International Trade and the Environment: Theoretical and Policy Linkages*

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Abstract. I review and extend three approaches to trade and environmental policies: competitive general equilibrium, oligopoly and monopolistic competition. The first two have surprisingly similar implications: deviations from first-best rules are justified only by constraints on policy choice (which motivates what I call a "single dividend" approach to environmental policy), and taxes and emissions standards differ in ways which reflect the Le Chatelier principle. I also show how environmental taxes may lead to a catastrophic relocation of industry in the presence of agglomeration effects, although not necessarily if there is a continuum of industries which differ in pollution intensity.

Key words: environmental policy, international trade policy, location and economic geography, pollution abatement, strategic trade policy

JEL classifications: O13, L13, F12

My objective in this paper is to review and extend some points of intersection between international trade theory and environmental economics. These two sub-fields of economics have much in common. At the theoretical level, both are branches of applied microeconomics, focusing on the implications of a set of important real-world phenomena: differential international mobility (of goods, factors or ideas) in the case of trade theory, specific externalities in the case of environmental economics. At the policy level, the interaction of trade and environmental policies is increasingly recognised by both analysts and policy-makers as central to the successful operation of both.

Two key areas of policy concern have motivated recent studies of the trade-environment nexus. One is the fear that trade liberalisation will increase pollution emissions, which raises the issue of whether environmental policy should be tightened to compensate for changes in trade policy. A

second major focus of linkages between the two areas is the debate over environmental regulation and international competitiveness. Ongoing debates about increased environmental regulation in the EU have renewed fears that such measures could reduce competitiveness, leading to both deindustrialisation and "carbon leakage" as polluting industries relocate internationally. The net effect would not only be to shift the costs of environmental degradation but also the benefits of industrial agglomeration towards foreign locations.

To explore these issues, I consider three alternative approaches to modelling the interaction between trade and environmental policies. First, I consider the benchmark case of a competitive small open economy and review the familiar but important second-best considerations, which can make lax environmental policies desirable if trade policy is constrained, or tariffs welfare-improving when environmental policy is constrained to be suboptimal.

Next, I consider models of technical choice by polluting oligopolists. Once again, it turns out that second-best considerations complicate the ranking of alternative interventions. Strategic considerations may mandate an investment subsidy to shift rents towards home firms, whereas environmental concerns may require a tax.

Finally, I turn to the less well-explored area of locational choice by firms which, because of increasing returns in differentiated product industries, confer pecuniary externalities on each other. Such externalities have been shown to introduce the possibility of agglomeration in equilibrium, with firms locating close together to avail of lower costs of serving the larger market. However, such an equilibrium is not a deeply rooted one, in the sense that a change in circumstances, such as the introduction of an environmentally motivated tax, may lead to a catastrophic relocation of industrial activity. I explore the extent to which these tendencies can be offset if there is a continuum of industries, which differ in their pollution intensity, and so in their vulnerability to environmental policies.

1. Second-Best Intervention in Competitive Open Economies

The first setting in which I illustrate the interaction of trade and environmental policies is a competitive general equilibrium model of a small open economy.[1] The economy produces and consumes $n+1$ goods and h "bads" or pollution emissions. I take an arbitrary good as numeraire, so its home and foreign price are set equal to unity and kept in the background throughout. The prices of the n non-numeraire goods equal p at home and p^* abroad, with the difference attributable to a vector of trade taxes $r = p - p^*$. The emissions are generated in the production sector and can be controlled either by binding standards z or by emission taxes t, while they cause

environmental damage only to consumers. I begin with the case of emissions standards, which is probably less realistic than taxes but is simpler and introduces some important concepts which will prove useful throughout.

It has become standard to characterise the behaviour of individual agents in such an economy using the dual techniques popularised by Dixit and Norman (1980). Thus the production side of the economy can be represented by a GDP function: $g(p, z) \equiv \text{Max}_{\{x\}}\{p'x : F(x, z) \leq 0\}$. Here x and z represent the net outputs of goods and emissions, respectively, which must be consistent with the economy's production possibilities, summarised by the aggregate production constraint $F(x, z) \leq 0$. (This constraint in turn depends on factor endowments, the state of technology and so on, but since I will not consider changes in these underlying variables I do not need to make their levels explicit.) From Hotelling's Lemma, the price derivatives of the GDP function give the equilibrium outputs of goods: $g_p = x$; while the derivatives with respect to emissions g_z give the marginal costs of reducing emissions or the marginal abatement costs. (Subscripts denote partial derivatives.)

As for consumers, I ignore distributional considerations and assume a single aggregate household whose behaviour can be represented by an expenditure function: $e(p, z, u) \equiv \text{Min}_q\{p'q : \mathbf{u}(q, z) \geq u\}$, where utility depends positively on consumption of goods and negatively on emissions: $\mathbf{u}_q > 0$ and $\mathbf{u}_z < 0$. From Shephard's Lemma, the price derivatives of the function equal the Hicksian demands: $e_p = q$; while from Neary and Roberts (1980) the derivatives with respect to z are the virtual prices of the pollution levels, and so measure the marginal willingness to pay for reductions in emissions.

It turns out to be very convenient to combine the consumption and production sides of the economy into a single function. I call this the *trade expenditure function*, which is simply the difference between the expenditure and GDP functions:

$$E(p, z, u) \equiv e(p, z, u) - g(p, z) \tag{1}$$

Two useful properties follow immediately, First, the derivative of E with respect to goods prices is the vector of net imports m, $E_p = e_p - g_p = q - x$, and its second derivative matrix E_{pp} is negative definite, so, heuristically, compensated net import demand functions slope downwards.[2] Second, the derivative of E with respect to emissions z measures the environmental distortions in the economy, the difference between consumers' marginal willingness to pay for a reduction in emissions and the marginal abatement costs: $E_z = e_z - g_z$.

Armed with these properties, the general equilibrium of the economy is easily expressed. I ignore intertemporal considerations, so all factor income is spent on current consumption. In addition, I assume that the government redistributes all tax revenue to consumers in a lump-sum fashion. Hence the

aggregate household's budget constraint, which is also the balance of payments equilibrium condition, requires that expenditure minus GDP (i.e., the value of the trade expenditure function) must equal tariff revenue:[3]

$$E(p, z, u) = r'm \tag{2}$$

The elements of the vector of net imports, m, can be either positive or negative. However, to avoid tedious repetition I will describe the results on the assumption that all exports are untaxed and subsumed into the numeraire good, so m is strictly positive. (The equations obviously apply more generally.)

Totally differentiating (2) (and using $E_p = m$ and $dp = dr$ to simplify) leads immediately to the conditions for a first-best optimum:

$$e_u du = r'dm - E_z'dz \tag{3}$$

The left-hand side is the change in utility expressed in numeraire units: call this the change in real income. For this to be maximised requires from the right-hand side that both tariffs r and environmental distortions E_z be eliminated.

These first-best rules are a crucial benchmark. But, of course, the interesting policy questions are those which arise when the economy is not already at the first best. To evaluate these, we eliminate dm from (3) to obtain:[4]

$$(1 - r'x_I)e_u du = r'E_{pp}dr + \delta'dz \tag{4}$$

where:

$$\delta' \equiv -E_z' + r'E_{pz} \tag{5}$$

The left-hand side of (4) is just the change in real income deflated by the "tariff multiplier" or "shadow price of foreign exchange" $(1 - r'x_I)^{-1}$: a scalar correction factor which must be positive if the equilibrium is stable and which can otherwise be ignored henceforward. As for the right-hand side, it depends on changes in the two instruments, tariffs and emissions standards, which I will consider in turn.

The tariff reform term in (4) has a simple form, since the matrix E_{pp} is negative definite. This gives the well-known result that a proportionate reduction in tariffs ($dr = -rd\alpha$, where $d\alpha$ is a positive scalar) must raise welfare. This result continues to hold irrespective of the levels of emissions, reflecting the principle that quantitative restrictions neutralise the byproduct distortions of sub-optimal taxes and so avoid second-best complications.[5]

As for the emissions term in (4), this is more complex because their optimal values are non-zero and because consumers are directly affected by the level of pollution. The h-by-1 vector δ measures the marginal welfare effect of an increase in emissions, and must be zero at the second-best

optimum. It equals the difference between marginal abatement costs g_z and the full social costs of emissions: both the direct cost e_z and the indirect cost through any induced reduction in tariff revenue, $-r'E_{pz}$.[6] Because of the latter term, second-best considerations cannot be avoided when considering reforms of emissions policy in the presence of irremovable tariffs. Setting δ equal to zero implies that marginal abatement costs should exceed marginal damage costs to the extent that higher pollution leads to increased imports and so (from (3)), raises welfare.

I turn next to the case where emissions are controlled by taxes. This has many similarities with the standards case just considered. However, we need to specify the production side of the model somewhat differently. Where before the level of emissions was a constraint on producers' behaviour, they now respond to prices for both goods and bads. To model this, I use the *flex-price* GDP function from Neary (1985): $\tilde{g}(p,t) \equiv \text{Max}_{\{x,z\}} \{p'x - t'z : F(x,z) \leq 0\}$. Now, Hotelling's Lemma implies that the price derivatives of the GDP function give the equilibrium outputs of *both* goods and emissions: $\tilde{g}_p = x$ and $\tilde{g}_t = -z$. In addition, the properties of the flex-price and emissions-constrained GDP functions can be directly linked by noting that the functions are related as follows:

$$\tilde{g}(p,t) = g(p,z) - t'z, \quad \text{where } g_z(p,z) = t \tag{6}$$

This implies a number of useful properties, In particular, the supply responses of the flexprice economy are greater than those of the emissions-constrained one, a result known as the Le Chatelier principle.[7] Finally, the equilibrium can now be specified in terms of the flexprice trade expenditure function (which depends on *both* t and z):

$$\tilde{E}(\pi, z, u) \equiv e(p,z,u) - \tilde{g}(p,t) \tag{7}$$

Here I have introduced a new $(n+h)$-by-1 vector π for the prices of both goods and bads, and a corresponding vector τ for tariffs and taxes; while the derivative of $\tilde{E}$ with respect to the full price vector π is the vector of net imports and emissions:

$$\pi \equiv \begin{bmatrix} p \\ t \end{bmatrix} \quad \tau \equiv \begin{bmatrix} r \\ t \end{bmatrix} \quad \tilde{E}_\pi \equiv \begin{bmatrix} m \\ z \end{bmatrix} \tag{8}$$

Note that the matrix of second derivatives $\tilde{E}_{\pi\pi}$ is negative definite.

Inspection of (6) and (7) shows that the equilibrium condition for this model is formally identical to (2): net spending by the private sector must

equal redistributed tax and tariff revenue. This can be written in compact form as follows:

$$\tilde{E}(\pi, z, u) = r'm + t'z$$
$$= \tau'\tilde{E}_\pi(\pi, z, u) \tag{9}$$

Totally differentiating gives:

$$e_u du = r'dm + (t - e_z)'dz \tag{10}$$

This is identical to (3) once we make allowance for the switch in policy instrument from standards to taxes, so that $t = g_z$. Hence the first-best policy prescription is essentially the same: free trade ($r = 0$) combined with pollution taxes which equal the consumers' marginal willingness to pay for abatement ($t = e_z$).

Eliminating the endogenous terms from the left-hand side of (10) (details are in Appendix 1), gives:

$$(1 - r'x_I)e_u du = \hat{\tau}'\tilde{E}_{\pi\pi}d\tau \tag{11}$$

where:

$$\hat{\tau}' = \begin{bmatrix} r \\ \tilde{\delta} \end{bmatrix}', \quad \tilde{\delta}' = t' - e_z' + r'e_{pz} \tag{12}$$

The right-hand side of (11) is more complicated than that of equation (4) in the standards case, since it contains four terms rather than two. But, as before, it depends on the "excess taxes", or the deviations of taxes from their optimal values, denoted by the new vector $\hat{\tau}$. In the case of trade taxes, these are just the tariff levels themselves (since their optimal values are zero); while in the case of emissions, the excess taxes on pollution take account of the indirect cost of emissions through any induced reduction in tariff revenue.

Notwithstanding the complexity of the model, the right-hand side of (11) has a very convenient and simple form, since the matrix $\tilde{E}_{\pi\pi}$ is negative definite.[8] This gives a direct proof of a result by Copeland (1994): welfare must rise following a uniform reduction in *all* distortions in proportion to their deviations from optimal. An across-the-board policy reform of this kind implies that $d\tau = -\hat{\tau}d\alpha$ (where $d\alpha$ is a positive scalar), and so the righthand side of (11) must be positive (since $\hat{\tau}'\tilde{E}_{\pi\pi}\hat{\tau}$ is a quadratic form in a negative definite matrix and so is unambiguously negative).

Consider next the case where only one set of policy instruments can be varied. If only tariffs are available ($dt = 0$), equation (11) can be solved for their optimal second-best values:

$$(r^0)' = -\tilde{\delta}'\tilde{E}_{tp}(\tilde{E}_{pp})^{-1} = \tilde{\delta}'\tilde{g}_{tp}(\tilde{E}_{pp})^{-1} \tag{13}$$

Symmetrically, if tariffs cannot be altered ($dr = 0$), Equation (11) can be solved for the optimal second-best values of the "excess" pollution taxes:

$$(\tilde{\delta}^0)' = -r'\tilde{E}_{pt}(\tilde{E}_{tt})^{-1} = -r'\tilde{g}_{pt}(\tilde{g}_{tt})^{-1} \tag{14}$$

These equations have a standard second-best interpretation: if one set of policy instruments is fixed at non-optimal levels, then the other set should deviate systematically from their first-best levels. More specifically, note that both equations (13) and (14) have in common a matrix which cannot be signed *a priori*: $\tilde{g}_{tp}$, which equals $-z_p$ (minus the responsiveness of emissions to tariffs) is the transpose of $\tilde{g}_{pt}$, which equals x_t (the responsiveness of importables to pollution taxes). I will describe importables as "pollution-intensive" if the elements of this matrix are negative on average. In that case, Equation (13) shows that, when environmental policy is constrained to be lax ($\tilde{\delta} < 0$), then imports should be subsidised to compensate; while equation (14) shows that, when tariffs cannot be cut ($r > 0$), then environmental policy should be tightened to compensate. The key to this example is that, with $\tilde{g}_{tp}$ negative, outputs and emissions are complements in production and hence tariffs and pollution taxes are alternatives from a policy perspective: if one cannot be lowered towards its optimal level then the other should be raised *above* its optimal level instead (and conversely).

A final result is that equation (14) is identical to the second-best optimal rule, $\delta = 0$, which we found for the case of emission standards. To see this, use the derivatives of (6) to simplify the right-hand side of (14).[9] The second-best optimal value of emissions taxes then becomes:

$$(t^0)' = e'_z - r'E_{pz} \tag{15}$$

This is identical to setting (5) equal to zero. Hence, whether environmental policy is implemented by standards or taxes, marginal abatement costs should equal marginal damage costs *less* the change in tariff revenue induced by an increase in emissions.

Figure 1 illustrates some of these results in the case of a single tariff and a single pollution tax, with the additional simplification that goods demands are unaffected by emissions ($e_{pz} = 0$). The two second-best loci must intersect at the first-best optimal point of free trade and $t = e_z$. Assuming for concreteness that the importable is pollution-intensive and so the two instruments are alternatives implies, from (13) and (14), that the loci are upward-sloping as shown. Every iso-welfare locus must therefore have the upward-tilted potato shape as shown (since it must be horizontal where it crosses a t^0 locus and vertical where it crosses a r^0 locus). The implications for each instrument of fixing the other one at an arbitrary level can then be read off the figure as shown. For example, if the tariff r is fixed at $\bar{r}$, then the optimal second-best pollution tax t^0 exceeds the first-best tax e_z.
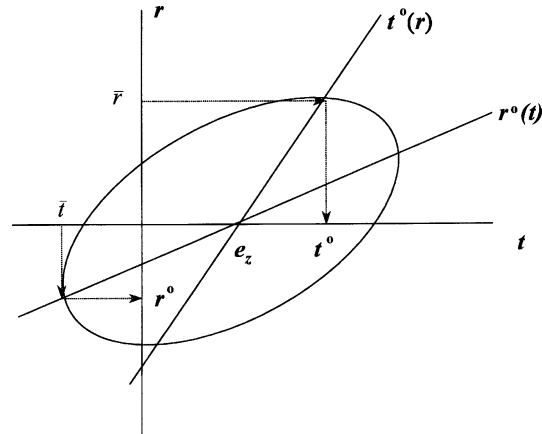
Figure 1. An Iso-Welfare locus in tax-tariff space.

Two extensions may be mentioned briefly. International factor mobility does not affect the formal analysis to any great extent, and the policy prescriptions are unaffected as long as factor movements are untaxed. From Neary (1985), the main difference is that supply responses to price are now more elastic and so specialisation in production is more likely, another reflection of the Le Chatelier principle. As noted by Copeland (1994), this implies that increased globalisation in the sense of greater openness of domestic markets to competition tends to exacerbate the costs of sub-optimal environmental policy. By contrast, extending the model to a large open economy requires some extra notation, mainly to keep track of the complications arising from income effects between countries. However, the policy prescriptions are largely unchanged with one key amendment: the benchmark for trade policy is no longer free trade but rather the "optimal tariff". (See Neary 1995.)

2. Strategic Trade and Environmental Policies

The general equilibrium framework of the last section provides an essential reference for the discussion of trade and environmental policies. However, it gives only a shadowy role to individual firms and so cannot throw light on issues such as how strategic considerations affect emissions policy or how firms respond to incentives to invest in pollution abatement. In recent years, an extensive literature has developed which addresses these issues using the theory of strategic trade policy pioneered by Brander and Spencer (1985).[10] In this section I again try to synthesise this literature within a common framework.

As in Brander and Spencer (1985), it is very convenient to consider a model with no domestic consumption, with two firms, one home and one foreign, competing in a third market. The firms engage in a non-cooperative

Nash game but, as in Brander (1995) and Neary and Leahy (2000), I leave open the nature of the competition between them. Thus, I assume only that each firm chooses the value of some "action", a for the home firm and a^* for the foreign firm. This allows me to develop a common set of results which apply both to Cournot competition (when the actions are quantities x and x^*) and to Bertrand competition (when the actions are prices p and p^*). The home firm also generates a level of pollution denoted by z. Finally, the home government may offer a subsidy to exports at a rate s and may also implement an environmental policy: to begin with, I assume that this takes the form of direct controls on the emissions level z.

Under these assumptions, the home firm's total profits Π can be written as the sum of its operating profits π and its subsidy revenue (the subsidy rate s times output x):

$$\Pi = \pi(a, a^*, z) + sx(a, a^*) \tag{16}$$

Operating profits consist of sales revenue R minus production costs C and pollution abatement costs $\bar{C}$. Writing this explicitly in the two cases:

$$\pi(a, a^*, z) = \begin{cases} \text{Cournot}: & R(x, x^*) - C(x) - \bar{C}(x, z) \\ \text{Bertrand}: & R(p, p^*) - C[q(p, p^*)] - \bar{C}[q(p, p^*), z] \end{cases} \tag{17}$$

I make standard assumptions about sales revenue and production costs: outputs are always substitutes in demand (implying $q_{p^*} > 0, R_{x^*} < 0$ and $R_{p^*} > 0$) and they are strategic substitutes in Cournot competition (so $R_{xx^*} < 0$); prices are strategic complements in Bertrand competition (so $R_{pp^*} > 0$); and production costs are increasing in output ($C_x > 0$) and not so convex as to violate the second-order conditions. As for pollution abatement costs, I assume they are decreasing ($\bar{C}_z < 0$) and convex ($\bar{C}_{zz} > 0$) in the level of pollution, and increasing in output both in total ($\bar{C}_x > 0$) and at the margin ($\bar{C}_{xz} > 0$). Finally, the subsidy income term on the right-hand side of (16) is just sx in the Cournot case (since $x = a$); while in the Bertrand case it equals $sq(p, p^*)$, where $q(p, p^*)$ is the demand function which is decreasing in the firm's own price p and increasing in the rival firm's price p^*.

Equation (17) is useful for reference when we want to distinguish between the Cournot and Bertrand cases. However, for most of the time I can concentrate on the more compact general case (16). Differentiating gives the home firm's first-order condition:

$$\Pi_a = \pi_a + sx_a = 0 \tag{18}$$

where x_a equals unity in Cournot competition and equals the own-price responsiveness of demand q_p (and so is negative) in Bertrand competition. The foreign firm faces an identical problem and so has an identical first-order condition, except for one simplification: as in Section 1, I assume that the

foreign government does not intervene, so the foreign firm simply equates its marginal operating profits to zero, $\pi_{a^*}^* = 0$.

Consider next the home government. With all output exported, the government does not care about the consumers of this industry's output. So its welfare function is just the firm's operating profits less the environmental damage caused by pollution:

$$W = \pi(a, a^*, z) - D(z). \tag{19}$$

Totally differentiating gives the change in welfare:

$$dW = \pi_a da + \pi_{a^*} da^* + (\pi_z - D_z)dz. \tag{20}$$

This may be simplified using the two firms' first-order conditions. Substituting the home firm's, Equation (18), is straightforward. More subtly, the government solves the foreign firm's first-order condition for its reaction function, $a^* = A^*(a)$, and uses this to eliminate da^*:

$$dW = -(sx_a - \pi_{a^*} A_a^*)da + (\pi_z - D_z)dz. \tag{21}$$

Equating the coefficients in (21) to zero gives the first-best optimum:[11]

$$\text{(i)} \quad s \cdot x_a = \pi_{a^*} A_a^* \quad \text{and} \quad \text{(ii)} \quad \pi_z = D_z. \tag{22}$$

The second of these conditions states that environmental policy should be efficient: emissions standards should be just sufficient to equate marginal abatement costs with marginal damage costs. The first is simply a restatement of the central results of strategic trade policy (due to Brander and Spencer (1985) and Eaton and Grossman (1986)). In Cournot competition (with x_a equal to unity, π_{a^*} negative, and downward-sloping reaction functions so A_a^* is negative), exports should be subsidised; while in Bertrand competition (with x_a negative, π_{a^*} positive, and upward-sloping reaction functions so A_a^* is positive), exports should be taxed. The key assumption underlying both results is that the home government is able to commit to the subsidy level in advance of both firms' decisions. It is this superior commitment power which allows the government to do something which the home firm would like to but (since it always plays a simultaneous Nash game against the foreign firm) cannot do on its own: namely, behave like a Stackelberg leader and push the foreign firm along its reaction function.

The first-best optimum thus exhibits a clear division of labour between environmental policy and trade policy. Naturally, this does not persist if there are second-best constraints on policy. Suppose in particular that trade policy cannot be altered. Solving (21) for the second-best optimal level of emissions with s fixed gives:

$$\pi_z = D_z + (s - \bar{s})x_a \frac{da}{dz} \tag{23}$$

where $\bar{s}$ is the formula for the optimal export subsidy from (22) (i). If the actual export subsidy s is constrained to equal zero, this equation gives the results of Barrett (1994). In Cournot competition $\bar{s}$ is positive and so the second term on the right-hand side is negative, which mandates an over-lax environmental policy $(\pi_z < D_z)$; while in Bertrand competition all this is reversed so environmental policy should be over-stringent $(\pi_z > D_z)$.[12] However, Equation (23) shows clearly that in both cases the justification for deviating from the efficient environmental rule is a purely second-best one, just as in Section 1. It is only the assumed inability to offer the optimal export subsidy which admits any strategic considerations to the determination of optimal environmental policy.

Consider next the case where emissions are subject to taxes rather than quantitative controls. Profits are now:

$$\tilde{\Pi} = \pi(a, a^*, z) + sx(a, a^*) - tz \tag{24}$$

where the operating profits function $\pi(a, a^*, z)$ is just as in (17). Now the firm has two decision variables, emissions z and output or price a. The first-order condition for a is given by (18) as before, while that for emissions is simply:

$$\tilde{\Pi}_z = \pi_z - t = 0 \tag{25}$$

The derivative of welfare is still given by (21), so essentially all the conclusions already stated continue to apply. The first-best policies are still given by (22), which from (25) implies that $t = D_z$: the emissions tax should be set equal to the marginal damage cost. As for the second-best case, Equation (23) still applies, which gives the results of Conrad (1993) and Kennedy (1994): the emissions tax should deviate from the marginal damage cost to an extent which compensates for the inability to impose the optimal export subsidy or tax.

There is one interesting difference between the tax and standards cases, and it concerns the slope of the foreign reaction function A_a^*. Under Cournot competition this is now greater in absolute value (i.e., more negative) than when emissions are controlled by standards; while under Bertrand competition it is presumptively less positive. So, other things equal, the optimal subsidy is algebraically greater when emissions are controlled by taxes than by standards. These differences are yet another reflection of the Le Chatelier principle: removing a quantity constraint on an economy or firm typically increases its responsiveness to shocks, whether of outputs to prices as in Section 1 or of own to rival's actions as here. (Proofs are given in Appendix 3.)

The final case to be considered is where each firm can make a prior investment in R&D in order to reduce emissions.[13] The main lessons can be

illustrated easily in a special case, where the level of emissions is uniquely determined (inversely of course) by the level of investment in abatement technology. (Appendix 4 considers the general case where the link between investment and emissions depends on the level of output.) Formally, this special case does not alter the specification of the model given in Equations (17) and (24). In particular, we can continue to treat the level of pollution z as one of the firm's choice variables, with the additional interpretation that it is also an *inverse* measure of the level of investment in pollution abatement. However, the change in interpretation invites a change in the assumptions about the timing of moves in the model: it now makes more sense to assume that each firm chooses its level of investment z *before* the actions a and a^* are chosen. This introduces a new strategic motive for choosing the level of emissions and hence a new reason for the home government to diverge from the first-best rule for emissions.[14]

If emissions are chosen before actions, each firm has an incentive to use its choice of z to influence its rival's choice of action in a way which will raise its profits. The first-order condition for a is given by (18) as before, but that for emissions is now:

$$\tilde{\Pi}_z = \pi_z + \tilde{\Pi}_{a^*} \frac{da^*}{dz} - t = 0 \tag{26}$$

Compared with (25), the new strategic term reflects incentives which have been summarised in the "animal spirits" taxonomy of Fudenberg and Tirole (1984). If the second-stage game is Cournot, the strategic effect is positive (higher emissions lower foreign output a^*, which raises home profits) and the firm has an incentive to behave like a "top dog", over-investing in emissions and so *under*-investing in pollution abatement relative to the efficient benchmark given by (25). Conversely, if the second-stage game is Bertrand, the strategic effect is negative (higher emissions lower the foreign price a^*, which lowers home profits) and the firm has an incentive to behave like a "puppy dog", under-investing in emissions and so *over*-investing in pollution abatement.

In a policy context, following Neary and Leahy (2000), this animal spirits taxonomy implies a corresponding "animal training" taxonomy of policy responses. To see this, substitute from (26) into (20) and set the coefficients to zero to solve for the first-best instruments as before:

$$\text{(i)} \ sx_a = \pi_{a^*} A_a^* \quad \text{and} \quad \text{(ii)} \ t = D_z + \tilde{\Pi}_{a^*} \frac{da^*}{dz}. \tag{27}$$

The condition for the optimal export subsidy is unchanged from (22), but that for the optimal emissions tax has an added term which exactly offsets the strategic effect. In the Cournot case, this means "restraining" the top dog by

a higher tax on emissions; while in the Bertrand case it means "encouraging" the puppy dog by a *lower* tax on emissions. In both cases, the optimal emissions tax diverges from the first-best optimal *rule*. However, (as in Spencer and Brander (1983)) optimal intervention has the effect of restoring the first-best optimal *condition*: substituting from (27) (ii) into (26) yields exactly the same first-best optimal condition as (22) (ii). So, even strategic investment behaviour by firms does not provide a first-best justification for diverging from optimal environmental policy. Of course, once again a constraint on the use of trade policy provides a second-best justification for "strategic" environmental policy. However, it can be checked that the divergence from the first-best is again given by Equation (23): strategic investment in pollution abatement introduces no new qualitative argument for deviating from the optimal rule for environmental policy.[15]

The results of this section can be used to throw some light on the so-called "Porter hypothesis" (see Porter 1991 and Porter and van der Linde 1995), which asserts that strict environmental policy would enhance rather than reduce competitiveness. This hypothesis can be formalised in different ways. For example, it can be interpreted to mean that tight regulation will raise profits. In the absence of strategic behaviour, as Palmer et al. (1995) argue, this requires that the firm is not maximising to begin with, and begs the question of why environmental regulation should be the trigger for greater efficiency. Alternatively, it can be interpreted as implying that tight regulation will raise total investment (including investment in pollution abatement). The results of Simpson and Bradford (1996) and Ulph (1996) show that this is sensitive to the functional forms assumed.[16] Finally, the Porter hypothesis can be interpreted simply as a call for tighter environmental policy on the grounds that this will raise welfare. The results of this section show that, on this interpretation, the validity of the Porter hypothesis, like so much else, hinges on the assumptions made about firm behaviour. Specifically, when trade policy cannot be used (so s is constrained to equal zero), the Porter hypothesis is valid (in the sense that π_z should exceed D_z), if firms are Bertrand competitors but not if they are Cournot competitors.

3. Environmental Regulation and Production Relocation

The final case I want to consider throws light on the issue of whether environmental policy can lead to relocation of industry. In this section, I want to consider the approach which draws on the recent work in economic geography by Krugman (1991) and Krugman and Venables (1995).[17] Venables (1999) has applied this approach to environmental taxation and the first part of this section presents a simple version of his model.

The model is one of Chamberlinian monopolistic competition. As in much recent work in a variety of fields, it is very convenient to parameterise this in terms of the symmetric constant-elasticity-of-substitution utility function pioneered by Dixit and Stiglitz (1977). Here, following Neary (1999) and (2001) respectively, I first present the basic ideas in a simple diagram and then sketch the consequences of environmental taxation using general functional forms.

The cost structure of a typical firm is extremely simple. A composite input is purchased at given price W, fixed costs are αW and production of x units incurs marginal costs of βW. Hence the total production cost function is:

$$C = (\alpha + \beta x)W. \tag{28}$$

This implies a marginal cost curve at the level βW, and an average cost curve which is a rectangular hyperbola with respect to the vertical axis and the horizontal marginal cost curve. Figure 2 illustrates.

Turning to demand, the utility function is:

$$u = \left(\sum_{i}^{\bar{n}} q_i^{\theta}\right)^{\frac{1}{\theta}} \tag{29}$$

where q_i is the amount of each variety demanded. Because this utility function embodies a preference for diversity, and (from (28)) there are increasing returns to scale, each firm produces a distinct variety. Hence the number of firms in the world (both at home and abroad), $\bar{n}$, is also the number of varieties consumed in both countries. This number is assumed to be relatively large, which allows us to assume that each firm ignores the actions of other firms in choosing its output (so the strategic considerations highlighted in the
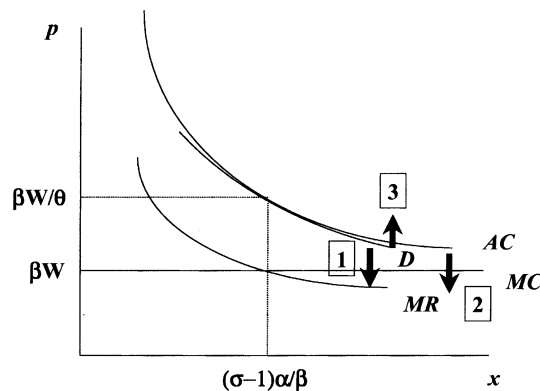

Figure 2. Monopolistically competitive equilibrium and the effects of entry by a new firm.

last section are assumed away). The typical firm then faces a simple constant-elasticity demand function which can be written (in inverse form) as:

$$p = Aq^{-1/\sigma}. \tag{30}$$

Here σ, which equals $1/(1-\theta)$, is the elasticity of substitution between varieties, while A is an intercept term, depending on income and the prices of other goods, and assumed to be taken as given by the firm. Marginal revenue is then easily shown to be:

$$MR = \theta p. \tag{31}$$

These two constant-elasticity curves are also shown in Figure 2. For the model to make sense we clearly require that $0 < \theta < 1$, or, equivalently, $1 < \sigma < \infty$.

Equilibrium for the firm now reflects the famous Chamberlinian tangency condition. Profit maximisation implies that marginal revenue equals marginal cost:

$$\theta p = \beta W \tag{32}$$

while free entry implies that profits must be zero:

$$px - (\alpha + \beta x)W = 0. \tag{33}$$

This simplifies, using (32), to give a remarkably simple result:

$$x = (\sigma - 1)\frac{\alpha}{\beta}. \tag{34}$$

This says that the output of each firm depends only on the cost parameters α and β and on the elasticity of substitution σ. Changes in any other parameters or variables (including the demand intercept A and the cost of the composite input W) lead to adjustments in industry output via changes in the number of firms only.

So far, this is just an illustration of an equilibrium, with much of the action taking place in the background: the values of the industry-wide parameters A and W, taken as given by firms, must be compatible with as yet unspecified constraints on aggregate demand and factor supply. When these are taken into account, the equilibrium level of profits can be written as the sum of revenues from home and foreign sales, R and R^*, respectively, less total production costs C and environmental taxation, tz:

$$\Pi = R(\underset{+}{P}, \underset{+}{e}) + R^*(\underset{+}{P^*}, \underset{+}{e^*}, \underset{-}{r}) - C(\underset{+}{P}) - tz. \tag{35}$$

Consider each of the terms on the right-hand side in turn. Revenue in each market depends positively on the industry price index (P and P^*) and on the level of expenditure (e and e^*) there, while revenue in the foreign market also

depends negatively on the level of trade costs r. Since every firm sells in both markets and consumers prefer greater variety, each price index depends negatively on the number of firms (n and n^*) producing in both markets and depends positively on trade costs:

$$P = P(\underset{-}{n}, \underset{-}{n^*}, \underset{+}{r}), \quad P^* = P^*(\underset{-}{n^*}, \underset{-}{n}, \underset{+}{r}). \tag{36}$$

The distinctive features of the Venables variant of economic geography enter through the expenditure and cost functions. I will only consider a partial equilibrium version of the model, so consumer demand and factor prices are given. However, each firm uses some of the output of every other firm as an input, which complicates the model in two significant ways. First, local demand in each country depends positively on the number of firms located there and on the local price index:

$$e = e(\underset{+}{n}, \underset{+}{P}), \quad e^* = e^*(\underset{+}{n^*}, \underset{+}{P^*}). \tag{37}$$

Second, the composite input is an aggregate of labour (supplied at an exogenous wage w) and the output of all the firms in the industry, whose price is just P. Assuming a Cobb–Douglas specification for simplicity, where μ is the cost share of intermediate inputs, we have:

$$W = w^{1-\mu}P^\mu. \tag{38}$$

Hence, as the penultimate term in (35) indicates, production costs depend positively on the local price index P. Finally, I assume for simplicity that emissions are proportional to output ($z = \gamma x$), so from the last term in (35) environmental taxes are also proportional to output.

What are the implications of these assumptions for the existence of an agglomerated equilibrium, even though the two countries are *ex ante* identical? To answer this, consider the following thought experiment. Assume the economy is initially in a diversified long-run equilibrium, and consider how the entry of one extra home firm affects the profits of existing firms (which are initially zero because of free entry). If they fall, then the diversified equilibrium is stable: losses force at least one firm to exit and the initial equilibrium is restored. However, if profits rise, the initial equilibrium is unstable and more firms are encouraged to enter. As a result, the world economy moves towards an equilibrium with agglomeration: the whole industry locates in the home country.

From the above equations, the effects of entry are easily deduced:

$$\frac{d\Pi}{dn} = \left[\frac{dR}{dP}P_n + \frac{dR^*}{dP^*}P_n^*\right] - C_P P_n + R_E e_n. \tag{39}$$

The first effect, represented by the bracketed terms on the right-hand side, is that an extra firm reduces the industry price index both at home and abroad which reduces revenue and hence profits. In Figure 2, the demand and marginal revenue curves tend to shift downwards. This effect is standard and encourages stability of the diversified equilibrium. By contrast, the two other effects tend to encourage instability and so lead to agglomeration. The reduction in price has *a cost* or *forward* linkage (represented by the middle term on the right-hand side of (39)), as the cost of the composite intermediate input is reduced for all firms, so raising profitability. In Figure 2, this shifts the cost curves downwards. Finally, the last term in (39) reflects a *demand* or *backward* linkage. An extra firm raises demand for the output of every other firm and so also raises profitability. This effect tends to shift the demand and marginal revenue curves upwards in Figure 2.

Setting (39) equal to zero, we can solve for the threshold level of trade costs $\hat{r}$ at which the diversified equilibrium switches from stability to instability. Such a threshold level must exist provided there is some incentive for agglomeration, which means, provided the share of intermediate inputs, μ, is positive. For sufficiently high r (possibly infinite) imports are so expensive that home production becomes profitable; while for sufficiently low r (possibly zero) diversification is ruled out since the countries are *ex ante* identical (neither has a comparative advantage). Then we can write the threshold value of r as a function of the other parameters of the model;

$$\hat{r} = \hat{r}(\underset{-}{\sigma}, \underset{+}{\mu}, \underset{+}{t}).$$ (40)

It is evident that $\hat{r}$ must be increasing in μ – the greater the importance of intermediate inputs the larger the range of trade costs at which diversification is not an equilibrium. It is also increasing in t because this tax on emissions (and hence on production) at home encourages agglomeration abroad. Finally, the threshold value of r is negatively related to σ, the elasticity of substitution in demand. This effect is the only one which hinges on Dixit–Stiglitz preferences. Higher σ means that consumers view different varieties as closer substitutes. Such a reduced preference for diversity leads (other things equal) to an equilibrium with fewer varieties and a higher output of each. (Recall Equation (34).) As a result, both countries are more likely to hold on to some production at lower trade costs.

The final step is to repeat the derivation of Equations (39) and (40) for the case where there are no home firms. This leads to a new threshold, r^0, which defines the level of trade costs at which agglomeration abroad is on the

margin of being an equilibrium. This new threshold has the same relationship to the underlying parameters as $\hat{r}$:

$$r^0 = r^0(\underset{-\ +\ +}{\sigma, \mu, t}) \geq \hat{r}. \tag{41}$$

Crucially, r^0 may (though need not) be higher than $\hat{r}$: if μ is large, so agglomeration economies are substantial, there will be some trade costs at which it would be profitable for a group of firms to locate in the home country but not for a single firm to enter on its own. It is the differences between r^0 and $\hat{r}$ which open up the possibilities of multiple equilibria and hysteresis that have been highlighted in the economic geography literature. Within the range where $r^0 > r > \hat{r}$, *both* agglomeration and diversification are possible stable equilibria, so history and policy have a potential role in influencing which equilibrium prevails.

The dashed lines in Figure 3 illustrate how the number and types of equilibria vary with the level of trade costs when there are no environmental taxes. (The figure assumes that intermediate input usage μ is sufficiently high to generate a significant range of parameter values, between $\hat{r}$ and r^0, in which either diversified or agglomerated equilibria may exist.) The solid lines show how the imposition of an emissions tax tilts the balance of location away from the home country. Now, the range of trade costs over which a diversified equilibrium is stable is reduced (both $\hat{r}$ and r^0 shift to the right); and, if such an equilibrium does emerge, it will be asymmetric, with more firms locating abroad ($n^* > n$).

However, this pessimistic scenario comes from a model where there is only one sector, subject to a uniform tax. Suppose instead that there is a continuum of sectors, each with a different value for the pollution intensity parameter γ. Figure 4 illustrates how changes in the uniform environmental tax affect the mix of industries which choose to locate at home. Equilibrium is
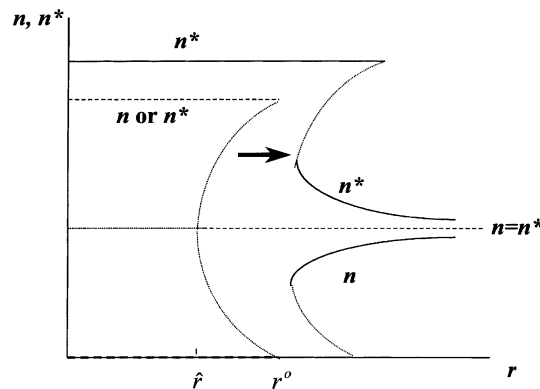

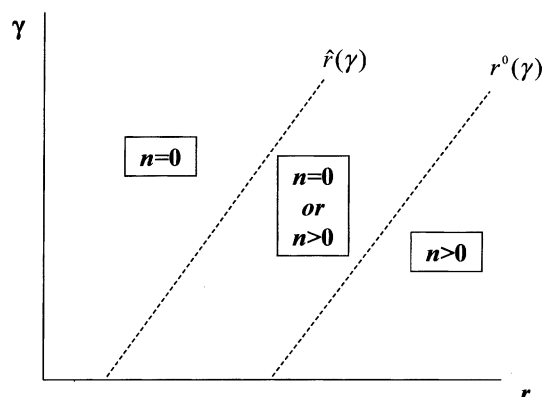*Figure 3.* Effects of a home emissions tax on agglomerated and diversified equilibria as a function of trade costs.

Figure 4. Threshold trade costs as functions of pollution intensity γ.

now a continuous function of parameters, without the cataclysmic effects of the one-sector case.

4. Conclusions

In this paper I have reviewed three types of models which have been applied to the study of environmental policy in open economies, and have tried to highlight their most interesting results in a compact and consistent manner.

A key finding from Sections 1 and 2 is that departing from the standard first-best rule of environmental policy is never justified in itself: whether taxes or emission standards are used, they should be set at a level which equates marginal abatement costs to marginal damage costs. "Inefficient" environmental policy can only be defended as a surrogate for some other policy assumed to be unavailable: free trade in Section 1 and export subsidies or taxes in Section 2. The benchmark optimal trade policy differs depending on whether firms' behaviour is competitive or oligopolistic. But in most other respects the policy conclusions are surprisingly similar.

As for the fear that environmental policy may lead to catastrophic relocation of economic activity, the economic geography model of Section 3 illustrated how this can indeed occur in certain circumstances. However, allowing realistically for a multiplicity of industries, with varying degrees of pollution intensity, suggests that fears of a dramatic loss of industrial competitiveness are probably misplaced.[18]

Naturally, even in a long paper I have had to ignore many important issues. I have assumed that economies are linked by trade alone and have not considered international spillovers of R&D or pollution. I have ignored actions by foreign governments, so ruling out consideration of international policy games, international environmental agreements and issue linkage.

Finally, while I have looked at the potentially catastrophic effects of environmental policy on industrial agglomeration, I have not considered the effects of lax policy on the environment itself, as in Brander and Taylor's (1998) model of ecological collapse.

Let me take up that point to end on a more speculative note. It should be recalled that the theories of trade with imperfect competition reviewed in Sections 2 and 3 had their origin in a general feeling of unease with the traditional competitive paradigm. In the same way, non-economists and even some economists may feel uneasy at the generally benign implications of the literature I have reviewed. Our models, even with stochastic elements added, do not seem capable of dealing with small but finite probabilities of cataclysmic events such as habitat destruction, environmental degradation and reduced species diversity – concerns not just of extreme environmentalists but of distinguished biologists such as Wilson (1984). All this suggests to me that the most important direction in which our models need to be extended is to take account of uncertainty about the long-term environmental effects of consumption, production and trade.

That said, while future work may lead to less optimism about the environmental and ecological consequences of free trade, it is unlikely to affect the main message of this paper, which can be summarised as advocating a ''single dividend'' approach to policy choice. Policy makers and analysts are best advised to concentrate on targeting trade and environmental policies towards their primary objectives. There are many reasons for departing from first-best rules, but second-best considerations depend on a host of factors which are not easily quantifiable. Foregoing the benefits of free trade is too high a price to pay for failing to develop and implement appropriate environmental policies.

Acknowledgements

Notes

1. The extensive literature on trade policy reform in this framework, stemming from Hatta (1977), has been extended to environmental policies by Copeland (1994), Beghin et al. (1997) and Ulph (1997), among others. I draw extensively on these papers in what follows, and use some techniques from my own work (especially Neary and Schweinberger (1986) and Neary (1993) which introduced the trade expenditure function and the potato diagram, respectively), to simplify and generalise the analysis.

2. Technical details are in appendices, available on my home page.

3. I assume throughout that all government revenue is returned costlessly to the private sector. Alternative assumptions about the disposition of government revenue from quotas or emission licences complicate the analysis in significant ways: see Anderson and Neary (1992).

4. Recall that $m = E_p$. Hence $dm = E_{pp}dr + E_{pz}dz + x_I e_u du$, where $x_I = e_{pu}/e_u$ is the vector of Marshallian income derivatives. See Neary (1995) for discussion and further references.

5. See Corden and Falvey (1985), Copeland (1994) and Neary (1995).

6. This has to be interpreted with care. Take, for example, a case considered by Ulph (1997), where extra pollution causes domestic residents to take more foreign holidays, which are subject to domestic taxes (so $E_{pz} > 0$). The trade taxes lead to sub-optimal levels of tourism imports and so, from (3), any measure which increases these imports (even an increase in pollution) is to that extent welfare-improving. Hence, in this case trade taxes *reduce* rather than increase the social cost of pollution.

7. Differentiating (6) twice gives: $\tilde{g}_{pp} - g_{pp} = -g_{pz}g_{zz}^{-1}g_{zp}$. Thus, since g_{zz} is negative definite, the difference between the two positive definite matrices of price-output responses, $\tilde{g}_{pp}$ and g_{pp}, is itself positive definite.

8. Equation (11) is essentially equation (7) in Copeland (1994), rewritten in more compact form. Very similar expressions are found in many policy reform contexts, including tariff reform in large open economies (Neary 1995), simultaneous reform of taxes on trade and international factor movements (Neary 1993), and multilateral trade policy reform by the members of a customs union (Neary 1998).

9. By relating the second derivatives of the $\tilde{g}$ and g functions, it can be checked that $\tilde{g}_{pt}(\tilde{g}_{tt})^{-1}$ equals $-g_{pz}$.

10. Applications of strategic trade policy to environmental issues include Barrett (1994), Conrad (1993), Kennedy (1994), Rauscher (1994), Ulph (1996, 1997) and Ulph and Ulph (1996).

11. The term "first-best" may seem odd in this context, given the presence of oligopolistic distortions. However, with no domestic consumption, it is indeed appropriate from the home country's point of view. Adding domestic consumers would provide an additional motive for increasing output, as pointed out by Brander and Spencer (1985). This in turn can rationalise a relaxation of environmental policy, as noted by Conrad (1993) and Kennedy (1994). However, even in this case, there would be no justification for departing from the first-best optimal rule of environmental policy if a full set of instruments was available: an export tax or subsidy to manipulate the foreign firm and a subsidy to home consumption to counteract the oligopolistic under-production.

12. In both cases, relaxing the emissions constraint raises output, so the expression outside the brackets, $x_a da/dz$, is always positive.

13. Ulph and Ulph (1996) show that the model can be extended to allow for investment in process R&D as well without affecting the results.

14. I assume that the equilibrium is sub-game perfect: each firm rationally anticipates the effect its choice of emissions will have on the actions chosen in the second stage. I also assume that the government can commit to its export subsidy before decisions on emissions are made; otherwise firms would have an incentive to vary their level of emissions in order to manipulate the export subsidy. (See Leahy and Neary 1999.)

15. The term "qualitative" in this sentence should be stressed. Because the foreign firm is also behaving strategically, the equilibrium attained in this case will be quantitatively different from that in the absence of strategic behaviour, even though the home first-order conditions are identical.

16. Yet another implication, explored by Rauscher (1997, Section 6.5), is that national welfare will rise if governments impose higher product quality standards.
17. For alternative approaches, see Markusen et al. (1993), Motta and Thisse (1994) and Hoel (1997).
18. The empirical evidence summarised by Jaffe et al. (1995) is consistent with this.

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