{ZK}\delta_L + \lambda_{ZL}\delta_K)\theta_{YK}\theta_{YL}(\lambda_{YL}\lambda_{XK} - \lambda_{YK}\lambda_{XL}) - (\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)\lambda_{YL}\lambda_{YK}(\theta_{YL}\theta_{XK} - \theta_{YK}\theta_{XL})]$$

$$= \frac{1}{|\theta|}[(\lambda_{ZK}\delta_L + \lambda_{ZL}\delta_K)\frac{r}{p}\frac{w}{p}(\frac{a_{YL}Y}{L}\frac{a_{XK}X}{K} - \frac{a_{XL}X}{L}\frac{a_{YK}Y}{K})$$
$$- (\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)\frac{Y}{L}\frac{Y}{K}(\frac{wa_{YL}}{p}\frac{ra_{XK}}{1} - \frac{ra_{YK}}{p}\frac{wa_{XL}}{1})$$

$$= \frac{1}{|\theta|}[(\lambda_{ZK}\delta_L + \lambda_{ZL}\delta_K)\frac{1}{p}(\frac{a_{YL}}{1}\frac{a_{XK}X}{1} - \frac{a_{XL}X}{1}\frac{a_{YK}}{1}) - (\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)\frac{Y}{1}(\frac{a_{YL}}{1}\frac{a_{XK}}{1} - \frac{a_{YK}}{1}\frac{a_{XL}}{1})$$

$$= [(\lambda_{ZK}\delta_L + \lambda_{ZL}\delta_K)\frac{1}{p}X - (\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)Y$$

$$[(\lambda_{ZK}\delta_L + \lambda_{ZL}\delta_K)X - (\lambda_{XL}\delta_K + \lambda_{XK}\delta_L)Yp$$

$$[(\frac{Ya_{ZK}}{K}\delta_L + \frac{Ya_{ZL}}{L}\delta_K)X - (\frac{Xa_{XL}}{L}\delta_K + \frac{Xa_{XK}}{K}\delta_L)Yp$$

$$[(\frac{a_{ZK}}{K}\delta_L + \frac{a_{ZL}}{L}\delta_K) - (\frac{a_{XL}}{L}\delta_K + \frac{a_{XK}}{K}\delta_L)p$$

$$\delta_L = (\lambda_{LX}\theta_{KX}\sigma_X + \lambda_{LY}\theta_{KY}\sigma_Y)$$

$$\delta_K = (\lambda_{KX}\theta_{LX}\sigma_X + \lambda_{KY}\theta_{LY}\sigma_Y)$$

$$(\frac{a_{ZK}}{K}(\lambda_{LX}\theta_{KX}\sigma_X + \lambda_{LY}\theta_{KY}\sigma_Y) + \frac{a_{ZL}}{L}(\lambda_{KX}\theta_{LX}\sigma_X + \lambda_{KY}\theta_{LY}\sigma_Y))$$
$$- (\frac{a_{XL}}{L}(\lambda_{KX}\theta_{LX}\sigma_X + \lambda_{KY}\theta_{LY}\sigma_Y) + \frac{a_{XK}}{K}(\lambda_{LX}\theta_{KX}\sigma_X + \lambda_{LY}\theta_{KY}\sigma_Y))p$$

$$(\frac{a_{ZK}}{K}(\frac{Xa_{LX}}{L}\theta_{KX}\sigma_X+\frac{Ya_{LY}}{L}\theta_{KY}\sigma_Y)+\frac{a_{ZL}}{L}(\frac{Xa_{KX}}{K}\theta_{LX}\sigma_X+\frac{Ya_{KY}}{K}\theta_{LY}\sigma_Y))$$
$$-(\frac{a_{XL}}{L}(\frac{Xa_{KX}}{K}\theta_{LX}\sigma_X+\frac{Ya_{KY}}{K}\theta_{LY}\sigma_Y)+\frac{a_{XK}}{K}(\frac{Xa_{LX}}{L}\theta_{KX}\sigma_X+\frac{Ya_{LY}}{L}\theta_{KY}\sigma_Y))p$$

$$(a_{ZK}(Xa_{LX}\theta_{KX}\sigma_X+Ya_{LY}\theta_{KY}\sigma_Y)+a_{ZL}(Xa_{KX}\theta_{LX}\sigma_X+Ya_{KY}\theta_{LY}\sigma_Y))$$
$$-(a_{XL}(Xa_{KX}\theta_{LX}\sigma_X+Ya_{KY}\theta_{LY}\sigma_Y)+a_{XK}(Xa_{LX}\theta_{KX}\sigma_X+Ya_{LY}\theta_{KY}\sigma_Y))p$$

Coefficient on $\sigma_X : X(a_{ZK}a_{LX}\theta_{KX}+a_{ZL}a_{KX}\theta_{LX})-(a_{XL}a_{KX}\theta_{LX}+a_{XK}a_{LX}\theta_{KX})p$

$$\sigma_X : X(a_{ZK}a_{LX}\frac{ra_{KX}}{1}+a_{ZL}a_{KX}\frac{wa_{LX}}{1})-(a_{XL}a_{KX}\frac{wa_{LX}}{1}+a_{XK}a_{LX}\frac{ra_{KX}}{1})p$$

$$\sigma_X : X(a_{ZK}r+a_{ZL}w)-(wa_{LX}+a_{XK}r)p$$

$$\sigma_X : \frac{(a_{ZK}r+a_{ZL}w)}{p}-\frac{(wa_{LX}+a_{XK}r)}{1}=0$$

The coefficients simplify to zero, implying the change in input prices have no net effect on income

Coefficient on $\sigma_Y : a_{ZK}a_{LY}\theta_{KY}+a_{ZL}a_{KY}\theta_{LY}-(a_{XL}a_{KY}\theta_{LY}+a_{XK}a_{LY}\theta_{KY})p$

$$\sigma_Y : a_{ZK}a_{LY}\frac{ra_{KY}}{p}+a_{ZL}a_{KY}\frac{wa_{LY}}{p}-(a_{XL}a_{KY}\frac{wa_{LY}}{p}+a_{XK}a_{LY}\frac{ra_{KY}}{p})p$$

$$\sigma_Y : a_{ZK}r+a_{ZL}w-(a_{XL}w+a_{XK}r)p$$

$$\sigma_Y : \frac{a_{ZK}r+a_{ZL}w}{p}-(\frac{a_{XL}w+a_{XK}r}{1})=0$$

$$dI=Yp\frac{1}{|\lambda||\theta|}[(\theta_{ZL}s_{AL}+\theta_{ZK}s_{AK})(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}}\frac{|\lambda|}{|\theta|}-(\theta_{ZL}s_{AL}+\theta_{ZK}s_{AK})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$$

Coefficient of $s_{AL} : [(\theta_{ZL}s_{AL})(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}}\frac{|\lambda|}{|\theta|}-(\theta_{ZL}s_{AL})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$

$$\frac{1}{|\theta|}\theta_{ZL}[|\lambda|(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)\theta_{YK}\theta_{YL}-\lambda_{YK}\lambda_{YL}|\theta|(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$$

$$\frac{1}{|\theta|}\theta_{ZL}[(\lambda_{YL}\lambda_{XK}-\lambda_{YK}\lambda_{XL})(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)\theta_{YK}\theta_{YL}-\lambda_{YK}\lambda_{YL}(\theta_{YL}\theta_{XK}-\theta_{YK}\theta_{XL})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$$

$$\frac{1}{|\theta|}\theta_{ZL}[(\frac{a_{YL}Y}{L}\frac{a_{XK}X}{K}-\frac{a_{XL}X}{L}\frac{a_{YK}Y}{K})(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)\frac{ra_{YK}}{p}\frac{wa_{YL}}{p}$$

$$-\frac{a_{YK}Y}{K}\frac{a_{YL}Y}{L}(\frac{wa_{YL}}{p}\frac{ra_{XK}}{1}-\frac{ra_{YK}}{p}\frac{wa_{XL}}{1})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$$

$$\frac{1}{|\theta|}\theta_{ZL}[\frac{XYrw}{LKp}\frac{1}{p}(a_{YL}a_{XK}-a_{XL}a_{YK})(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)a_{YK}a_{YL}$$

$$-\frac{YYrw}{LKp}a_{YK}a_{YL}(a_{YL}a_{XK}-a_{XL}a_{YK})(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$$

$$[\frac{X}{p}(\lambda_{ZK}\delta_L+\lambda_{ZL}\delta_K)-Y(\lambda_{XL}\delta_K+\lambda_{XK}\delta_L)]$$

$$[X(\frac{Ya_{ZK}}{K}\delta_L+\frac{Ya_{ZL}}{L}\delta_K)-Yp(\frac{Xa_{XL}}{L}\delta_K+\frac{Xa_{XK}}{K}\delta_L)]$$

$$[(\frac{a_{ZK}}{K}\delta_L+\frac{a_{ZL}}{L}\delta_K)-p(\frac{a_{XL}}{L}\delta_K+\frac{a_{XK}}{K}\delta_L)]$$

Substituting in $\delta_L=(\lambda_{LX}\theta_{KX}\sigma_X+\lambda_{LY}\theta_{KY}\sigma_Y)$

$$\delta_K=(\lambda_{KX}\theta_{LX}\sigma_X+\lambda_{KY}\theta_{LY}\sigma_Y)$$

$$[(\frac{a_{ZK}}{K}(\lambda_{LX}\theta_{KX}\sigma_X+\lambda_{LY}\theta_{KY}\sigma_Y)+\frac{a_{ZL}}{L}(\lambda_{KX}\theta_{LX}\sigma_X+\lambda_{KY}\theta_{LY}\sigma_Y))-$$

$$p(\frac{a_{XL}}{L}(\lambda_{KX}\theta_{LX}\sigma_X+\lambda_{KY}\theta_{LY}\sigma_Y)+\frac{a_{XK}}{K}(\lambda_{LX}\theta_{KX}\sigma_X+\lambda_{LY}\theta_{KY}\sigma_Y))]$$

Coefficient on σ_X $:[(\frac{a_{ZK}}{K}\lambda_{LX}\theta_{KX}+\frac{a_{ZL}}{L}\lambda_{KX}\theta_{LX})-p(\frac{a_{XL}}{L}\lambda_{KX}\theta_{LX}+\frac{a_{XK}}{K}\lambda_{LX}\theta_{KX})]$

$$\sigma_X:[(\frac{a_{ZK}}{K}\frac{Xa_{LX}}{L}\theta_{KX}+\frac{a_{ZL}}{L}\frac{Xa_{KX}}{K}\theta_{LX})-p(\frac{a_{XL}}{L}\frac{Xa_{KX}}{K}\theta_{LX}+\frac{a_{XK}}{K}\frac{Xa_{LX}}{L}\theta_{KX})]$$

$$\sigma_X:[(a_{ZK}a_{LX}\theta_{KX}+a_{ZL}a_{KX}\theta_{LX})-p(a_{XL}a_{KX}\theta_{LX}+a_{XK}a_{LX}\theta_{KX})]$$

$$\sigma_X : [(a_{ZK} a_{LX} r a_{KX} + a_{ZL} a_{KX} w a_{LX}) - p(a_{XL} a_{KX} w a_{LX} + a_{XK} a_{LX} r a_{KX})]$$

$$\sigma_X : [(a_{ZK} r + a_{ZL} w) - p(a_{XL} w + a_{XK} r)]$$

$$\sigma_X : [\frac{(a_{ZK} r + a_{ZL} w)}{p} - \frac{(a_{XL} w + a_{XK} r)}{1}] = 0$$

Each coefficient simplifies to zero, implying the change in input prices have no net effect on income

Change in income due to change in effective endowment is seen in the following calculations.

Term inside parenthesis:

$$[\{\lambda_{ZK} * \lambda_{ZL} s_{AL} - \lambda_{ZL} * \lambda_{ZK} s_{AK}\}\{\frac{\theta_{YK}\theta_{YL}}{\lambda_{YK}\lambda_{YL}} \frac{|\lambda|}{|\theta|}\} + \{\lambda_{XL} * \lambda_{ZK} s_{AK} - \lambda_{XK} * \lambda_{ZL} s_{AL}\}]$$

If abatement if only capital using or only labor using, both should reduce income. So each term should be accompanied by a negative coefficient.

$$s_{AK} : \frac{1}{\lambda_{YK}\lambda_{YL} |\theta|}\{\lambda_{XL} * \lambda_{ZK} \lambda_{YK}\lambda_{YL} |\theta| - \lambda_{ZL} * \lambda_{ZK} \theta_{YK}\theta_{YL} |\lambda|\}$$

$$s_{AK} : \frac{1}{|\theta|}\{\lambda_{XL}\lambda_{YK} |\theta| - \theta_{YK}\theta_{YL} |\lambda|\} < 0$$

$$s_{AL} : \frac{1}{\lambda_{YK}\lambda_{YL} |\theta|}\{\lambda_{ZK} * \lambda_{ZL} \theta_{YK}\theta_{YL} |\lambda| - \lambda_{XK} * \lambda_{ZL} \lambda_{YK}\lambda_{YL} |\theta|\}$$

$$s_{AL} : \frac{1}{|\theta|}\{\theta_{YK}\theta_{YL} |\lambda| - \lambda_{XK} * \lambda_{ZL} |\theta|\} < 0$$

Reduction in effective endowment has a negative effect on aggregate income as shown by the negative coefficients