

Unanticipated Consequences of Environmental Regulation on Pollution, Income distribution, Product composition and Trade*

by

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Abstract:

Using a general equilibrium model of an open economy, the paper discusses several consequences of command and control environmental regulatory programs. The existing literature seems to suggest a degree of certainty in the effectiveness of such programs in controlling the damage to the environment. The paper questions this conviction and shows that there are some unanticipated consequences of regulation. Varying standards influence factor rewards, which in turn have implications for the distribution of income, product composition and the level of pollution. Under certain conditions, regulation that is more stringent may lead to a rise in the output of the polluting industry. In such cases, the pattern of trade is indeterminate. The paper casts serious doubts on the dogma that developing countries export pollution and need to be restrained by interconnecting trade agreements with Multilateral Environment Agreements. Environmental regulation may involve substantial losses to the working class, which is an issue the national governments will have to deal with carefully.

Keywords: Environmental regulation; neoclassical trade theory; general equilibrium; race to the bottom; non-tariff barriers

JEL Classification: D50, D78, F11, F18, Q56

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1. Introduction

The interface between trade and environmental policies has become a matter of close official scrutiny in a number of international institutions including the United Nations, the OECD and the GATT since 1990 [5]. This was stimulated in particular by events such as the dispute between US and Mexico over tuna fishing and the adoption of the Montreal Protocol. The topic of trade and environment was a mainstream item for discussion in the 4th Ministerial meeting of the WTO in Doha in 2001. There is a growing concern among advocates of free trade that environmental policies can be used as non-tariff barriers to trade. Opponents argue that free trade agreements will start a “race to the bottom”, forcing developed nations to lower their environmental standards to match those in the less developed nations. There are several contributions of the paper to the current trade and environment controversy. It addresses the heart of the debate, which is the issue of the effectiveness of regulation in reducing pollution, the subject of investigation in the current literature. First, contrary to custom, the focus is placed on command and control (CAC)¹ programs of regulation² which are clearly preferred by countries to decentralized regulatory programs³. Second, most partial equilibrium [14] and general equilibrium models [1], [6], [9], [10], [12] in the literature, explicitly treat pollution as an input in the production process. In the paper, pollution as an input is given a special status by placing the emphasis on abatement. Just as in the case of production, abatement requires factor inputs of labor and capital, although the abatement technology is different from the

¹ Terms CAC and decentralized regulatory programs are acquired from Cropper & Oates survey paper [7].

² Bohm and Russell [4], Baumol and Oates [2] review the CAC instruments that involve explicit limitations on the allowable levels of emissions and the use of specified abatement techniques.

³ Baumol and Oates [2], Cropper and Oates [7] elaborate on the effluent charge or Pigouvian tax that is set to reflect the damages done by each unit of emissions. For detailed discussion on tradable pollution permits, see Tietenberg [13] and Montgomery [11].

manufacturing technology. Changing environmental norms influence the wage rental ratio. As a direct response, polluting industries use more capital and labor for abatement. The indirect response is to substitute in favor of the cheaper factor. To accommodate abatement, the structure of the model is modified which leads to the third contribution of the paper. Existing models in the literature, though informative, are so designed that they are unable to deal with the linkages between regulation and factor substitution in abatement. Hence, they seem to suggest a degree of certainty in the effectiveness of environmental standards in controlling the damage to the environment. The paper questions this conviction and shows that there are unanticipated consequences of regulation on pollution, production structure, income distribution and the pattern of trade.

A general equilibrium framework is used in which the factors of production are needed in two distinct but related activities, namely production of goods and abatement of pollution that is caused by production. Following the dictum ‘the more you produce, the more you pollute’, a positive monotonic relationship between production and pollution is hypothesized. The model assumes that there are two sectors, one of which is the polluting sector facing the standard set by the regulator. There are two factors, labor and capital, both fully employed in an economy where all markets are perfectly competitive. The main results of the study are the following. Pollution cannot be reduced without affecting income distribution. A stricter environmental standard enforced by the regulator will reduce real wages (or rental on capital), if the polluting units are labor (or capital) intensive. The effect of a change in the environmental standard on the structure of production is uncertain because its effect on the input output coefficients is indeterminate unless a special assumption is made. For example, a stricter environmental

standard, commonly believed to reduce the output of the labor-intensive polluting good, may actually raise it due to the fall in the real wages, which makes output expansion profitable in that sector. The special assumption simply states that if the polluting industry is labor intensive, then a variation in the environmental standard will affect the labor output ratio used in abatement more strongly than the capital output ratio and the reverse is true if the polluting industry is capital intensive. Under this assumption, countries with weak environmental regulation tend to develop comparative advantage in the polluting good and export it and those with stronger standards tend to export non-polluting goods. This seems to agree with the current belief that the developing countries ‘export’ pollution. However, the paper shows that with neoclassical production functions it is theoretically possible that the opposite is true. The robustness of the model is established when it is shown that for any given standard, the neo-classical trade theorems, i.e., Samuelson-Stolper, Rybczynski and Heckscher-Ohlin theorems hold. The general equilibrium model of trade under regulation is explored in section 2. This is followed by the effect of regulation on the pattern of trade as well as the volume of exports in sections 3 and 4. Main conclusions of the paper are summarized in section 5.

2. General Equilibrium Model of Trade Under Quantity Control Regulation

2.1 Production Analysis

In this model, pollution abatement is included in the standard two-sector neoclassical framework with X_1 and X_2 representing the output levels of the polluting and non-polluting industries respectively. The clean industry needs L_2 units of labor and K_2 units of capital for production. The polluting industry requires a total of L'_1 units of labor

and K_1' units of capital to produce the dirty good and to achieve a certain level of environmental standard. Labor and capital are mobile between industries but immobile between countries. In addition, there are no transport costs, tariffs or other obstructions to free trade. The technology for production as well as abatement is characterized by constant returns to scale and diminishing marginal productivity of labor and capital. The markets for products and factors are perfectly competitive. Thus, the input-output coefficients in the non-polluting industry ($C_L^2 = L_2/X_2$ and $C_K^2 = K_2/X_2$) are uniquely determined by the wage rental ratio ($w/r = \omega$).

$$(1) \quad C_i^2 = C_i^2(\omega); i = L, K$$

The polluting industry faces an environmental standard (e) that might be the allowable level of air pollution or the level of tolerable impurity in the water discharged from factories per unit of output. A low value of e indicates a low level of pollution and a strong environmental standard ($\bar{e} < e \leq 1$). There is a technological limit to reducing pollution. Hence, e cannot fall below \bar{e} . No standard is set when e is unity. Given e , the input-output coefficients in the industry ($C_L^1 = L_1'/X_1$, $C_K^1 = K_1'/X_1$) are determined by the factor prices. At the same time, if the pollution standard is relaxed less of both inputs will be required per unit of output for abatement.

$$(2) \quad C_i^1 = C_i^1(\omega, e); i = L, K$$

The total supply of labor in this economy is $L = L_1' + L_2$ and that of capital is $K = K_1' + K_2$. The first set of equilibrium conditions is full employment of both resources.

$$(3) \quad C_L^1 X_1 + C_L^2 X_2 = L$$

$$(4) \quad C_K^1 X_1 + C_K^2 X_2 = K$$

The second set of equilibrium conditions follows from free entry and exit under perfect competition. P_j ($j = 1, 2$) is the unit price of the good produced by the j^{th} industry. In the long run, the profit is zero in each industry and producers equate price to average cost.

$$(5) \quad wC_L^1 + rC_K^1 = P_1$$

$$(6) \quad wC_L^2 + rC_K^2 = P_2$$

With given product prices, factor endowments and environmental standard, the equations (1) through to (6) determine the output levels and the input prices. The relative commodity price in the autarky equilibrium is determined by incorporating the demand functions (section 3). When no environmental standard is imposed ($e \rightarrow 1$), both sets of coefficients (C_i^1, C_i^2) are uniquely determined by factor prices and the model is reduced to the standard model.

2.1.1 Determination of input-output coefficients

The non polluting industry will chose labor (L_2) and capital (K_2) to minimize total production costs (wL_2+rK_2) subject to the production constraint ($g_2(L_2, K_2) \geq 1$). This optimization exercise yields the optimal factor requirements per unit of output in production as functions of factor prices ($C_i^2 = C_i^2(\omega); i = L, K$). The polluting industry abates $\alpha - e$ units of emissions per unit of output, where e is the environmental standard and α is emissions of the industry per unit of output prior regulation. It chooses capital (K_p) and labor (L_p) used in production along with capital (K_A) and labor (L_A) used in abatement to minimize total costs ($wL_p+rK_p+wL_A+rK_A$) subject to the production constraint ($g_1(K_p, L_p) \geq 1$) and the abatement constraint ($h(L_A, K_A) \geq \alpha - e$), where $K'_1 = K_p + K_A$ and $L'_1 = L_p + L_A$. This optimization exercise with two inequality constraints is

equivalent to minimizing costs in production (minimizing wL_p+rK_p subject to $g_1(K_p, L_p) \geq 1$ w.r.t $\{K_p, L_p\}$) and abatement (minimizing wL_A+rK_A subject to $h(L_A, K_A) \geq \alpha - e$ w.r.t $\{K_A, L_A\}$) separately. Both exercises will yield optimal factor requirements per unit of output in production as functions of ω and in abatement as functions of ω as well as e . In order to keep the analysis simple, the input-output coefficients for production and abatement are combined and represented by a single variable $C_i^1 = C_i^1(\omega, e); i = L, K$. Factor substitution in the polluting industry can take place either in production or in abatement with no scope of shifting factors from production to abatement or vice versa. There exists a proportional relation between production and pollution. The firm cannot produce more and abate less. Details on the cost minimization exercise followed by both industries are available in appendix 1 and 2. Following equations relate changes in the input output coefficients for both industries with changes in the wage-rental ratio and the environmental standard.

$$(7) \quad (C_L^2)^* = -(\theta_{K2}/(\theta_{L2} + \theta_{K2}))\sigma_2\omega^*$$

$$(8) \quad (C_K^2)^* = (\theta_{L2}/(\theta_{L2} + \theta_{K2}))\sigma_2\omega^*$$

$$(9) \quad (C_L^1)^* = -(\theta'_{K1}/(\theta'_{L1} + \theta'_{K1}))\sigma_e\omega^* - A_{L1}e^*$$

$$(10) \quad (C_K^1)^* = (\theta'_{L1}/(\theta'_{L1} + \theta'_{K1}))\sigma_e\omega^* - A_{K1}e^*$$

2.1.2 Impact of Regulation on Income Distribution

$$(11) \quad \omega^* = \frac{S}{|\theta|}e^* + \frac{1}{|\theta|}P^*$$

The relationship between the factor prices (ω), environmental standard (e) and terms of trade ($P=P_1/P_2$) derived in appendix 3. As seen in appendix 4 b), the sign of the determinant $|\theta|$ depends upon the factor intensity relationship. In the standard model, for a fixed environmental norm ($e^*=0$), ω is uniquely determined by the terms of trade. However, ω is also affected by a change in e as shown in equation (11) and illustrated by fig. 1. This may be considered as a restatement of the factor price equalization theorem. Factor prices are equalized across nations only if product prices and environmental standards are “harmonized”⁴.

Proposition 1: *There exists a unique relationship between factor rewards and product prices when the environmental standard is kept fixed ($e^*=0$). At constant terms of trade, ($P^*=0$), a stricter environmental standard ($e^*<0$) reduces [or raises] the wage rental ratio if the polluting industry is labor [or capital] intensive. The effect on ω is opposite under weaker regulation.*

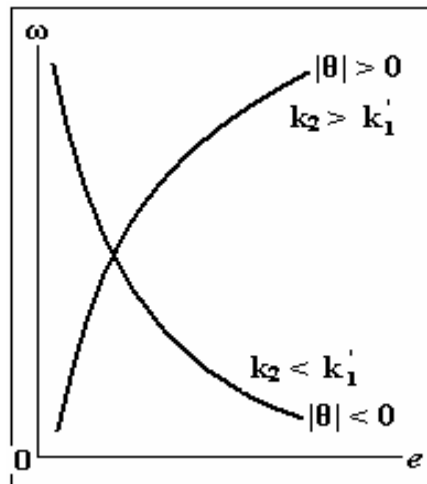


Fig. 1. Relationship between ω and e when $P^*=0$

⁴ The term was coined by Bhagwati and Hudec in [3]

$$(12) \quad w^* = P_1^* = (\theta_{K2}/\theta)Se^* + (\theta'_{K1}/\theta)P^*$$

$$w^* - P_2^* = (\theta_{K2}/\theta)Se^* + (\theta_{K2}/\theta)P^*$$

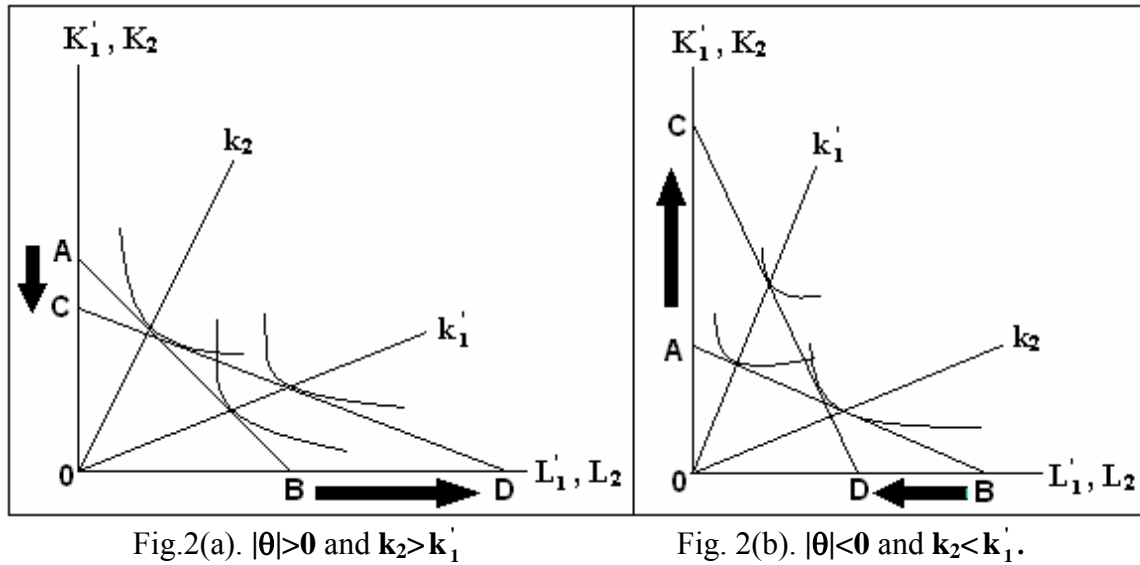
$$(13) \quad r^* - P_1^* = -(\theta_{L2}/\theta)Se^* - (\theta'_{L1}/\theta)P^*$$

$$r^* - P_2^* = -(\theta_{L2}/\theta)Se^* - (\theta_{L2}/\theta)P^*$$

Expressions (12) and (13) for real factor rewards are derived in appendix 5. The Stolper Samuelson theorem states that an increase [or decrease] in the price of a good will raise [or lower] the real rewards of the factor intensively used in producing that good and lower [or raise] the real rewards of the other factor. In (12) and (13), the Samuelson-Stolper theorem is valid for a given level of pollution ($e^*=0$) if there is no factor intensity reversal ($k_2 > k_1$ for some ω and $k_2 < k_1$ for others). Analogously, the impact of stricter environmental standards on real factor rewards can also be obtained. A fall in e raises the average cost in the polluting industry. This is equivalent to a reduction in the price since both effects have the same impact on profits. Factor substitution occurs. At constant product prices, the real rental rises [or falls] and the real wage rate falls [or rises], if the polluting industry is labor [or capital] intensive.

As seen in figure 2(a), under regulation that is more stringent, the labor intensive polluting industry has to employ more labor as well as capital for abatement. This is equivalent to a Hicks neutral technical retardation. Industry 1's isoquants shift to the right. The wage-rental ratio falls, which is represented by the common tangent rotating to the left from AB to CD. Real rewards to labor decrease (from $1/OB$ to $1/OD$) and real rewards to capital increase (from $1/OA$ to $1/OC$). Figure 2(b), illustrates the case for a capital-intensive polluting industry. The wage-rental ratio rises when the regulator lowers

e. The common tangent rotates to the right from AB to CD. Real rewards to labor increase (from $1/OB$ to $1/OD$) and real rewards to capital decrease (from $1/OA$ to $1/OC$).



Proposition 2 *Under constant terms of trade, if the polluting industry is labor [or capital] intensive, a stricter environmental standard reduces [or raises] real wage rate and raises [or lowers] the real rental of capital. With the standard remaining constant, the changes in the real factor rewards due to a change in the terms of trade are determined in accordance with the Samuelson-Stolper theorem.*

The two propositions stated above are relevant for a small trading country that takes the international terms of trade as given. If the polluting industry happens to be labor intensive, then the enforcement of a stricter environmental standard will lead to a decline in the real wage rate. This problem is faced by many labor abundant developing countries where attempts have been made to control industrial pollution. There are

instances in which the trade unions and factory owners have jointly campaigned against strict enforcement of environmental law.

2.1.3 Consequences of Regulation on Input-Output coefficients

The production coefficients C_i^2 are determined by factor prices; and factor prices as well as the environmental standard determine the production-abatement coefficients C_i^1 . As far as the functional relationship is concerned, this is true. However, a change in the standard will indirectly affect the production coefficients through its effect on the wage-rental ratio, as shown in (11). In other words, ω^* in equations (7) through (10) needs to be replaced by the expression for ω^* given in equation (11). Using the properties c) and d) of $|\theta|$ from appendix 4, this exercise yields the equations (14) and (15).

$$(14) \quad \begin{aligned} (C_L^2)^* &= -(\theta_{K2}/|\theta|)\sigma_2 S e^* - (\theta_{K2}/|\theta|)\sigma_2 P^* \\ (C_K^2)^* &= -(\theta_{L2}/|\theta|)\sigma_2 S e^* - (\theta_{L2}/|\theta|)\sigma_2 P^* \end{aligned}$$

$$(15) \quad \begin{aligned} (C_L^1)^* &= -A_{L1} e^* - (\theta'_{K1}/|\theta|)\sigma_e S e^* - (\theta'_{K1}/|\theta|)\sigma_e P^* \\ (C_K^1)^* &= -A_{K1} e^* + (\theta'_{L1}/|\theta|)\sigma_e S e^* + (\theta'_{L1}/|\theta|)\sigma_e P^* \end{aligned}$$

As seen in (14), the effect of regulation on the production coefficients of the non-polluting industry is straightforward and depends on the factor intensity relationship (sign of $|\theta|$). As seen in (11), under constant terms of trade and when the industry is capital intensive [or labor intensive], if e falls, then the wage rental ratio decreases [or increases]. Substitution occurs in favor of the relatively cheaper factor (C_L^2 rises [or falls] and C_K^2 falls [or rises]). This is one of the unanticipated effects of regulation. As seen in (15), the

effect of a change in e on the production-abatement coefficients of the polluting industry is more complex. If the regulator lowers e , the producer will require more labor and capital for abatement. This is the direct effect of regulation (In (15), if $e^* < 0$ then $-A_{L1}e^* > 0$ and $-A_{K1}e^* > 0$). At the same time the factor rewards change post regulation and substitution will occur in favor of the relatively cheaper factor (In (15), if $e^* < 0$ then $-(\theta'_{K1}/|\theta|)S\sigma_e e^* > 0$ and $(\theta'_{L1}/|\theta|)S\sigma_e e^* < 0$). This is another indirect effect of regulation. If the polluting industry is labor intensive, the effect on C_L^1 is unambiguous. The fall in e directly raises it and the subsequent factor substitution raises it even further. In the case of C_K^1 , the direct effect of a fall in e is to raise it but factor substitution due to fall in ω lowers it. The ambiguity is on labor if the industry is capital intensive. The ambiguity is removed when the direct effect of a higher standard on factor inputs required for abatement (A_{L1} , A_{K1}) is insignificant whereas the elasticity of factor substitution (σ_e) is sufficiently high. Under this special circumstance, if e falls, then C_L^1 rises and C_K^1 falls, in the labor intensive polluting industry, provided that the terms of trade are kept constant. The effects move in the reverse direction if the industry is capital intensive.

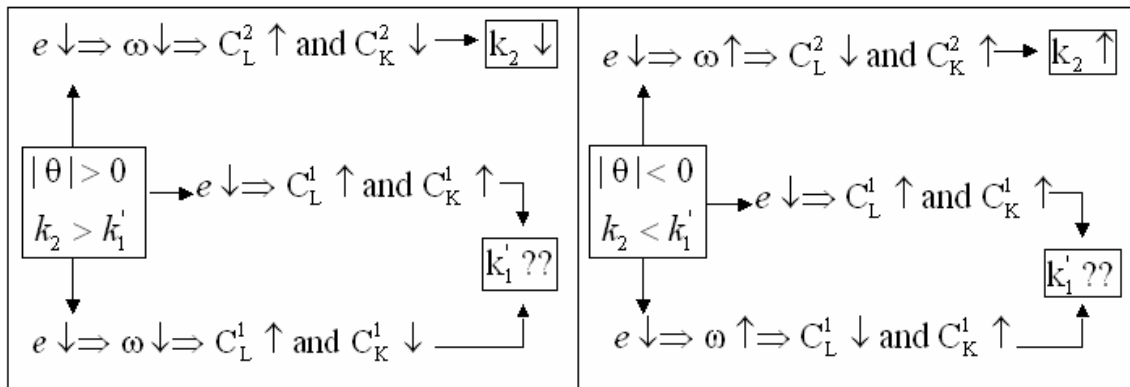


Fig. 3. Possible directions of changes

2.1.4 Effect of Regulation on the Composition of Industrial Output

As explained in appendix 6, equation (16), relates the change in the output ratio ($X_1^* - X_2^*$) with the changes in factor endowment ratio ($k^* = K^* - L^*$), environmental standard (e^*) and the terms of trade ($P^* = P_1^* - P_2^*$).

$$(16) \quad X_1^* - X_2^* = \frac{-k^*}{|\lambda|} + \frac{(J_{Ke} + J_{Le})}{|\lambda|} e^* + \frac{(J_{Kp} + J_{Lp})}{|\lambda|} P^*$$

$$(J_{Kp} + J_{Lp}) = (\sigma_e / |\theta|) (\lambda'_{K1} \theta'_{L1} + \lambda'_{L1} \theta'_{K1}) + (\sigma_2 / |\theta|) (\lambda_{L2} \theta_{K2} + \lambda_{K2} \theta_{L2})$$

$$(J_{Ke} + J_{Le}) = (\lambda'_{L1} A_{L1} - \lambda'_{K1} A_{K1}) + (S\sigma_e / |\theta|) (\lambda'_{K1} \theta'_{L1} + \lambda'_{L1} \theta'_{K1}) + (S\sigma_2 / |\theta|) (\lambda_{K2} \theta_{L2} + \lambda_{L2} \theta_{K2})$$

The coefficient of k^* in equation (16) is a function of $|\lambda|$. Thus, the effect of a change in factor endowment ratio on the composition of output depends on the factor intensities (appendix 7 b)). At constant terms of trade and environmental standard, an increase in the supply of a factor, raises the output of the good intensively using that factor in its production. This can be viewed as a restatement of the Rybczynski theorem under environmental regulation. The coefficient of P^* in equation (16) is positive ($(|\lambda| \times |\theta| > 0)$). This establishes that, irrespective of the factor intensity relationship, as the price of the polluting good rises relative to that of the clean good, the output of the dirty good rises relative to that of the clean good, keeping factor endowments and environmental standard constant.⁵ None of this is different from the standard model. Deviation from the standard model arises from the introduction of environmental regulation. The coefficient of e^* in (16) has an indeterminate sign. In view of what is noted in section 2.1.3, this is only to be expected. Two terms in $J_{Le} + J_{Ke}$ are independent of $|\theta|$. Rest of the terms in $J_{Le} + J_{Ke}$ have

⁵ Under the assumption of diminishing marginal productivities of labor and capital, there will be an absolute increase in the output of the dirty good and an absolute decrease in the output of the clean good.

a common factor $|\theta|$. When these terms are divided by $|\lambda|$, their sign becomes positive and independent of factor intensity relationship. The remaining terms responsible for the ambiguity are $(\lambda'_{L1}A_{L1} - \lambda'_{K1}A_{K1})/|\lambda|$.

$$(17) \quad \lambda'_{L1}A_{L1} \geq \lambda'_{K1}A_{K1} \text{ if } |\lambda| \geq 0 \text{ and } \lambda'_{L1}A_{L1} < \lambda'_{K1}A_{K1} \text{ if } |\lambda| < 0.$$

Under condition (17), the coefficient of e^* is positive. The output of the dirty industry decreases relative to that of the clean industry when e falls. The condition simply states that if the polluting industry is labor intensive, then a variation in the environmental standard will affect the labor coefficient used in abatement more strongly than the capital coefficient. The reverse is true if the polluting industry is capital intensive. Using the properties of $|\theta|$ and $|\lambda|$ (appendix 4 and 7) the coefficient of e^* in equation (16) is rearranged and stated before conditions (18) and (19). Under these conditions, the coefficient of e^* is negative. Under regulation that is more stringent, the output of the polluting industry rises relative to that of the clean industry.

$$\frac{(J_{Ke} + J_{Le})}{|\lambda|} = A_{L1} - \frac{\lambda'_{K1}(A_{K1} - A_{L1})}{|\lambda|} + \frac{S\sigma_e}{|\theta||\lambda|}(\lambda'_{L1} - |\lambda|\theta'_{L1}) + \frac{S\sigma_2}{|\theta||\lambda|}(\lambda_{L2} + |\lambda|\theta_{L2})$$

(18) (i) A_{K1} significantly dominates A_{L1} and A_{L1} is negligible. Standards have a greater impact on capital coefficients used in abatement than on labor coefficients. Regulation is perceived as capital using technical retardation by the polluting industry.

$$(ii) \quad \begin{cases} (|\lambda|\theta'_{L1} - \lambda'_{L1})\sigma_e \geq (\lambda_{L2} + |\lambda|\theta_{L2})\sigma_2 & \text{if } |\lambda| > 0 \\ (|\lambda|\theta'_{L1} - \lambda'_{L1})\sigma_e \geq (\lambda_{L2} - |\lambda|\theta_{L2})\sigma_2 & \text{if } |\lambda| < 0 \end{cases}$$

$$\frac{(J_{Ke} + J_{Le})}{|\lambda|} = A_{K1} - \frac{\lambda'_{L1}(A_{L1} - A_{K1})}{|\lambda|} + \frac{S\sigma_e}{|\theta||\lambda|}(\lambda'_{L1} - |\lambda|\theta'_{L1}) + \frac{S\sigma_2}{|\theta||\lambda|}(\lambda_{L2} + |\lambda|\theta_{L2})$$

- (19) (i) A_{L1} significantly dominates A_{K1} and A_{K1} is negligible. Standards have a greater impact on labor coefficients used in abatement than on capital coefficients. Regulation is perceived as labor using technical retardation by the polluting industry.
- (ii) Same as part (ii) of condition (18).

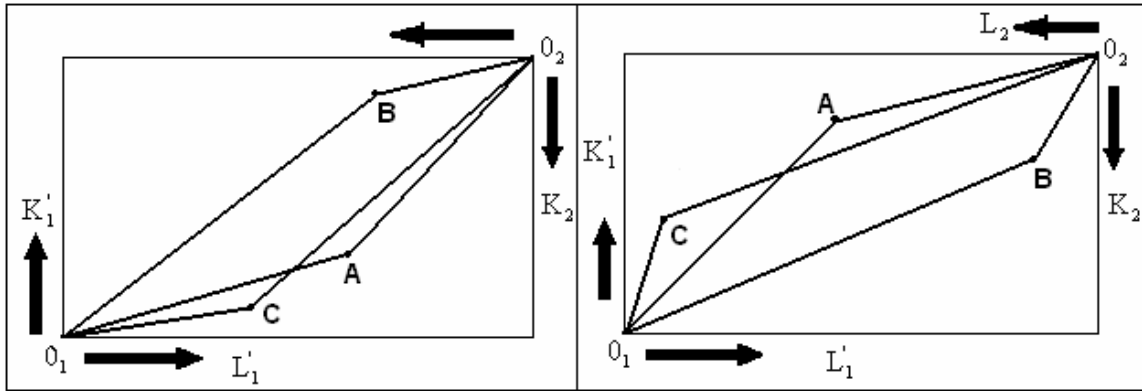


Fig. 4(a). $|\lambda| > 0$ and $k_2 > k_1'$

Fig. 4(b). $|\lambda| < 0$ and $k_2 < k_1'$

The uncertainty in the sign of the coefficient of e^* is due to the ambiguous effect of regulation on the input-output coefficients discussed in section 2.1.3. In fig. 4(a), the polluting industry is labor intensive. Under constant terms of trade, if e falls, k_2 falls (refer to fig. 3). If at the same time k_1' falls, the output of the polluting industry decreases from 0_1A to 0_1C (in (16), coefficient of $e^* > 0$). If however, k_1' rises, the output of industry-1 increases from 0_1A to 0_1B (coefficient of $e^* < 0$). In fig. 4(b), the polluting industry is capital intensive. Under constant terms of trade, if e falls, k_2 rises (fig. 3). If at the same time k_1' increases, the output of the polluting industry decreases from 0_1A to

O_1C (coefficient of $e^* > 0$). If however, k'_1 falls, the output of industry-1 increases from O_1A to O_1B (coefficient of $e^* < 0$).

Proposition 3 *The effect of the environmental standard on the composition of output is indeterminate. If (17) holds, a variation in the environmental standard will affect the labor [or capital] coefficient used in abatement by the labor intensive [or capital intensive] polluting industry more strongly than the capital [or labor] coefficient; regulation will lower the output of the polluting good, under constant terms of trade and factor supply. If regulation is perceived as capital using technical retardation (18) or labor using technical retardation (19) by the polluting industry; rising environmental standard may even increase the output of the polluting good.*

2.2 Demand Analysis

The consumer's utility function $U = U(D_1, D_2)$ is homothetic in D_1 (the quantity of the 'dirty' good the consumer wants to buy) and D_2 (quantity of the 'clean' good demanded). The consumer's problem is to maximize his utility subject to his budget constraint ($P_1D_1 + P_2D_2 = Y$), with respect to $\{D_1, D_2\}$. The Marshallian demand functions from the maximization problem are $D_1 = D_1(P)$ and $D_2 = D_2(P)$, where $P = P_1/P_2$. The variation in the demand ratio is determined by the terms of trade and the elasticity of substitution (σ) between the two goods.

$$(20) \quad D_1^* - D_2^* = -\sigma (P_1^* - P_2^*) = -\sigma P^*$$

3. Impact of Regulation on Comparative Advantage and the Pattern of Trade

$$(21) \quad P^* = \frac{k^*}{(\sigma |\lambda| + J_{Kp} + J_{Lp})} - \frac{(J_{Ke} + J_{Le})}{(\sigma |\lambda| + J_{Kp} + J_{Lp})} e^*$$

In equilibrium, $D_1^* - D_2^* = X_1^* - X_2^*$. Using equations (16) and (20), the solution for P^* is obtained in equation (21), where $k^* = K^* - L^*$. There is no ambiguity in the sign of the coefficient of k^* in (21). It is positive if the polluting good is labor intensive and negative if the polluting good is capital intensive. For any given level of pollution ($e^* = 0$), the pattern of trade is guided by the Heckscher-Ohlin theorem if there is no factor intensity reversal. A labor abundant country has comparative advantage in the good produced by the labor-intensive industry and a capital abundant country has comparative advantage in the good produced by the capital-intensive industry. The coefficient of e^* in (21) is negative and independent of the factor intensity relationship provided condition (17) holds. For countries identical in respect of both factor endowment and consumer preferences, a difference in the environmental standard is the basis for trade. In fig. 5, the home and foreign countries are initially identical in every respect including the environmental standard and are identically placed at the autarky equilibrium point **P**. Under a weaker standard, the home country's production point will shift to **A** as resources are transferred from abatement to production. At constant terms of trade (p_f), the home country will produce more of the polluting good and less of the non-polluting good. Due to homothetic and identical preferences, **B** will be the home country's demand point. There is an excess demand for the clean good and excess supply of the dirty good. Markets in the home country adjust until the autarky equilibrium point is **C** and the equilibrium price is $p_h < p_f$.

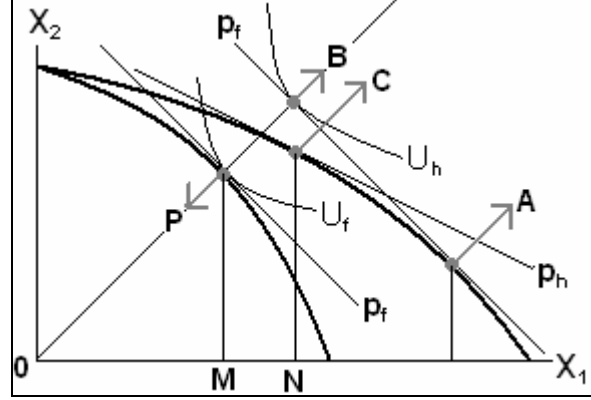


Fig. 5. Pattern of trade

Proposition 4 *The pattern of trade between two countries, identical in factor endowment, technology and consumer preferences, is determined by differences in the environmental standards. The country with a higher environmental standard will have comparative advantage in the good produced by the non-polluting industry and the country with a lower standard will have comparative advantage in the good produced by the polluting industry. The factor intensity relationship has no role to play in the determination of this pattern of trade. This result is based on the assumption that condition (17) holds, without which the pattern of trade is indeterminate.*

4. Regulation and Balance of trade

Under condition (17), if the regulator lowers e , exports of the polluting industry will fall relative to that of the non-polluting industry. Without this assumption, no comment can be made on either the pattern of trade or the volume of exports. Equation (22) describes the effect of regulation on a nation's balance of trade.

$$(22) \quad (X_1^* - X_2^*) - (D_1^* - D_2^*) = \left(\frac{-k^*}{|\lambda|} \right) + \left(\frac{J_{Ke} + J_{Le}}{|\lambda|} \right) e^* + \left(\frac{J_{Lp} + J_{Kp} + \sigma |\lambda|}{|\lambda|} \right) P^*$$

5. Conclusion

The paper contributes to the existing debate among environmentalists and advocates of free trade. The issue of the effectiveness of regulation in controlling pollution lies at the heart of the debate. The general prediction is that countries with lower environmental compliance costs specialize in the production and export of products produced by polluting industries. It is also suggested that some nations actively seek foreign investment by becoming pollution havens. The theoretical model presented in this paper attempts to provide an analytical framework for the debate. The simple general equilibrium model of trade under CAC programs of environmental regulation, attempts to highlight certain unanticipated consequences of governmental intervention. Regulation alters the wage-rental ratio which has implications for factors used in abatement. It is only a special case when a country with lax environmental standards has comparative advantage in and exports the goods produced by the polluting industry. There are cases possible where the dirty sector expands post regulation. The pattern of trade and the effect of regulation on net export in such cases is indeterminate. The model allows the possibility of a country with weaker environmental standard reducing the production of the polluting good and therefore exporting less of it, contradicting the hypothesis that the developing countries export pollution. The real rewards to factors are also sensitive to changes in environmental policies. Such changes can hurt the working class of a country, which is an issue to be handled carefully.

APPENDIX

The relative rate of change is represented by a (*) star (for any variable X , $X^* = dX/X$). A hat (^) denotes partial relative rate of change (for any variable X , $\hat{X} = \partial X/X$).

Appendix 1 (Cost Minimization in Industry-2) The non polluting industry will minimize average production costs $wC_L^2(\omega) + rC_K^2(\omega)$ w.r.t. $\{C_L^2, C_K^2\}$. This implies that $w dC_L^2 + r dC_K^2 = 0$. The cost share of the i^{th} factor ($i = L, K$) used in production by the industry is θ_{i2} . Since, $\theta_{L2} = wC_L^2/P_2$ and $\theta_{K2} = rC_K^2/P_2$, it is seen that, $\theta_{L2}(C_L^2)^* + \theta_{K2}(C_K^2)^* = 0$ (equation [1]). As depicted by $-(C_L^2)^* + (C_K^2)^* = \sigma_2 \omega^*$ (equation [2]), where σ_2 is the elasticity of factor substitution, industry-2 will react to changes in ω by substituting between factors. From the system of equations [1] and [2] solutions for $(C_L^2)^*$ and $(C_K^2)^*$ are calculated.

$$[3] (C_L^2)^* = -(\theta_{K2}/(\theta_{K2} + \theta_{L2}))\sigma_2 \omega^*$$

$$[4] (C_K^2)^* = (\theta_{L2}/(\theta_{K2} + \theta_{L2}))\sigma_2 \omega^*$$

Appendix 2 (Cost Minimization in Industry-1) The polluting industry chooses C_L^1, C_K^1 optimally, given e and ω . The environmental standard e is policy determined and ω is determined in the factor markets. Given e , industry-1 will minimize average total costs $wC_L^1(\omega, e) + rC_K^1(\omega, e)$ with respect to $\{C_L^1, C_K^1\}$. This implies that, $w dC_L^1 + r dC_K^1 = 0$. The cost share of the i^{th} factor used in either production or abatement by the industry is θ'_{i1} . Since, $\theta'_{L1} = wC_L^1/P_1$ and $\theta'_{K1} = rC_K^1/P_1$, it is seen that, $\theta'_{L1}\hat{C}_L^1 + \theta'_{K1}\hat{C}_K^1 = 0$ (equation

[5]). As portrayed by $-\hat{C}_L^1 + \hat{C}_K^1 = \sigma_e \hat{\omega}$ (equation [6]), where given e , σ_e is the elasticity of factor substitution, the producer will also react to any changes in ω by substituting between factors. From the system of equations [5] and [6], solutions for \hat{C}_L^1 and \hat{C}_K^1 are calculated and written below.

$$\hat{C}_L^1 = -(\theta'_{K1}/(\theta'_{K1} + \theta'_{L1}))\sigma_e \hat{\omega}$$

$$\hat{C}_K^1 = (\theta'_{L1}/(\theta'_{K1} + \theta'_{L1}))\sigma_e \hat{\omega}$$

At the same time, a fall in e will force the polluting industry to hire more labor as well as capital for abatement. Partial elasticities for factors, when e changes and ω remains fixed are defined by $A_{L1} = -\hat{C}_L^1/\hat{e}$ and $A_{K1} = -\hat{C}_K^1/\hat{e}$. By definition, these are positive. Input-output coefficients for the industry are functions of e and ω ($C_i^1 = C_i^1(\omega, e)$; $i=L,K$). Totally differentiating with respect to e and ω , it is seen that, $(C_i^1)^* = (\hat{C}_i^1/\hat{\omega})\omega^* + (\hat{C}_i^1/\hat{e})e^*$. Using the solutions for \hat{C}_L^1 and \hat{C}_K^1 along with the definitions of A_{L1} and A_{K1} , C_i^1 is re-calculated.

$$[7] \quad (C_L^1)^* = (\theta'_{K1}/\theta'_{K1} + \theta'_{L1})\sigma_e \omega^* - A_{L1}e^*$$

$$[8] \quad (C_K^1)^* = (\theta'_{L1}/\theta'_{K1} + \theta'_{L1})\sigma_e \omega^* - A_{K1}e^*$$

Appendix 3 (Income distribution) In the long run, every firm in the polluting industry will equate price to average cost ($wC_L^1 + rC_K^1 = P_1$). By totally differentiating the average cost condition and using the cost minimizing condition (from appendix 2), along with the definitions of θ'_{L1} and θ'_{K1} , it is seen that $\theta'_{L1}w^* + \theta'_{K1}r^* = P_1^* + Se^*$ (equation [9]); where $S \equiv (\theta'_{L1}A_{L1} + \theta'_{K1}A_{K1}) > 0$. Similarly, every firm in the non-polluting industry will also follow the average cost condition ($wC_L^2 + rC_K^2 = P_2$). Again differentiating the

average cost condition and using the cost minimization condition (from appendix1), along with the definitions of θ_{L2} and θ_{K2} , it is seen that $\theta_{L2}w^* + \theta_{K2}r^* = P_2$ (equation [10]). From the system of equations [9] and [10], solutions for w^* and r^* are obtained (where, $|\theta| = \theta'_{L1}\theta_{K2} - \theta_{L2}\theta'_{K1}$).

$$[11] \quad w^* = (\theta_{K2}/|\theta|)(P_1^* + Se^*) - (\theta'_{K1}/|\theta|)P_2^*$$

$$[12] \quad r^* = (\theta'_{L1}/|\theta|)P_2^* - (\theta_{L2}/|\theta|)(P_1^* + Se^*)$$

$$\Rightarrow \omega^* = w^* - r^* = \frac{-P_2^*}{|\theta|}(\theta'_{K1} + \theta'_{L1}) + \frac{(P_1^* + Se^*)}{|\theta|}(\theta_{K2} + \theta_{L2})$$

The above expression can be simplified into equation [13] by using the definition of $P^* = P_1^* - P_2^*$ along with the property (f) of $|\theta|$ worked out in appendix 4.

$$[13] \quad \omega^* = \frac{S}{|\theta|}e^* + \frac{P^*}{|\theta|}$$

Appendix 4 (Properties of $|\theta| = \begin{vmatrix} \theta'_{L1} & \theta'_{K1} \\ \theta_{L2} & \theta_{K2} \end{vmatrix}$)

$$a) \quad |\theta| = \theta'_{L1}\theta_{K2} - \theta_{L2}\theta'_{K1} = \frac{wL'_1L_2}{P_1P_2X_1X_2} \left(\frac{K_2}{L_2} - \frac{K'_1}{L'_1} \right) = \frac{wL'_1L_2}{P_1P_2X_1X_2} (k_2 - k'_1)$$

$$b) \quad |\theta| > 0 \quad \text{if } k_2 > k'_1 \quad (\text{Polluting industry is labor intensive.})$$

$$|\theta| < 0 \quad \text{if } k_2 < k'_1 \quad (\text{Polluting industry is capital intensive.})$$

$$c) \quad wC^1_L + rC^1_K = P_1 \Rightarrow \frac{wL'_1}{P_1X_1} + \frac{rK'_1}{P_1X_1} = 1 \Rightarrow \theta'_{L1} + \theta'_{K1} = 1$$

$$d) \quad wC^2_L + rC^2_K = P_2 \Rightarrow \frac{wL_2}{P_2X_2} + \frac{rK_2}{P_2X_2} = 1 \Rightarrow \theta_{L2} + \theta_{K2} = 1$$

$$e) \quad |\theta| = \theta'_{L1}\theta_{K2} - \theta_{L2}\theta'_{K1} = (1 - \theta_{L2})\theta'_{L1} - (1 - \theta'_{L1})\theta_{L2} = \theta'_{L1} - \theta_{L2}$$

$$f) \quad |\theta| = \theta'_{L1} \theta_{K2} - \theta_{L2} \theta'_{K1} = \theta_{K2} (1 - \theta'_{K1}) - \theta'_{K1} (1 - \theta_{K2}) = \theta_{K2} - \theta'_{K1}$$

Appendix 5 (Real factor rewards) To obtain the real rewards to labor, P_1^* or P_2^* is subtracted from both sides of the equation [11]. Using property f) of $|\theta|$ from appendix 4, it is seen that,

$$[14] \quad w^* - P_1^* = (\theta_{K2}/|\theta|)S e^* + (\theta'_{K1}/|\theta|)P^*$$

$$[15] \quad w^* - P_2^* = (\theta_{K2}/|\theta|)S e^* + (\theta_{K2}/|\theta|)P^*$$

Similarly, to obtain the real rewards to capital, P_1^* or P_2^* is subtracted from both sides of the equation [12]. Using property e) of $|\theta|$ from appendix 4, it is seen that,

$$[16] \quad r^* - P_1^* = -(\theta_{L2}/|\theta|)S e^* - (\theta'_{L1}/|\theta|)P^*$$

$$[17] \quad r^* - P_2^* = -(\theta_{L2}/|\theta|)S e^* - (\theta_{L2}/|\theta|)P^*$$

Appendix 6 (Composition of output) Fraction of the labor force employed by the polluting and non-polluting industries respectively are λ'_{L1} and λ_{L2} (where, $\lambda'_{L1} = L'_1/L$ and $\lambda_{L2} = L_2/L$). Fraction of the capital force employed by the polluting and non-polluting industries respectively are λ'_{K1} and λ_{K2} (where, $\lambda'_{K1} = K'_1/K$ and $\lambda_{K2} = K_2/K$). By totally differentiating the full employment of labor condition ($C_L^1 X_1 + C_L^2 X_2 = L$), using the definitions of $\lambda'_{L1}, \lambda_{L2}$ (stated above) along with definitions of $(C_L^1)^*, (C_L^2)^*$ (from section 2.1.3) and rearranging terms, equation [18] is derived.

$$[18] \quad \lambda'_{L1} X_1^* + \lambda_{L2} X_2^* = L^* + J_{Le} e^* + J_{Lp} P^*$$

$$J_{Le} = \lambda'_{L1} A_{L1} + (\lambda'_{L1} \theta'_{K1}/|\theta|)S \sigma_e + (\lambda_{L2} \theta_{K2}/|\theta|)S \sigma_2$$

$$J_{Lp} = (\lambda'_{L1} \theta'_{K1}/|\theta|)S \sigma_e + (\lambda_{L2} \theta_{K2}/|\theta|)S \sigma_2$$

Equation [19] is derived by totally differentiating the full employment of capital condition ($C_K^1 X_1 + C_K^2 X_2 = K$), using the definitions of $\lambda'_{K1}, \lambda_{K2}$ (stated earlier) along with the definitions of $(C_K^1)^*, (C_K^2)^*$ (from section 2.1.3) and rearranging terms.

$$[19] \quad \lambda'_{K1} X_1^* + \lambda_{K2} X_2^* = K^* - J_{Ke} e^* - J_{Kp} P^*$$

$$J_{Ke} = -\lambda'_{K1} A_{K1} + (\lambda'_{K1} \theta'_{L1} / |\theta|) S \sigma_e + (\lambda_{K2} \theta_{L2} / |\theta|) S \sigma_2$$

$$J_{Kp} = (\lambda'_{K1} \theta'_{L1} / |\theta|) \sigma_e + (\lambda_{K2} \theta_{L2} / |\theta|) \sigma_2$$

From the system of equations, [18] and [19], solutions are obtained for X_1^* and X_2^* .

Taking the difference between the two yields equation [20].

$$X_1^* = (\lambda_{K2} / |\lambda|) L^* - (\lambda_{L2} / |\lambda|) K^* + ((J_{Le} \lambda_{K2} + J_{Ke} \lambda_{L2}) / |\lambda|) e^* + ((J_{Ip} \lambda_{K2} + J_{Kp} \lambda_{L2}) / |\lambda|) P^*$$

$$X_2^* = (-\lambda'_{K1} / |\lambda|) L^* + (\lambda'_{L1} / |\lambda|) K^* - ((J_{Ke} \lambda'_{L1} + J_{Le} \lambda'_{K1}) / |\lambda|) e^* - (J_{Kp} \lambda'_{L1} + J_{Lp} \lambda'_{K1} / |\lambda|) P^*$$

$$[20] \quad X_1^* - X_2^* = \left(\frac{L^* - K^*}{|\lambda|} \right) + \left(\frac{J_{Ke} + J_{Le}}{|\lambda|} \right) e^* + \left(\frac{J_{Lp} + J_{Kp}}{|\lambda|} \right) P^*$$

Appendix 7 (Properties of $|\lambda| = \begin{vmatrix} \lambda'_{L1} & \lambda_{L2} \\ \lambda'_{K1} & \lambda_{K2} \end{vmatrix}$)

a) $|\lambda| = \lambda'_{L1} \lambda_{K2} - \lambda_{L2} \lambda'_{K1} = \frac{L'_1 L_2}{L K} (k_2 - k'_1)$

b) $|\lambda| > 0$ if $k_2 > k'_1$ (Polluting industry is labor intensive.)

$|\lambda| < 0$ if $k_2 < k'_1$ (Polluting industry is capital intensive.)

$\Rightarrow (|\theta| \times |\lambda|) > 0$. In other words, $|\theta|$ and $|\lambda|$ have the same sign.

c) $C^1_L X_1 + C^2_L X_2 = L \Rightarrow (L'_1 / L) + (L_2 / L) = 1 \Rightarrow \lambda'_{L1} + \lambda_{L2} = 1$

$$d) C_K^1 X_1 + C_K^2 X_2 = K \Rightarrow (K_1'/K) + (K_2/K) = 1 \Rightarrow \lambda'_{K1} + \lambda_{K2} = 1$$

$$e) |\lambda| = \lambda'_{L1} \lambda_{K2} - \lambda_{L2} \lambda'_{K1} = (1 - \lambda_{L2}) \lambda_{K2} - (1 - \lambda_{K2}) \lambda_{L2} = \lambda_{K2} - \lambda_{L2}$$

$$f) |\lambda| = \lambda'_{L1} \lambda_{K2} - \lambda_{L2} \lambda'_{K1} = \lambda'_{L1} (1 - \lambda'_{K1}) - \lambda'_{K1} (1 - \lambda'_{L1}) = \lambda'_{L1} - \lambda'_{K1}$$

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