Tradable Permits in Greenhouse Gas Emissions: A Macroeconomic Analysis in the North-South Context

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The paper presents an analytical macroeconomic model of North-South interaction covering a scheme of tradable permits in greenhouse gas emission encompassing the two regions. The delineation between the fix-price North and the flex-price South is along traditional structuralist lines. A number of parameter changes are analyzed including transfers to and from the South, as well as changes in emission efficiency in the two regions. Transfers from North to South could induce the participation of the South in global schemes for environmental control, as well as be linked to improvements in the South's emission efficiency. (*JEL* Classifications: F49, Q26)

I. Introduction

Concern about the environment is one of the most pressing issues of our time. The global nature of the problem cannot be overemphasized, as the events leading on to the 1992 world conference (at Rio de Janeiro) on the environment demonstrate. This is because environmental issues such as global warming affect all or most nations simultaneously, raising questions of interdependence amongst countries. The same interdependent theme is valid when one analysis policies to cope with environmental problems.

The bulk of the recent literature on the environment concentrates on estimating the costs of controlling pollution, see Nordhaus (1991), Pearce (1991), Boero, Clarke and Winters (1991) for example, the idea

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[**Seoul Journal of Economics** 1995, Vol. 8, No. 3]

of sustainable development following the publication of the Brundtland (1987) report, Pearce and Mäler (1991) for example, ways to respond to negative international externalities, see Mäler (1990), Baumol and Oates (1988) for example, and trade theoretic North-South models related to the environment, See Chichilnisky (1991), Copeland and Taylor (1992) for example. All of these are undeniably important, but relatively scant attention is paid to analytical *macroeconomic* issues particularly in the North-South[1] context.

One of the proposed solutions to global environmental problems is the idea of internationally traded emission permits which is the subject of this paper. Proposals for such schemes can be found in Grubb (1989), Tietenberg (1990) and Mohr (1991), among others. In an international setting tradable permit schemes appear to have found greater favor among economists compared to other alternative schemes. This is because it is felt that it is easier to implement an element of transfer between countries or regions under this scheme. Tradable permit schemes also have the great merit of flexibility as those with high abatement costs can buy the right to pollute from those with lower abatement costs. The scheme puts a ceiling on total emissions after negotiations and as such are like quotas compared to tariffs. Interestingly, the alternative scheme to control emissions, a carbon tax, works like a tariff. Tariffs (carbon taxes) and quotas (tradable permits) are equivalent under certainty about demand conditions. When demand for emissions is uncertain, a tariff or carbon tax is likely to be a superior revenue raising instrument, whereas quotas or tradable permits would be a better emission controlling device. We chose to focus on tradable permit schemes in this paper.

The purpose of this paper is to present an analytical model incorporating a system of tradable permits in greenhouse gas (GHGs) emissions, in the setting of *macroeconomic* interaction between North and South. A number of parameter changes are then analyzed such as increases in Northern autonomous expenditure, transfers to and from the South, as well as changes in emission efficiency in the two regions. It should be pointed out that there are several greenhouse gases besides carbon dioxide. Due to the difficulties in deriving a one to one relation between output and these other gases, this paper will concentrate on tradable permits dealing with carbon dioxide.

[1]By North I mean the richer countries of the world who are members of the OECD, the South refers to the poorer developing nations of the world.

Obviously one of the major problems with such a scheme would be to induce wide participation by sovereign states. *It is not the purpose of this paper to analyze the problems of achieving international cooperation in environmental matters or the difficulties of policing these agreements.* We analyze the macroeconomic consequences of a scheme of tradable permits involving the North and the South once the scheme is in place. Nevertheless, enough participation by key countries in the South could be ensured by side payments, taking the form of an over issue of permits to them which could be later sold by them. It might also be necessary to make income transfers to the South to induce cooperation by that region in environmental matters (see Nunnenkamp 1993). Given that the South too has property rights over the atmosphere, transfers to the South to reduce emissions could even be justified on Coasean grounds.

One problem does, however, deserve mention before we begin outlining the model. This has to do with the allocation of the initial tranche of emission permits and there are a number of proposals each of which is unlikely to be acceptable to all countries in their original form. First of all there is the system of 'grandfathering'. Under this proposal permits are assigned according to the current emission levels of different countries at some date. This system would clearly favor richer countries in the North as they industrialized earlier. Countries in the South would face a constraint on their ability to industrialize, a constraint not faced by the North in earlier times. To make such a scheme acceptable in the South would require countervailing compensation, not forthcoming at the moment given the disappointing results of the Rio Summit. Secondly, tradable permit allocation could be linked to historical responsibility. Most of the developed industrialized countries in the North have in the past emitted vast amounts of GHGs compared to the South simply by virtue of their earlier industrialization and low environmental concern at these junctures. One could argue that they have accumulated a vast amount of *natural debt*, see Smith (1991) on this. This scheme is extremely unlikely to be acceptable in the North. Thirdly, there is the proposal of linking the allocation of permits to GNP. This would favor countries in the North, particularly those countries with low fossil fuel consumption per unit of GNP such as Japan and France. Once again such a scheme would be perceived to be unfair in the South. Finally, there are proposals to link permit allocations to population size. As Grubb (1989) has argued it amounts to giving every human being an equal right to a claim on the atmosphere and the environment. Clearly, this scheme would be most beneficial to the South, particularly the more populous nations there such as China and India, but it is unlikely to be acceptable in the North. If any progress is to be made in advancing a scheme of tradable permits the actual scheme would need to be a *combination* of the proposals discussed above to gain acceptance, and monitored by an international agency acceptable to both North and South. Also to induce participation by the South, in matters relating to the environment, there would have to be an element of transfer from North to South.

The rest of this paper is organized as follows: Section II outlines a macroeconomic model of North-South interaction with a tradable permit scheme incorporated into the model, thereafter Section III goes on to analyze various parameter changes such as increases in transfers from one region to another as well as changes in emission efficiency in the two regions; finally Section IV concludes.

II. A Macroeconomic Model of Tradable Permits and North-South Interaction[2]

A system of tradable permits would first of all, require policy co-ordination between North and South regarding the upper limit or ceiling on total globally permissible level of emission, $\bar{E}$. Along with this agreement on the upper level of emission, a mechanism about the distribution of the revenues from the sale of the permits between North and South also needs to be decided upon *ex ante* which could take the form:

$$\mu\bar{E} = \mu\alpha_S\bar{E} + \mu(1 - \alpha_S)\bar{E}, \tag{1}$$

where α_S represents the proportion of total revenues going to the South, and $1 - \alpha_S$ the fraction of revenues which the North obtains; μ represents the internationally traded price (in Northern currency) of a unit of emission which is market determined. There would be an initial bench-mark price on a unit of emission, but the final equilibrium price is determined by international trading.

Equation (1) is generated by the fact that each pre-allocated unit of emission in (1) has to be paid for in advance. The actual allocation of

[2]Our model investigates the impact effects of a tradable permit scheme and does not analyze the dynamic effects of a gradual reduction in total emissions over time.

permits to the two regions is given in equation (2) below, and based on a notional output to be produced in the two regions. The international agency in charge of the scheme allocates a bench-mark price for the permits, and international negotiations arrive at the number of permits each region receives. The important point is that each region makes an *advance* payment into the scheme and this *generates the advance revenues* in (1) *The value of payments into the scheme need not coincide with the value of permits allocated.* If the value of permits allocated to a region exceeds its payments to the scheme, there is a net transfer to that region. Transfers to the South have been suggested (see Pearce 1991 for example) as a way of inducing that region's cooperation in a scheme of emission control. This point discussed in greater detail below.

The ex-ante allocation of permits corresponds to a *notional maximum output* that can be produced with it.[3] The ex-post equilibrium output in both regions could be different from this notional output, subject to the constraint that the global ceiling on emissions is not exceeded. That is precisely what will lead to *trade* in emission permits. The equilibrium (ex-post) output actually produced depends on goods market clearing mechanisms in the two regions and various parameter changes.

Three other points are well worth noting at this juncture. First, the price of the tradable permit in GHG emission is competitively determined. Excess demand leads to its price being bid up and vice versa. We abstract from problems about the monopolization of the price of tradable permits, as far as this model is concerned these are dealt with in Bertram (1991). The price of the tradable permit is also the tax rate on a unit of emission, see (2) below. Secondly, the initial allocation of permits could be based on population as Grubb (1989) advocates; or it could be based on GNP or some acceptable combination of the two. The exact initial allocative rule behind the scheme makes little difference to our interactive analysis, which is focused on parameter changes.

[3]These notional outputs in the two regions have to satisfy the individual rationality (IR) and incentive compatibility (IC) constraints of North and South to make the scheme work. See Maskin and Tirole (1990), as well as Murshed and Sen (1995), on these issues. Assuming that the South is less enthusiastic about emission control, it will have to be given a utility (output) level that satisfies a minimum reservation utility. That is why transfers to the South are potentially important. As far as the North is concerned it will have to be guaranteed a utility (output) level such that it is incentive compatible for it to truthfully reveal its true preferences about emission abatement.

Thirdly, the global constraint on total emissions, $\bar{E}$ may not be binding. Actual use of $E < \bar{E}$, but increased demand would push up prices from one equilibrium to another, as along an upward sloping supply curve. $E(\mu)$ and $E_1 > 0$. This represents a positive elasticity of supply with respect to price. Once the constraint is binding and the ceiling on emissions, has been reached the elasticity of supply is zero.

Turning now to the equation which equates global revenues from the scheme, to tax receipts from actual global emission:

$$\mu\bar{E} = \mu e_n P_N Q_N + \mu e_S \sigma Q_S / \sigma, \tag{2}$$

where Q_N and Q_S are output levels in the North and South respectively[4]; σ is the Southern price or terms of trade, the Northern price $P_N = 1$; $e_n = E_N/Q_N$ is the emission/output ratio, an exogenously determined (in the short run) technical parameter, the inverse of emission efficiency as a rise in E_N (emission in the North) relative to Q_N represents a worsening of emission efficiency; $e_S = E_S/Q_S$ is the same parameter as far as the South is concerned. Utilizing the fact that:

$$Q_S = F(\sigma) \tag{3}$$

where $F_1 > 0$, Southern output rises with its terms of trade

$$\mu\bar{E} = \mu e_n Q_N + \mu e_S F(\sigma) \tag{4}$$

or

$$E(\mu) = \mu e_n Q_N + \mu e_S F(\sigma) \quad \text{with } E_1 > 0, \tag{4$'$}$$

if the ceiling has not been reached Equation (4)′ describes equilibrium in the global market for tradable permits. The left hand side denotes supply and the right hand side demand which depends on actual output in the North and South, Q_N and F. Excess demand causes prices to be bid up and vice versa. There is no requirement for ex-ante permit allocations to match ex-post (or actual) use in any single region, however. Consequently the value of revenues received by each region need not exactly match the value of emissions. The value of emissions is, of course, the tax paid out by each region for emitting GHGs, which takes the form of payment for the tradable permits. Each unit of emission used by a region has to be paid for at the market price, the total

[4]These are the *notional maximum* output levels that can be produced in the two regions given an ex-ante permit allocation. The ex-post equilibrium outputs in the two regions may differ, that is why permits are traded.

amount of which represents a tax *paid* by society: $\mu e_s F$ and $\mu e_n Q_N$ for the South and North respectively. On the other hand the ex-ante allocation scheme decides on the allocation of permits and revenues. Thus, the sums of the two terms on the right hand side of (1) $\mu \alpha_S \bar{E}$ and $\mu(1 - \alpha_S)\bar{E}$ represent the sums which the South and North respectively *receive*. There is no reason, in any particular region, for payments to match (exactly) the receipts. If, for example, receipts exceed payments in the North, $\mu(1 - \alpha_S)\bar{E} > \mu e_n Q_N$, there will be net transfers from South to North.

Since each unit of output requires emission levels given by coefficients e_n and e_s and these will have to be paid for in the form of purchase of tradable permits (the tax), we need to introduce the concept of net income, gross output less the sum paid for the privilege of polluting. For the North, for example, this is:

$$P_N Q_N - \mu e_n P_N Q_N, \tag{5}$$

(5) represents aggregate supply or net income in the North. In equilibrium it is equal to aggregate demand or total expenditure. We set the Northern price, $P_N = 1$, hence

$$\begin{aligned} Q_N - \mu e_n Q_N = A(Y_N^D;\, \sigma) + G + C_S\,(1 - v_S) \\ \sigma Q_S(Y_S^D) - \sigma S(Y_N^D;\, \sigma), \end{aligned} \tag{6}$$

where A represents absorption, G autonomous expenditure, the trade balance, is exports $c_S(1 - V_S)\ Q_S$ less imports, S from the South. Absorption depends positively on disposable income, Y_N^D and the terms of trade σ, the Laursen-Metzler effect. Imports, S, are negatively related to the terms of trade, σ, but vary positively with Y_N^D.

$$Y_N^D = Q_N - \mu e_n Q_N + \mu(1 - \alpha_S)\ \bar{E} + D. \tag{7}$$

Disposable income in the North is the value of output less the value of payments made to purchase emission rights, $\mu e_n Q_N$, plus revenues received from the (initial) allocation scheme regarding sharing revenues, $\mu(1 - \alpha_S)\bar{E}$, plus transfers to the North from the South as a result of the latter's indebtedness to the former. If the sum of the last three terms in (7) are positive, the North receives positive transfers from the South.

Turning to the South, net income or aggregate supply in that region is:

$$\sigma Q_S - \mu e_S Q_S. \tag{8}$$

Note that the price of the globally traded permit is denominated in Northern currency units, P_N. Employing a linear expenditure system for the South, in equilibrium (aggregate demand = aggregate supply) implies:

$$\sigma Q_S - \mu e_S Q_S = \sigma c_S(Y_S^D) - \sigma c_S(1 - \upsilon_S)(Y_S^D) + \sigma_S(\cdot), \tag{9}$$

where c_S is the total propensity to absorb in the South of which υ_S is on home and $1 - \upsilon_S$ is expended on Northern goods (imports), $c_S(1 - \upsilon_S)$ (Y_S^D) represents imports and, S exports. Disposable income in the South

$$Y_S^D = \sigma Q_S - \mu e_S Q_S + \mu \alpha_S \bar{E} - D, \tag{10}$$

where $\mu e_S Q_S$ is payment for emitting GHGs, $\mu \alpha_S \bar{E}$ revenues received from the scheme and D represents debt servicing on the debt owed by the South to the North. If the sum of the last three terms are negative the South makes net positive transfers to the North. Substituting (10) into (9), utilising (3), cancelling terms and normalizing by σ (which also converts values denominated in Northern currency to Southern currency units), we get:

$$\begin{aligned} F(\sigma)\{1 - (\mu e_S/\sigma)\} = \sigma c_S \upsilon_S [F(\sigma)\{1 - (\mu e_S/\sigma)\} \\ + \mu \alpha_S \bar{E}/\sigma - D/\sigma] + S(\cdot). \end{aligned} \tag{11}$$

For the North, we substitute (7) into (6), utilising (3), the Northern price $P_N = 1$, thus:

$$\begin{aligned} Q_N(1 - \mu e_n) = A\{Q_N(1 - \mu e_n) + \mu(1 - \alpha_S)\bar{E} + D; \sigma\} \\ + G + c_S(1 - \upsilon_S)\{F(\sigma - \mu e_S) + \mu \alpha_S \bar{E} - D\} \\ - \sigma_S\{Q_N(1 - \mu e_n) + \mu(1 - \alpha_S)\bar{E} + D; \sigma\}. \end{aligned} \tag{12}$$

Thus, (12), (11) and (4) or (4)′ are the fundamental equilibrium relations of the model which determine Q_N, σ and μ. Note that in (7), (10)-(12) we can have either E fixed (if the ceiling on emissions is bending) or E (μ) if the ceiling has not been approached. Also once the ceiling has been reached output in one region can only rise at the expense of another region. (see Appendix)

Our model of North-South interaction following Taylor (1983) will be 'structuralist' in that quantities adjust to clear markets in the fix-price North, and changes in prices bring about equilibrium in the flex-price Southern goods market. This means that there is excess capacity in the North and capacity constraints in the South. Increases in the Southern price can ease capacity constraints in the South as it is able to import more from the North. See Murshed (1992) for more details on these models. Our model will also take into account the commercial debt owed by the South to the North in analyzing transfers.

III. Variations in Parameters

In order to proceed we totally differentiate equations (12), (11) and (4) or (4)′ and arrange them in matrix form (see Appendix for details).

A. An Increase in Autonomous Expenditure, G, in the North

A rise in autonomous demand in the North, *G*, benefits the North in the form of higher output Q_N, and the South via improved terms of trade σ. Thus 'global Keynesianism' appears to work (see (A6) and (A7) below) if the ceiling on emissions, $\bar{E}$, has not been reached.

These results can be depicted diagrammatically in Figure 1, see (A4) and (A5) in the Appendix describing the derivation of the *NN* and *SS* schedules in Q_N and σ space. The *NN* schedule represents equilibrium in the Northern goods market. It is upward sloping, as for any given Southern terms of trade σ, a rise in Q_N implies excess demand for the Southern product Q_S, pushing up σ, the price of the Southern good. The *SS* schedule is also upward sloping for the same reason; the *SS* schedule is the locus of points which represent equilibrium in the Southern goods market. An increase in G shifts *NN* to NN^1 along the *SS* curve, we move from A to B in Figure 1.

Gross output in both regions will increase if the global ceiling on total emissions had not been arrived at before the rise in *G*. It should be noted that although gross output rises in both regions, Q_N and Q_S (via higher σ) increase, *net* income does not necessarily rise proportionately. This is because a fraction of income in both regions will go towards the financing of tradable permits. As equation (A8) demonstrates below the price of tradable permits will increase as demand for them rises. There could be, however, some transfers from North to South, if as is plausible, and as (A6) and (A7) suggest, Northern gross income rises by more than gross income in the South. This would take place under any pre-arranged scheme of revenue sharing between North and South. As Northern gross income increases by more relative to the South, and as the price of tradable permits is bid up, the North pays more into the 'global fund' and the South receives more from it.

If the global ceiling on emissions had been reached before the rise in *G*, from (4), the rise in Northern output can only be achieved at the cost

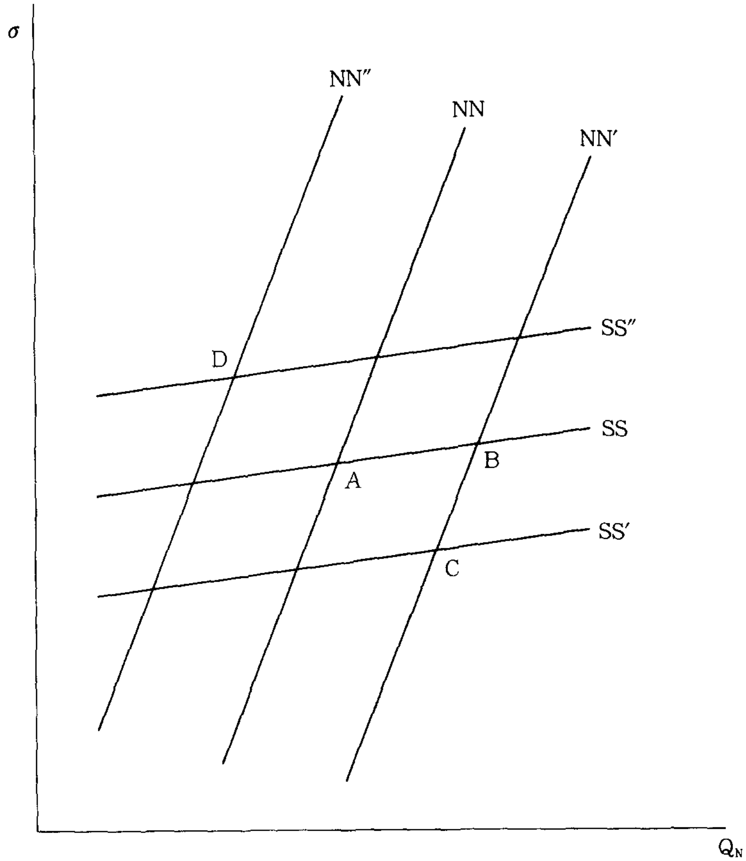

FIGURE 1
TRANSFERS TO AND FROM THE SOUTH

of a fall in Southern output. Analytically it means $a_{31} > 0$, $a_{32} < 0$ and $E_1 = 0$ in (A3). The price of tradable permits would still rise.

B. An Increase or Decrease in Transfers to the South

A decrease in transfers to the South manifested itself throughout the 1980s via the mechanism of the debt crisis, in relation to the heavily indebted countries in Latin America and Sub-Saharan Africa. The 1980s, dubbed a lost decade for these regions in the South, was characterized by net negative transfers to these regions, implying positive transfers to the richer North. The debt instrument is similar to a long-term bond whose price is denominated in 1 unit of Northern currency. This allows us to equate the value of the stock of debt to the flow of repayments on it.

An increase in indebtedness or debt servicing, a transfer from South to North, will lower the Southern terms of trade and is very likely to raise Northern gross income, Q_N, as suggested by (A9) and (A10) below. In terms of Figure 1, the *NN* schedule shifts rightwards to NN^1, whereas the *SS* schedule moves downwards to SS^1. The new equilibrium is at point *C*, moving there from the initial point at *A*. As far as the price of tradable permits, μ, is concerned, (A11) suggests that the effect is ambiguous. On the one hand, the decline in Southern disposable income via terms of trade deterioration and increased transfers lowers demand for GHG emission. But on the other hand, rising (gross) income in the North, does put upward pressure on the demand for tradable permits. Comparing (A10) with (A9) the latter could dominate, and μ could rise. As transfers lead to an increase in income in one region, and a decline in the other region, the results are qualitatively unchanged even when the ceiling on emissions has been reached.

What is the effect of an increase in debt servicing flows, *D*, on the future stock of debt $D(t + 1)$? The future stock of debt will rise if the present balance of payments deficit of the South rises after a rise in *D*. The balance of payments deficit (surplus) of the South (North) is given by the right hand side of (13).

$$D(t + 1) = c_S(1 - \upsilon_S)(\cdot) - \sigma s(\cdot) + D, \tag{13}$$

where *D* represents debt servicing.

The arguments in $(\cdot)$ are given by (12).

$$\begin{aligned}\frac{dD(t+1)}{dD} = {} & c_S(1 - \upsilon_S)\, F(1 - \mu e_S) \underset{(-)}{} \frac{d\sigma}{dD} \underset{(-)}{} - c_S(1 - \upsilon_S) \\ & - \sigma S_1(1 - \mu e_n) \underset{(-)}{\frac{dQ_N}{dD}} - \underset{(-)}{\sigma S_1} \\ & - S(1 + \Omega)\frac{d\sigma}{dD} + 1,\end{aligned} \tag{14}$$

$|\Omega| < 1$, price inelastic demand for Southern exports in the North is necessary for the future stock of debt, $D(t + 1)$, to rise following an exogenous increase in current debt servicing, *D*. $\Omega = \sigma S_2/S$.

Many would argue that the cumulative effect of the 1980s' debt crisis which involved high transfers via debt servicing to the North, resulted in a worsening of the emission efficiency in the South, as they struggled to keep up debt repayment. Thus the debt crisis has been particularly harmful to the global environment, causing a negative externality to shift back to the North.

Secondly, it can be strongly argued that reversing the trend of the debt crisis, positive transfers from North to the South could provide just the necessary inducement for the South to participate in an environmentally friendly scheme which the model outlines. Such positive transfers could take the form of debt reduction (including debt for nature swaps) or could take the form of issuing a higher share of tradable permits and revenues from the sales of these. In the terms of our model this latter approach would involve raising α_S in equations (1) and (4) and analytically has the same effect as a reduction in D. The approach of overissuing permits and GHG revenues to the South could be a more satisfactory method of aiding the South and "cajoling" it to more environmentally friendly policies. This is because debt for nature swaps are more difficult to implement given Northern commercial bank and official interests, although there are a few isolated examples. In Figure 1, increased transfers (positive net transfers) to the South from the North would lead to an outcome depicted by point D, showing a higher Southern terms of trade.

C. A Change in Emission Efficiency in the South

In the Appendix we examine the effects of an increase in e_s, but with reversed signs the analysis would apply to a rise in emission efficiency. An increase in emission efficiency in the South could be a result of technical progress or it could occur due to a deliberate policy response —one that is induced by making transfers to the South or debt forgiveness as discussed above or a condition of existing aid. As far as the South is concerned, it will tend to lower her terms of trade, whereas Northern gross income is likely to increase (A13 and A12). In the South increased emission efficiency will cause aggregate supply to rise relative to demand and hence the terms of trade will decline. This does not, however, necessarily imply a decline in welfare in the South, as *net* output could rise and absorption definitely rises. Also less sums are paid to purchase emission permits, these sums representing a diminution of disposable income. Gross Northern income is likely to rise from positive export multiplier effects emanating from the South. In terms of Figure 2, starting from point A, the decline in e_s, is likely to shift NN to the right (NN^1) and SS downwards to SS^1 with the new equilibrium at point B showing higher Q_N and lower σ. The effect on the price of trad-

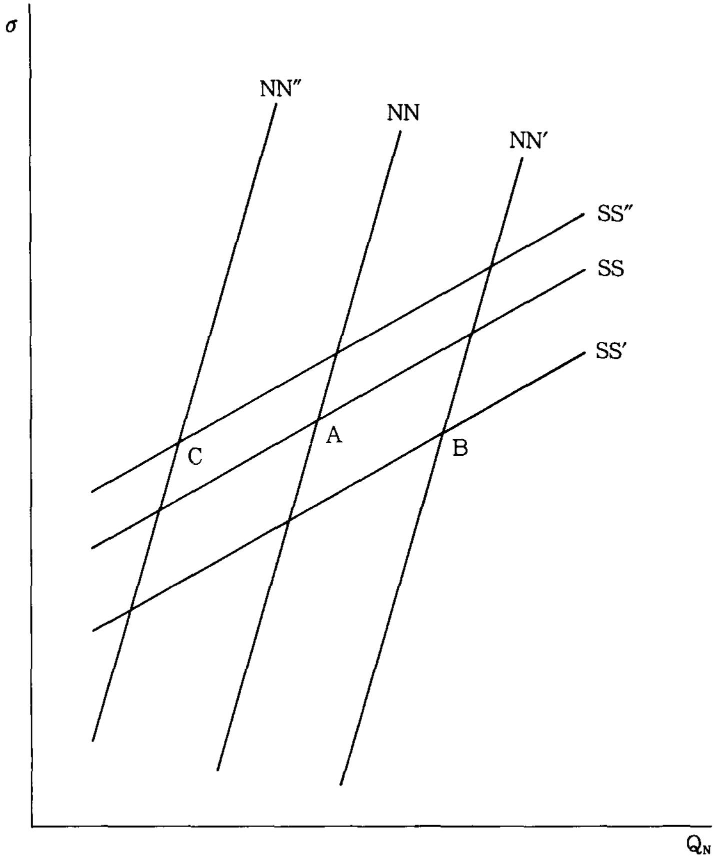

FIGURE 2
CHANGES IN EMISSION EFFICIENCY

able permits is ambiguous, but is likely to decline if the last two terms in (A14) dominate. Both here and in the case below the results are qualitatively unaffected if the ceiling $\bar{E}$ had been reached before the change in parameters.

D. An Increase in Emission Efficiency in the North

This would be represented by a decline in e_n induced say by regulatory policies and other pressures to adopt environmentally cleaner technologies. Equations (A15) to (A17) should be evaluated with negative signs. As (A15) suggests gross output in the North is likely to fall. This is because al lower emission to output ratio, e_n creates net excess supply causing gross output to decline in the North. But net income is likely to fall by less and could even rise if there was a very large improvement in energy efficiency (fall in e_n). The depletion of disposable income is less as smaller sums are paid to purchase emission rights.

As far as the South is concerned, there is a decline in that region's terms of trade (A16). Thus unlike in the case of an improvement in the Southern and emission efficiency, improvements in the North's emission efficiency ratio does not benefit the other region. In Figure 2 this is represented by a leftward and upward shifts in *NN* and *SS* schedules respectively to NN^{11} and SS^{11}. We move from the initial equilibrium at *A* to point *C* showing a decline in Q_N and σ. The price of tradable permits, μ, is set to fall (A17) as Q_N declines.

IV. Conclusions

This paper has attempted to model the macroeconomic effects of a tradable permit scheme in the North-South context. This represents a departure from most of the literature which focuses attention on the bargaining, cooperation and incentive issues in tradable permit schemes. Our model is short-run in that the emission efficiency parameters are exogenously fixed. In the longer run emission efficiency will depend on expenditure on research and development in the North and the speed with which it is implemented in the South. It is also static because the global ceiling on total emissions is not being continuously revised over time. To summarize our results an increase in autonomous expenditure in the North may not raise net income proportionately in the North, this could also be achieved via a decline in Southern output. But it could induce a rise in the transfer element from North to South under the pre-arranged revenue sharing arrangements within the tradable permit scheme. A rise in direct transfer from North to South will raise the latter's terms of trade but the effect on the global price of tradable permits is ambiguous. A rise in emission efficiency in the South could be connected with increased transfers to that region. This will raise disposable income in the South even if its terms of trade decline and may raise net income in the North. Increases in emission efficiency in the North lower the South's terms of trade. The price of the tradable permit declines and even though gross income in the North declines, net income could rise if the emission efficiency improvement is large. Improvements in the South's emission efficiency benefit the North, but not vice versa—a major asymmetry.

From the standpoint of North-South interaction the environment is likely to be a major area of interest, as it is this aspect of North-South interdependence which is going to cause the greatest interest in the North. Other issues surrounding North-South interaction such as trade policy and the debt crisis are of greater concern to the South than the North. The environment, however, is the area where the North cannot afford to ignore the South. This is due to the nature of the problem. Major environmental problems such as global warming involving the emission of GHGs involve reciprocal externalities and the control of these emissions of necessity requires the participation of the South, particularly large countries such as India and China.

The policy of making side payments to the South to induce its cooperation in environmental matters needs to be seriously considered. Side payments can take the form of the relaxation of the formidable trade barriers which the North has erected towards the South and/or further relief in international indebtedness. The important point here is that these side payments from North to South can be justified on both *efficiency* (as it induces participation in environmental control) and *equity* grounds (historical responsibility). Finally, in spite of the herculean task in devising it, an international system of tradable permits with a ceiling on GHG emission could be one way forward in tackling (international) GHG emission. The analytical model of the last section seems to suggest that such a system could be in the interests of both regions, especially if accompanied by transfers or side payments to the South *tied* to improvements in emission efficiency.

Appendix

From (4) as:

$$\mu\bar{E} = \mu e_n Q_N + \mu e_S F(\sigma), \tag{A1}$$

or

$$\mu E(\mu) = \mu e_n Q_N + \mu e_S F(\sigma). \tag{A2}$$

If the constraint is binding, $d\bar{E} = 0$ and, $\mu e_n dQ_N = -\,\mu e_S F_1 d\sigma$ and vice versa. The price of the tradable permit could rise if the rise in output in one region is greater than the fall in output in the other region.

Totally differentiating (11) and (12) and (4)′ and writing them in matrix form yields:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} dQ_N \\ d\sigma \\ d\mu \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \end{bmatrix} \begin{bmatrix} dG \\ dD \\ d\alpha_s \\ de_S \\ de_n \end{bmatrix} \tag{A3}$$

where: $a_{11} = (A_1 - 1 - \sigma S_1)(1 - \mu e_n) < 0$

$$a_{21} = S_1(1 - \mu e_n) > 0$$
$$a_{31} = e_n \mu > 0$$
$$a_{12} = -\varepsilon S + c_S(1 - v_S) F + c_S(1 - v_S) F_1 (\sigma - \mu e_S) - \sigma S_2 > 0$$

by the Marshall-Lerner conditions.

$$a_{22} = -e_S F \mu / \sigma^2 + (\sigma c_S v_S - 1) F_1 \{1 - (\mu e_S / \sigma)\} + S_2 < 0$$
$$a_{32} = e_S F_1 \mu > 0$$

$$a_{13} = e_n Q_N (1 - A_1 + \sigma S_1) - c_S(1 - v_S) F e_S + (E + \mu E_1) \{(1 - \alpha_S)(A_1 - \sigma S_1) + c_S(1 - v_S)\} > 0$$

$$a_{23} = (F e_S / \sigma)(1 - \sigma c_S v_S) - S_1 Q_N e_n + (E + \mu E_1)\{c_S v_S \alpha_S + (1 - \alpha_S) S_1\} > 0$$

$$a_{33} = -\mu E_1 - E < 0.$$

If the ceiling on emissions is reached, $E_1 = 0$ in the above and we need to make assumptions about the signs of a_{31} and a_{32}.

$$b_{11} = -1;\; b_{21} = 0;\; b_{31} = 0$$
$$b_{12} = c_S(1 - v_S) - A_1 + \sigma S_1;\; b_{22} = c_S v_S - S_1;\; b_{32} = 0$$
$$b_{13} = \mu \bar{E}(A_1 - \sigma S_1 - c_S(1 - v_S));\; b_{23} = (S_1 - c_S v_S)\mu \bar{E};\; b_{33} = 0$$
$$b_{14} = c_S(1 - v_S) F \mu;\; b_{24} = (\sigma c_S v_S - 1) F \mu / \sigma;\; b_{34} = -F\mu$$
$$b_{15} = (A_1 - 1 - \sigma S_1)\mu Q_N;\; b_{25} = S_1 \mu Q_N;\; b_{35} = -Q_N \mu.$$

The trace of the Jacobian is negative and the determinant $|J|$ is assumed negative by the requirement of stability. This requires the leading diagonal of the Jacobian in (A3) to dominate, see McKenzie (1961).

N.B. $A_1 > 0;\; A_2 = S(1 - \varepsilon) > 0;\; S_1 > 0;\; S_2 < 0;\; F_1 > 0$

The slope of the *NN* curve from (A3), equation (11) using (4)

$$\frac{d\sigma}{dQ_N}\Big|_{NN} = -\frac{a_{11} + \dfrac{a_{13} e_n}{\mu E_1} + E}{a_{12} + \dfrac{a_{13} e_s F_1}{\mu E_1} + E} > 0 \tag{A.4}$$

$$\text{if} \quad a_{11} > a_{13}\frac{e_n}{\mu E_1} + E.$$

The SS curve is given form (12) and (4) utilising (A3)

$$\frac{d\sigma}{dQ_N}\Big|_{SS} = -\frac{a_{22} + \dfrac{a_{23}e_n}{\mu E_1} + E}{a_{22} + \dfrac{a_{23}e_S F_1}{\mu E_1} + E} > 0. \tag{A5}$$

$$\text{if} \quad a_{22} > a_{23}$$

The *NN* curve is steeper than the SS curve

$$\frac{dQ_N}{dG} = \frac{(\mu E_1 + E)a_{22} + e_S F_1 \mu a_{23}}{|J|} > 0, \tag{A6}$$

as $|J| < 0$ and using the stability conditions

$$\frac{d\sigma}{dG} = \frac{S_1(1 - \mu e_n)(-\mu E_1 - E) - e_n \mu a_{23}}{|J|} > 0 \tag{A7}$$

$$\frac{d\mu}{dG} = \frac{e_n a_{22}\mu - S_1(1 - \mu e_n)e_S F_1 \mu}{|J|} > 0 \tag{A8}$$

$$\begin{aligned} \frac{dQ_N}{dD} = &\{c_s(1 - v_s) - A_1 + \sigma S_1\}\{a_{22}(-\mu E_1 - E) - e_S F_1 \mu a_{23}\} \\ &+ a_{12}(\mu E_1 + E)(c_s v_s - S_1) + a_{13}(c_s v_s - S_1)e_S F_1 \mu \\ &\text{divided by } |J| < 0 \end{aligned} \tag{A9}$$

$$\frac{d\sigma}{dD} < 0 \quad \text{only if} \quad |c_s v_s| > |S_1|$$

$$\begin{aligned} \frac{d\sigma}{dD} = &\{(A_1 - 1 - \sigma S_1)(1 - \mu e_n)\}\{(E + \mu E_1)(S_1 - c_s v_s)\} \\ &+ \{c_s(1 - v_s) - A_1 + \sigma S_1\}\{(E + \mu E_1)S_1(1 - \mu e_n) + e_n \mu a_{23}\} \\ &+ a_{13}\mu e_n(S_1 - c_s v_s) \\ &\text{divided by } |J| < 0 \end{aligned} \tag{A10}$$

$$\frac{d\sigma}{dD} < 0 \quad \text{only if} \quad |c_s v_s| > |S_1|$$

$$\begin{aligned} \frac{d\mu}{dD} = &\{(1 - A_1 + \sigma S_1)(1 - \mu e_n)(e_S F_1 \mu)(c_s v_s - S_1)\} \\ &+ a_{12} e_n \mu (c_s v_s - S_1) + \{c_s(1 - v_s) - A_1 + \sigma S_1\} \\ &\{S_1(1 - \mu e_n)e_S F_1 \mu - e_n \mu a_{22}\} \end{aligned} \tag{A11}$$

divided by $|J| < 0$

$$\frac{dQ_N}{de_S} = c_s(1-v_s)F\mu\{a_{22}(-\mu E_1 - E) - a_{23}e_S F_1\mu\}$$
$$+ a_{12}\{(\mu E_1 + E)(\sigma c_s v_s - 1)\left(\frac{F\mu}{\sigma}\right) + F\mu a_{23}\}$$
$$+ a_{13}\{F\mu a_{22} + e_S F_1\mu(\sigma c_s v_s - 1)\frac{F\mu}{\sigma}\} \tag{A12}$$

divided by $|J| < 0$

$$\frac{d\sigma}{de_S} = a_{11}\{(-\mu E_1 - E)(\sigma c_s v_s - 1)\left(\frac{F\mu}{\sigma}\right) + F\mu a_{23}\}$$
$$+ c_s(1-v_s)F\mu\{a_{21}(E + \mu E_1) + e_n\mu a_{23}\}$$
$$- a_{13}\{F\mu a_{21} + e_n\mu(\sigma c_s v_s - 1)\frac{F\mu}{\sigma}\} \tag{A13}$$

divided by $|J| < 0$

$$\frac{d\mu}{de_S} = a_{11}\{-a_{22}F\mu - e_s F_1\mu(\sigma c_s v_s - 1)\frac{F\mu}{\sigma}\}$$
$$- a_{12}\{F\mu a_{21} + e_n\mu(\sigma c_s v_s - 1)\frac{F\mu}{\sigma}\} \tag{A14}$$
$$+ c_s(1-v_s)F\mu\{e_s F_1\mu a_{21} - e_n\mu a_{22}\}$$

divided by $|J| < 0$

$$\frac{dQ_N}{de_n} = \{A_1 - (1-\sigma S_1)\mu Q_N\}\{-a_{22}(\mu E_1 + E) - a_{23}e_s F_1\mu\}$$
$$+ a_{12}\{S_1\mu Q_N(\mu E_1 + E) - Q_N\mu a_{23}\} \tag{A15}$$
$$+ a_{13}\{S_1\mu Q_N e_s F_1\mu + Q_N\mu a_{22}\}$$

divided by $|J| < 0$

$$\frac{d\sigma}{de_n} = \frac{Q_N\mu\{(A_1 - 1 - \sigma S_1)a_{23} - a_{13}S_1\}}{|J|} > 0 \tag{A16}$$

$$\frac{d\mu}{de_n} = \frac{Q_N\mu\{(A_1 - 1 - \sigma S_1)(-a_{22}) + a_{12}S_1\}}{|J|} > 0$$

$$\text{if } |a_{22}| > |a_{12}| \quad \frac{d\mu}{de_n} > 0 \tag{A17}$$

(Received August, 1995; Revised November 1995)

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