POLLUTION ABATEMENT AND INTERNATIONAL SELF-SUFFICIENCY

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INTRODUCTION

As noted by López [1994], there is no consensus regarding the relationship between trade and environmental quality. Although much of the recent work has focused on trade liberalization and the resulting effects on environmental quality, we consider the opposite causality by investigating the effects of environmental quality, in terms of effectiveness of abatement, on the volume of trade.[1] When pollution abatement by emitter industries reduces the damage to receptor industries, Dorfman [1973] reasons that the exports of those receptor industries will increase. In addition to the output effect of reduced pollution damage on exports, Dorfman also anticipated a demand effect in the same direction, as command and control abatement raises the price of pollutive goods relative to receptor goods. From outside of the environmental economics literature, Rose [1991] finds that the ratio of nominal exports plus imports to nominal gross national product increases for small countries, but, since 1973, has been decreasing for large countries. As Feenstra puts it, "Large economies trade less with others, and more internally" [1998, 31].

In the paper we develop a two-good, two-country model that mutes the price effect and focuses on the output effect of abatement on trade. Contrasting two levels of abatement effectiveness, we find that world production of both goods always increases as the effectiveness of pollution abatement increases. However, the percent of world production that is exported always *decreases* as the effectiveness of abatement and the volume of world production both increase. It may be that pollution abatement has made the larger countries in Rose's [1991, 422] sample more self-sufficient.[2] The growth in total output and the decline in the percent traded are explained in terms of the *scale*, *technique*, and *composition* effects of Grossman and Krueger [1993] and Copeland and Taylor [1994].

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SIMULATING EFFICIENT PRODUCTION AND ABATEMENT IN A CLOSED ECONOMY

Consider a two-sector economy in which the production functions for a pollutive good Y and a pollution-damageable good X are given by the following hypothetical equations, which are linearly homogeneous with respect to the inputs, labor L_i and capital K_i.

$$Y = 128\, L_y^{1/6} K_y^{5/6} \tag{1}$$

and

$$X = 16\, L_x^{5/6} K_x^{1/6} (1 - e^2). \tag{2}$$

These equations typify the kind of Cobb-Douglas functions that economists use to simulate the production functions of individual industries comprised of identical firms operating at the point of locally constant returns to scale. Pollution damage to industry X increases at an increasing rate with respect to the domestic pollution level, e, which is assumed to be a fraction and is related to domestic production by the equation:

$$e = (0.0001)\, Y[Y/(\Omega K_a + Y)]. \tag{3}$$

The term in parentheses is the contribution to the ambient pollutant concentration per unit of pollutive output Y in the absence of abatement, whereas the ratio in brackets is the net fraction of total pollution that is emitted after abatement. This net fraction realistically increases with the pollutive output Y, but decreases with abatement capital K_a. Following Rauscher [1997, 31], it is assumed that abatement requires capital alone and in the more specific formulation used here, abatement is more effective the larger the cofactor of K_a, which is omega. The production functions (1) and (2) and the emission/abatement function (3) are taken from Kohn [1997].

In a Pigouvian market economy in long run competitive equilibrium, with the wage rate set at one unit of the country's currency, the rental price of capital is $r = Y_K / Y_L$, the price of good x is $p_x = 1/X_L$, the Pigouvian tax on emissions is $T = -\, p_x X_e$, and the price of good y is $p_y = 1/Y_L + Te_y$, where the subscripts of Y, X and e denote corresponding derivatives. Because of cost minimization by the polluting industry, the marginal cost of abatement is equated to the Pigouvian tax so that $r/(-\, e_K) = T$. In the competitive market equilibrium, the ratio of prices, p_x/p_y, equals the marginal rate of substitution in consumption, U_x/U_y, where $U(x, y)$ is the community utility function and x and y are the quantities consumed.

SIMULATING HECKSCHER-OHLIN-SAMUELSON EQUILIBRIA

Assuming that the world consists of two economies identically described by equations (1)-(3) but with different quantities of endowed inputs, free trade fosters a Heckscher-Ohlin-Samuelson equilibrium with all of the conventional properties. That is, the equality of relative prices, marginal rates of substitution in consumption, and terms of trade (except, as James [1974, 213] first noted in the case in which pollution damage is different in the two countries) the ratio of factor prices is not equalized by product trade. In contrast to the focus of Jaffe *et al.* [1995] on countries with different commitments to abatement, it is assumed here, following Perroni and Wigle [1994, 555], that the abatement technology is identical across the two countries. Pollution damage in each country is caused exclusively by emissions originating in that country. The alternative case of trans-boundary pollution is modeled in Kohn [1991, 1997].

The model satisfies the conditions in Kohn [1998] for Salvatore's [1990, 116] special case in which two countries are equally well off before trade and equally better off after trade. Such a model, which is similar to the Nash bargaining solution with identical threat points and equal bargaining strength, has the important property for this paper that the ratio of exports of a good to the total world production of that good *is the same ratio for both goods.* This eliminates ambiguous cases in which abatement increases the percent of one good traded but reduces the percent traded of the other. It also yields a simple equation, relating the ratio of exports to world production, that helps to explain the results of the model. When there is free trade, Y^T is exported by the country with an abundance of capital and X^T by the country with an abundance of labor. Letting asterisks denote the country that is more heavily endowed with the input in which the pollutive production is relatively intensive, the quantities of goods actually consumed are $y^* = Y^* - Y^T$, $x^* = X^* + X^T$, $y = Y + Y^T$, and $x = X - X^T$, and there is a Heckscher-Ohlin-Samuelson equilibrium when

$$U_x^* / U_y^* = y^*/x^* = p_x^*/p_y^* = U_x/U_y = y/x = p_x/p_y\ (y^* + y)/(x^* + x) = (Y^* + Y)/(X^* + X) = Y^T / X^T. \tag{4}$$

We simulate this free-trade equilibrium with a computer program incorporating Equations (1)–(3) for each country, along with the formulas for the respective market prices and Pigouvian tax, the equality of the marginal cost of abatement to the Pigouvian tax in each country, and the arbitrary resource endowments, $L_0^* = 1000$, $K_0^* = 80$ and $L_0 = 1250$, $K_0 = 64$. The model is run with Ω equal to 5,000 and then to 10,000, where the higher value of omega represents more effective abatement in which a lower net fraction of total pollution is emitted for any given quantities of K_a and Y. Whether trade is measured in terms of one good or the other, the fraction traded is unambiguous because

$$X^T/(X^* + X) = Y^T/(Y^* + Y), \tag{5}$$

which conveniently follows from the Salvatore properties of equation (4).

RESULTS OF THE SIMULATIONS

The numerical results of the simulations are summarized by the data in Table 1. Although world production of both goods is higher when Ω is higher, the proportion of the total world output that is traded is lower. To rule out the bias of specific constants, every parameter of the model that could be changed was changed in an effort to find a counter-example in which the fraction of goods traded increases or stays constant rather than decreases with more effective abatement. The scale parameter, 16, in equation (2) was increased and then decreased to alter the relative prices of the two goods, but this did not cause $Y^T/(Y^* + Y)$ to increase with Ω. In fact, such an increase in scale simply simulates Hicks neutral technical progress, so that the ratios remain exactly the same as those in Table 1. To eliminate the possibility that the capital intensity of abatement introduces a Rybczynski effect that biases the results, the model was run with labor, L_a, replacing capital, K_a, in the bracketed ratio in Equation (3) and deducted from L_0. Instead of reversing the results in Table 1, this intensifies them, causing Y^T, like X^T, to decline absolutely as well as proportionately as abatement effectiveness increases.

In our further search for a counter-example, we extended the range of Ω in both directions, raised and lowered the capital endowments relative to labor, raised and lowered the pre-abatement emission rate, which is 0.0001 in Equation (3), raised and lowered the exponent 2 of the pollution level e in Equation (2), which included the case of unity to allow for constant marginal damage, and also introduced a cofactor of e^2 in that same equation to augment or diminish the damage effects. By making that same cofactor of e^2 as small as 0.001, we were able to increase the pre-abatement emission rate from 0.0001 to 0.01 and obtain feasible pollution levels, e^* and e, well above unity. None of these changes caused $Y^T/(Y^* + Y) = X^T/(X^* + X)$ to increase or even remain constant as Ω increases. Finally, we reversed the endowments, but this simply reversed the direction of trade. All of our simulations with this model indicate that the proportion of total production traded goes down as abatement effectiveness increases. It may be that contrary results can be obtained using a different functional form for the abatement function; however, the one used here, which is taken from Harford [1989], has the property of linear homogeneity with respect to the inputs, K_a and Y, that Rauscher [1997, 31] likewise assumes.

Some insight into what is happening in this model is gained from the conceptual framework of Grossman and Krueger [1993, 14-15] and of Copeland and Taylor [1994, 768-70] in which the relationship between pollution and trade is decomposed into a *scale effect*, a *technique effect*, and a *composition effect*. What happens in all the simulations, including the variants described above, is characterized by the shifts from the first pair of columns in Table 1 to the second pair of columns. The greater effectiveness of abatement releases inputs from abatement to production, increasing the *scale* of both outputs. The more effective abatement, equivalent to a change in the *technique* of production, reduces the damage to industry X and therefore increases its output. Because more effective abatement lowers pollution damage, the Pigouvian tax is less and there is a shift in the *composition* of outputs from good X to good Y. Thus, in both countries, K_y and L_y are higher in the second pair of columns in Table 1. It follows from equation (4) that the ratio of the quantity of either good traded to the total production of that good is

TABLE 1
Abatement Capability and the Ratio of Trade to Total Production[a]

Country	Ω = 5000 K_0 Abundant	Ω = 5000 L_0 Abundant	Ω = 10000 K_0 Abundant	Ω = 10000 L_0 Abundant
K_a	5.950077	4.119360	4.125694	2.887848
K_y	63.61547	44.71298	65.59737	46.35533
L_y	196.0556	131.8486	203.3896	139.5318
Y	9822.954	6853.576	10139.19	7129.711
X	5864.997	8481.075	5925.653	8474.839
Y^T	1502.607	-	1516.609	-
X^T	-	1292.625	-	1264.696
$\mathbf{Y^T/(Y^* + Y)}$	**0.0901031**	**0.0901031**	**0.0878231**	**0.0878231**
y	8320.348	8356.182	8622.585	8646.320
x	7157.622	7188.449	7190.350	7210.142
Y_K	128.6762	127.7328	128.8059	128.1714
Y_L	8.350485	8.663442	8.308515	8.516233
X_K	93.68001	93.19250	96.09956	95.71664
X_L	6.079397	6.320756	6.198820	6.359809
e_y	$4.348291*10^{-5}$	$4.370071*10^{-5}$	$3.556333*10^{-5}$	$3.567999*10^{-5}$
e_K	$3.080696*10^{-2}$	$3.116792*10^{-2}$	$3.891760*10^{-2}$	$3.920497*10^{-2}$
T	500.1930	473.0467	398.3514	383.8860
r	15.40943	14.74388	15.50288	15.05024
p_x	0.1644900	0.1582089	0.1613210	0.1572374
p_y	0.1415034	0.1361000	0.1345251	0.1311199
e	0.2438269	0.1711142	0.2000214	0.1411700

a. These Heckscher-Ohlin-Samuelson solutions satisfy equations (1) – (6). The quantities of inputs used in industry X can be readily calculated from the data in Table 1 and the corresponding input constraints, $L_0^* = 1000$, $K_0^* = 80$, $L_0 = 1250$ and $K_0 = 64$. The price of labor is one unit of each country's respective currency.

(6)
$$\begin{aligned} X^T/(X^*+X) &= Y^T/(Y^*+Y) \\ &= 0.5[Y^*/(Y^*+Y) - X^*/(X^*+X)] \\ &= 0.5[X/(X^*+X) - Y/(Y^*+Y)]. \end{aligned}$$

The more effective abatement reduces damage so much more in the capital abundant country that on balance $X^*/(X^* + X)$ rises and $Y^*/(Y^* + Y)$ declines. In the labor abundant country, where damage is less, the *composition effect* dominates the *technique effect* so that $Y/(Y^* + Y)$ rises and $X/(X^* + X)$ declines. Thus in each country there is less specialization in the good in which that country has a comparative advantage, and therefore less is exported relative to total world production. The negative relationship between decreased specialization and the volume of world trade is well known [Helpman, 1999, 136]. Because the first ratio in each of the bracketed terms in Equation (6) always falls with more effective abatement and the second ratio always rises, the resulting decline in the percent of world output that is traded is an especially strong result in the present model.

In the case of X^T in Table 1, trade in the receptor good declines absolutely, which is contrary to the result that Dorfman [1973] anticipated. Dorfman anticipated a stronger price effect in which command and control abatement reduces the relative price of the receptor good. This does not hold here because in this model, like that of Copeland and Taylor [1994, 763-768], both countries tax emissions at a rate equal to marginal pollution damage. As more effective abatement reduces the tax and the relative price of the pollutive good, the relative price of the receptor good actually increases.

Although the strong, unambiguous results of this paper do not depend upon individual parameters nor functional forms, they may depend upon the *combination* of parameters, functional forms and resource endowments dictated by the strong Salvatore version of the Heckscher-Ohlin-Samuelson model. The Salvatore version, which is needed here to derive unambiguous results, is appropriate for simulating the case in which countries of comparable size trade with each other. To the extent that these are large countries, and therefore more self-sufficient than small countries [Feenstra, 1998], the results of this model in which abatement increases output, but reduces the proportion of output traded, may explain Rose's [1991] comparable results for large countries. Although "Current estimates of environmental control costs are relatively small", according to Copeland and Taylor, they emphasize that "marginal control costs are likely to become an increasingly important influence on trade in the future"[1994, 757]. It may be that Rose's [1991] empirical data for large countries are already picking up this "important influence."

CONCLUDING REMARKS

The Salvatore version of the Heckscher-Ohlin-Samuelson model is extended to incorporate a linear homogeneous abatement technology. The model simulates the increases in production that Dorfman [1973] anticipates from pollution abatement, but indicates that the quantities of goods traded may not increase as rapidly as world production of those goods. This result holds because the relative price effect of more efficacious abatement in the capital abundant country increases the output of the receptor industry more than that of the polluting industry, whereas the relative price effect of more efficacious abatement in the labor abundant country expands its polluting industry more than its receptor industry. In both countries, the relative expansions are in the goods that each imports, so that there is less trade relative to total world output. Assuming that our results apply to large countries, which are more self-sufficient than small countries, they may help explain Rose's [1991] finding, which he finds remarkable, that since 1973, international trade has been declining between large economies, despite their growth, in contrast to the experience of small countries.

NOTES

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1. For a survey of literature regarding trade and the environment, see Dean [1992]. Similar to this paper, Robison [1988] also considers the effects of abatement on trade but in a command and control regulatory context in which abatement imposes a cost on pollutive goods. In the present model, it is the Pigouvian tax that imposes a cost on pollutive goods, whereas abatement moderates that cost.
2. For larger countries in the sample of Rose [1991], we find only slightly higher abatement expenditures as expressed as a percentage of gross domestic product. Due to poor quality of the environmental compliance costs for OCED countries as noted by Jaffe *et al.* [1991, 158], we are reluctant to conclude that larger countries use more abatement.

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