Welfare economics of agricultural trade liberalisation and strategic environmental policy

Thilo W. Glebe*

Abstract

The paper employs a partial equilibrium model of international trade to derive optimal environmental policy responses to tariff reduction requirements and assesses the impact of such policies on social welfare. The domestically optimal policy adjustment for a large importing country committing itself to tariff reduction is to lower the environmental tax rate. Nevertheless, the distorting effect of a strategic environmental policy is generally smaller than that of an optimal tariff. The paper thereby suggests that strategic distortions of environmental policy will not undermine the standard policy proposition that trade liberalisation enhances global efficiency.

Key words: *trade liberalisation, optimum tariff, strategic environmental policy*

Introduction

The increased recognition of environmental problems associated with agricultural trade has brought forward doubts with regard to the merits of international trade liberalisation. While the main goal of freer trade is to enhance international specialization, some OECD countries fear that trade liberalisation and the reduction of agricultural support may adversely affect the delivery of public goods that are jointly produced with agricultural commodities (Mahé 2001; Latacz-Lohmann and Hodge 2001; Potter and Burney 2002). Other countries have expressed concern that domestic support policies promoting the provision of agricultural non-market goods might be used strategically as a substitute for conventional border protection without genuinely pursuing environmental goals (Bagwell and Staiger 2001; Blandford *et al.* 2003). Choosing a distorted environmental policy as a substitute for trade policy has the strategic advantage that trading partners may not be able to prove its distorting character, given the difficulty of attaching monetary values to agriculture's non-market goods.

The economic rational of distorted environmental policies has been discussed by economists in various theoretical studies (Krutilla 1991; Peterson *et al.* 2002). However, little theory is available, yet, about the welfare effects of strategically distorted environmental policies. If nations do not necessarily gain from tariff concessions by other

* Thilo W. Glebe, Ph.D.(Cantab) is research associate of the Environmental Economics and Agricultural Policy Group at the Technical University of Munich, Germany.
Corresponding address: TUM Business School, Technical University of Munich, Alte Akademie 14, D-85350 Freising-Weihenstephan, Germany.
Telephone: +49-8161-715965; fax: +49-08161-713408; e-mail: glebe@wzw.tum.de.

countries, because those simultaneously distort environmental policy, they are unlikely to cooperate in trade negotiations. If the distorting effect of strategic environmental policy does more than outweigh the welfare enhancing effect of free trade, environmental regulations and trade concessions would need to be negotiated simultaneously to achieve global welfare improvements. In the light of these policy issues, the objective of the present paper will be to analyse the welfare economics of strategically chosen environmental policy in the wake of trade liberalisation.

The source of the strategic interaction between nations is that a large country can take advantage of its monopolistic price leverage in the world market. Building upon the theory of an optimal tariff, Vandendorpe (1972) and Markusen (1975) demonstrate that in the presence of domestic production externalities, the optimal policy response for a large country is a combined production tax and tariff. If the tariff instrument is not available, and a government tries to improve the terms of trade merely with an environmental tax instrument, the tax rate will inevitably deviate from a Pigouvian (1920) tax.

The present paper contributes to the literature on the agricultural trade and environment nexus in three ways. First, it discusses the rationale for a strategically chosen environmental policy by examining how the optimality conditions for an optimal environmental policy change as trade is gradually liberalised. Second, the paper analyses the welfare effects of trade liberalisation and simultaneous changes of environmental policy in order to compare the distorting effect of environmental versus trade policies (Feenstra 1995; Anderson 2003). Throughout the analysis *marginal* policy changes are considered, because tariffs are mostly reduced gradually in practice. The welfare effects of trade liberalisation and strategic environmental policy have also been studied by Burguet and Sempere (2003). However, unlike Burguet and Sempere's modeling framework, the present study is based on competitive (rather than on oligopolistic) supply markets. This extension better reflects the characteristics of agricultural markets, which are considered to be the main contributors to welfare gains from trade liberalisation in future WTO trade rounds (Abbott and Kallio 1996; Anderson 2004).

The third contribution of the present study is to analyse the welfare effects of tariff reductions and strategic environmental policy within a retaliatory setting of tariffs and environmental taxes. Given the fact that agricultural trade negotiations have been dominated by only a few large countries/trading blocs (Josling 2003), the analysis is built upon a model of bilateral strategic interactions. Following Johnson (1953), most studies analysing retaliatory trade policies, are based on tariff-setting games between importing countries. This paper chooses a different approach by considering a game between an importing and an *exporting* country. The analysis thereby makes use of Lerner's (1936) symmetry theorem, suggesting that a game between an exporter and importer of a single commodity leads to the same results as a tariff game between two countries importing different commodities. Modelling a game in export taxes versus input tariffs is done merely for conceptual reasons, acknowledging that export taxes can rarely be found in practice.

The structure of the paper is as follows. After presenting the model, Section 3 analyses a large country's optimal adjustment of environmental policy if it deliberately offers tariff concessions. Section 4 then analyses the welfare effects of tariff reductions based on a non-cooperative game in tax/tariffs combinations. The paper concludes with a summary of the main findings.

The model

Consider a bilateral trade model in which country i ($i = 1,2$) produces the quantity S_i of a homogeneous agricultural good at cost $C_i(S_i)$. Let $E_i(S_i)$ denote the monetary value of the environmental effects, which are associated with the production of the commodity. Consider further that the environmental impact of farming is not internalized into the market system and that the externality does not spill over national boundaries. Marginal environmental effects ($E_{iS} = \partial E_i / \partial S_i$) are assumed to be constant as production increases ($\partial E_{iS} / \partial S_i = 0$). No market distortions exist on the remaining markets.

Two policy instruments are available: a tariff (T_i), defined as a specific tax or subsidy on exports or imports, and an environmental tax (t_i), modelled as a tax or subsidy ($-t_i$) on production. National supply $S_i(P_{S_i})$ and demand $D_i(P_{D_i})$, specified as functions of domestic supply and demand prices, are assumed to be well-behaved and linear, hence $S_{iP} = \partial S_i / \partial P_{S_i} > 0$, $\partial S_{iP} / \partial P_{S_i} = 0$ and $D_{iP} = \partial D_i / \partial P_{D_i} < 0$, $\partial D_{iP} / \partial P_{D_i} = 0$.[1]

Given these relationships, a country's *national* welfare (W_i) can be expressed as the sum of consumer surplus (CS), producer benefit (PB), and also includes tax revenues (tR), tariff revenues (TR) and the value of the environmental externality (E):

$$W_i(t_i, T_i, t_j, T_j) = \underbrace{\int_{P_{D_1}}^{\infty} D_i(P_{D_i}) dP_{D_i}}_{CS} + \underbrace{P_{S_i} S_i(P_{S_i}) - C_i(S_i(P_{S_i}))}_{PB} + \underbrace{t_i S_i(P_{S_i})}_{tR} + \underbrace{T_i(D_i(P_{D_i}) - S_i(P_{S_i}))}_{TR} + \underbrace{E_i(S_i(P_{S_i}))}_{E} \quad (1)$$

For simplicity's sake, transaction and transportation costs are neglected. Hence, the margin between the two countries' demand price is solely determined by the tariff rate, whereas the environmental tax rate exclusively determines the difference between domestic supply price and demand price. Furthermore, assume that factor markets and product markets operate perfectly. Consequently, supply prices equal marginal production costs both at home and abroad:

$$P_{S_i} = \partial C_i / \partial S_i = P_{D_i} - t_i \quad \text{and} \quad P_{D_i} - T_i = P_{D_j} - T_j \quad \text{where } i, j = 1,2 \text{ and } j \neq i. \quad (2)$$

Consider the trade equilibrium requirement of excess supply ($X_i = S_i - D_i$) at home being equal to excess demand abroad:

$$X_i(t_i, T_i, t_j, T_j) = -X_j(t_i, T_i, t_j, T_j) \quad (3)$$

The model is closed by specifying *global* welfare (W) as the sum of the national welfare functions ($W = W_i + W_j$).

Economic rational for a strategically chosen environmental policy

We first specify the conditions for a domestically optimal policy combination prior to trade liberalisation. A policy is being referred to as 'optimal' if domestic welfare is maximised. The first-order condition for an interior maximum of the domestic welfare function can be derived by taking the partial derivatives of equation (1) with respect to the tax and tariff rates. Setting these equal to zero and applying equations (2) and (3) to simplify the result, we obtain:[2]

$$t_i^* = \left(X_i + T_i \alpha_j\right)\left(-D_{iP} + \alpha_j\right)^{-1} - E_{iS} \quad (4)$$

$$T_i^* = -X_i \alpha_j^{-1} + \left(t_i + E_{iS}\right) S_{iP} \alpha_i^{-1} \quad 5)$$

where $\alpha_i = S_{iP} - D_{iP}$ and $\alpha_j = S_{jP} - D_{jP}$. Simultaneously solving (4) and (5) yields:

$$t_i^*\left(T_i^*\right) = -E_{iS} \quad (6)$$

$$T_i^*\left(t_i^*\right) = -X_i / \alpha_j \quad (7)$$

Equations (6) and (7) constitute the first-best policy set. The optimal environmental policy is the Pigouvian tax/subsidy rate ($-E_{iS}$), whereas the first-best tariff is identical to Bhagwati and Ramaswami's (1963) optimal tariff of international trade theory. The optimal tariff is determined by the home country's trade flow (X_i) and the price responsiveness of foreign excess supply (α_j). If the home country (country *i*) is a net importer ($X_i < 0$), its optimum tariff will be positive ($T_i^*(t_i^*) > 0$), and it will increase with the country's influence on the terms of trade. In contrast, a net-exporting trading partner (country *j*) will choose a negative tariff rate.

Having established this benchmark, we now turn to the question of how the optimal environmental policy changes if the home country offers tariff reductions. With a given tariff rate, the home country can only vary its environmental tax/subsidy rate to maximize its welfare. Hence, changes of the optimal environmental policy induced by marginal variations of the optimum tariff rate can be gauged by taking the derivative of equation (4) with respect to T_i:[3]

$$\frac{\partial t_i^*\left(T_i^*\right)}{\partial T_i} = \left(\frac{\partial X_i}{\partial T_i} + \alpha_j\right)\left(-D_{iP} + \alpha_j\right)^{-1} = \frac{2\alpha_i \alpha_j + \alpha_j^2}{\left(\alpha_i + \alpha_j\right)}\left(-D_{iP} + \alpha_j\right)^{-1} \quad (8)$$

Since equation (8) takes a positive value, we conclude that a large importing country has an incentive to reduce (increase) the environmental tax (subsidy) rate as it commits to tariff reductions. The rationale for this proposition is that as a country liberalises trade it can enhance domestic welfare by using the environmental instrument to partially substitute for an optimum tariff policy. Lowering the environmental tax rate as a response to a tariff reduction is plausible, since this would reduce the world price and thereby improve an importer's terms of trade. A large net-importing country may therefore have an incentive to legitimate a strategically distorted environmental policy by 'overemphasising' the importance of agriculture's positive externalities while 'playing down' negative agri-environmental non-market effects.

Welfare effects of trade liberalisation

We will now analyse how trade liberalisation may affect countries' social welfare. As a benchmark scenario we consider a game in tariffs at which both countries maintain a Pigouvian tax/subsidy rate (equation 6). Later, we will analyse the welfare effects of trade liberalisation if environmental policy is being adjusted.

Since the traded quantity is determined by all policy variables (equation 3), equation (7) represents the home country's tariff reaction function. A country's tariff reaction function indicates the tariff rate at which domestic welfare is maximised for a given foreign tariff. The slope of the tariff reaction function can be obtained from equation (2), (3) and (7):[3]

$$\frac{\partial T_i^*(T_j)}{\partial T_j} = -\frac{\partial X_i}{\partial T_j}\frac{1}{\alpha_j} = \frac{\alpha_i}{(\alpha_i + \alpha_j)} \tag{9}$$

Since equation (9) assumes a positive value for $X_i \leq 0$, the tariff reaction function will be positively sloped. The strategic interaction of optimum tariff rates is illustrated in Figure 1. Consider a set of national indifference curves. The home country's highest indifference curve ($\overline{W}_i^{\max}$) is reached at the point where its reaction function ($T_i^*(T_j)$) intersects the vertical axis.[4] Implementing a (negative) tariff in the foreign country will deteriorate the home country's terms of trade. Hence, welfare in the home country will steadily decline while moving south-westwards along its reaction function. At the Nash-equilibrium ($\phi = t_i^*, T_i^*, t_j^*, T_j^*$), both countries' indifference curves ($\overline{W}_i, \overline{W}_j$) intersect in such a way that no country will have an incentive to alter its policy set.

Trade liberalisation without environmental policy adjustments

The Nash-equilibrium in optimum tariffs represents a Prisoner Dilemma, since both countries could be better off if they agreed to abolish tariffs. However, if tariffs are reduced only gradually, mutual welfare gains are not certain. We will demonstrate that the direction of national welfare effects depends on the extent to which each country is willing to open up its national market. To simplify the algebraic analysis, we assume symmetry between trading partners ($S_{iP} = S_{jP}$, $D_{iP} = D_{jP}$). Moreover, since the ratio of tariff rate changes ($dT_j / dT_i = \lambda$) is the outcome of a trade negotiation process, λ will be dealt with as an exogenous parameter.

The minimum trade policy concession the home country will demand from its trading partner to forsake its optimum tariff policy deliberately can be derived from the national welfare function. Dividing the total differential of (1) by the tariff change, we obtain:

$$\frac{dW_i}{dT_i} = \frac{\partial W_i}{\partial T_i} + \frac{\partial W_i}{\partial T_j}\lambda + \frac{\partial W_i}{\partial t_i}\frac{dt_i}{dT_i} + \frac{\partial W_i}{\partial t_j}\frac{dt_j}{dT_j}\lambda . \tag{10}$$

At the Nash-equilibrium, the necessary condition for optimal tax/tariff rates $\partial W_i(\theta)/\partial T_i = \partial W_i(\theta)/\partial t_i = 0$ is fulfilled. Given symmetry between trading partners and assuming that environmental policy will not be strategically adjusted, so that both countries maintain their first-best environmental policy ($dt_i = dt_j = 0$), equation (10) can consequently be written as:[3]

$$\frac{dW_i(\theta)}{dT_i} = \frac{\partial W_i(\theta)}{\partial T_j}\lambda = -\frac{X_i(\theta)}{2}\lambda \tag{11}$$

Equation (11) suggests that the home country will only benefit from trade concessions ($dW_i(\theta)/dT_i < 0$) if both trading partners simultaneously liberalise trade (if $\lambda < 0$). Hence, to secure mutual welfare gains, a net-importer needs to reduce its (positive) tariff, while a net-exporter is required to increase its (negative) optimum tariff. The condition for mutual welfare improvements is illustrated in Figure 1. Starting from the Nash-equilibrium, a country will benefit from trade reforms if the accepted tariff rate combination lies above its respective Nash-equilibrium indifference curve ($\overline{W}_i$). The question to be dealt with in the following subsection is how the scope of tariff rate combinations at which both countries' social welfare is enhanced (grey area in Figure 1) will be affected if governments strategically adjust environmental tax/subsidy rates.

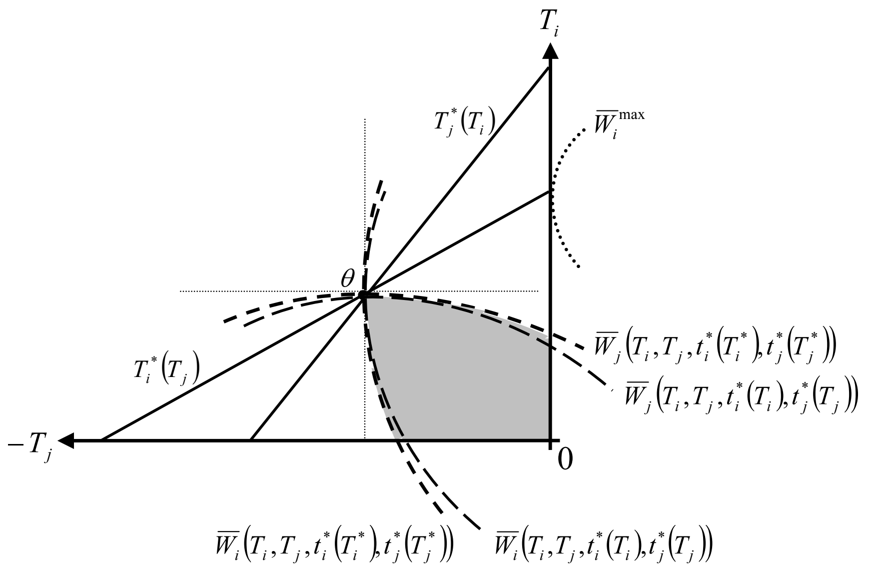

Figure 1. Reaction functions for the optimal tariff rates

Trade liberalisation with environmental policy adjustments

If both countries adjust their optimal environmental policy as they offer trade policy concessions, the first-order condition for an optimal environmental policy ($\partial W_i/\partial t_i = 0$) will be maintained. Hence, we can write:

$$d\left(\frac{\partial W_i}{\partial t_i}\right) = \frac{\partial^2 W_i}{\partial t_i^2}dt_i + \frac{\partial^2 W_i}{\partial t_i \partial t_j}dt_j + \frac{\partial^2 W_i}{\partial t_i \partial T_i}dT_i + \frac{\partial^2 W_i}{\partial t_i \partial T_j}dT_j = 0\,. \tag{12}$$

Applying equation (12) to the two countries, the marginal national welfare change of the home country (equation 10) can be transformed to:

$$\frac{dW_i}{dT_i} = \frac{\partial W_i}{\partial T_i} + \frac{\partial W_i}{\partial T_j}\lambda + \frac{1}{\psi}\left(\left(\frac{\partial W_i}{\partial t_i}\frac{\partial^2 W_j}{\partial t_j^{\,2}} - \frac{\partial W_i}{\partial t_j}\frac{\partial^2 W_j}{\partial t_i \partial t_j}\right)\omega + \left(\frac{\partial W_i}{\partial t_j}\frac{\partial^2 W_i}{\partial t_i^{\,2}} - \frac{\partial W_i}{\partial t_i}\frac{\partial^2 W_i}{\partial t_i \partial t_j}\right)\sigma\right) \tag{13}$$

where $\omega = \frac{\partial^2 W_i}{\partial t_i \partial T_i} + \frac{\partial^2 W_i}{\partial t_i \partial T_j}\lambda$, $\sigma = \frac{\partial^2 W_j}{\partial t_j \partial T_i} + \frac{\partial^2 W_j}{\partial t_j \partial T_j}\lambda$ and $\psi = \frac{\partial^2 W_i}{\partial t_i \partial t_j}\frac{\partial^2 W_j}{\partial t_i \partial t_j} - \frac{\partial^2 W_j}{\partial t_j^{\,2}}\frac{\partial^2 W_i}{\partial t_i^{\,2}}$.

Since we consider a Nash-equilibrium as benchmark, the derivatives of (13) need to be evaluated at the domestically optimal environmental and trade policy combinations of (6) and (7). Making use of (1), (2) and (3), equation (13) can be written as:[3]

$$\frac{dW_i(\theta)}{dT_i} = \frac{X_i(\theta)D_P\left(\lambda(3\alpha - D_P) + S_P\right)}{2\alpha(\alpha - D_P)} \tag{14}$$

where $S_P = S_{iP} = S_{jP}$, $D_P = D_{iP} = D_{jP}$ and $\alpha = \alpha_i = \alpha_j$.

We can derive from equation (14), that the home country will only gain from tariff rate changes ($dW_i(\theta)/dT_i < 0$) if:

$$\lambda < -S_P/(3\alpha - D_P) \tag{15}$$

From (15) we infer that λ needs to be smaller than a specific negative value to guarantee domestic welfare improvements. On the other hand, it was derived from equation (11) that λ requires to be smaller than zero to secure domestic welfare gains, if environmental policy is not strategically adjusted. We conclude that countries need to offer larger tariff cuts to reach an agreement on trade liberalisation if environmental policy is strategically distorted. Figure 1 illustrates how the condition for mutual welfare improvements changes as a result of strategic environmental policy. A country's indifference curves will be stronger curved due to environmental policy adjustments and thereby shift from $\overline{W}_i(T_i,T_j,t_i^*(T_i^*),t_j^*(T_j^*))$ to $\overline{W}_i(T_i,T_j,t_i^*(T_i),t_j^*(T_j))$. The scope of tariff rate combinations at which both countries will gain (grey area) will consequently shrink.

Aggregate welfare effects of trade liberalisation

We will now demonstrate that it is always possible to find a λ at which both countries will gain from trade liberalisation. In order to prove this proposition, we need to calculate the foreign country's welfare effects. Analogously to the previous procedure, the foreign country's welfare change can be derived by simultaneously solving (10) and (12):

$$\frac{dW_j}{dT_i} = \frac{\partial W_j}{\partial T_i} + \frac{\partial W_j}{\partial T_j}\lambda + \frac{1}{\psi}\left(\left(\frac{\partial W_j}{\partial t_i}\frac{\partial^2 W_j}{\partial t_j^{\,2}} - \frac{\partial W_j}{\partial t_j}\frac{\partial^2 W_j}{\partial t_i \partial t_j}\right)\omega + \left(\frac{\partial W_j}{\partial t_j}\frac{\partial^2 W_i}{\partial t_i^{\,2}} - \frac{\partial W_j}{\partial t_i}\frac{\partial^2 W_i}{\partial t_i \partial t_j}\right)\sigma\right) \tag{16}$$

Making selective use of (1) – (3), equation (16) can be simplified to:[3]

$$\frac{dW_j}{dT_i} = -\frac{X_i D_P \left((3\alpha - D_P) + \lambda S_P \right)}{2\alpha (\alpha - D_P)} \tag{17}$$

From (17) we infer that the foreign country will benefit from tariff reductions if:

$$\lambda > -(3\alpha - D_P)/S_P \tag{18}$$

Bringing together (15) and (18), we obtain the condition for *mutual* welfare gains:

$$-(3S_P - 4D_P)/S_P < \lambda < -S_P/(3S_P - 4D_P) \tag{19}$$

Since the left hand side of equation (19) is smaller than the right, it is proven that there exists always a λ at which both countries will gain from tariff reductions. This result is important because it implies that the distorting effect of an optimal tariff is greater than the trade distortions caused by strategic environmental policies. This is plausible in as much as social welfare gains for one country, as a result of terms of trade improvements, are achieved at the expense of welfare losses for the rest of the world. Terms of trade improvements are maximized by an optimal tariff; this explains why an optimal tariff policy is more trade-distorting than a strategic environmental policy.

Nevertheless, strategic distortions of environmental policy will generally reduce *global* welfare. The aggregate welfare effect of the two countries following environmental policy adjustments can be calculated by adding equations (14) and (17):

$$\frac{dW}{dT_i} = -\frac{X_i D_P (1 - \lambda)}{\alpha} \tag{20}$$

The welfare change *without* strategic environmental policy can be derived from (11):

$$\frac{dW}{dT_i} = \frac{dW_i}{dT_i} + \frac{dW_j}{dT_j}\lambda = -\frac{X_i(\theta)}{2}\lambda - \frac{X_j(\theta)}{2} = -X_i(1 - \lambda) \tag{21}$$

Since equation (20) takes a smaller absolute value than equation (21), it is demonstrated that strategic environmental policy reduces global welfare gains which could be realised by tariff reductions.

Conclusions

This paper has analysed the incentives for strategic environmental policy in the wake of agricultural trade liberalisation and has assessed the impact of such policies on national and global welfare. The analysis was based on a partial-equilibrium trade model where production is associated with a domestic environmental externality. The study was motivated by some governments' concern that trading partners might substitute environmental policy for conventional border protection.

We showed that strategic adjustments of environmental policy will reduce countries' social welfare. Governments should therefore demand higher trade concessions from trading partners if they suspect that domestic policy is used strategically. Nevertheless, though strategic environmental policy may reduce the scope for trade agreements at which all countries will benefit, it is unlikely to impede the process of agricultural trade liberalisation. The reason is that there exists always a combination of tariff rate reductions leading to mutual welfare gains. The paper thereby demonstrated that, if tariff concessions offered by a large country are accompanied by a switch from a Pigouvian tax to a strategic environmental policy, the global welfare effects can be always positive. We conclude that though strategic environmental policy reduces global welfare, it is less trade-distorting than an optimum tariff policy.

Given the welfare reducing effect of a strategically chosen environmental policy, a challenge for future trade negotiations will be to agree on criteria by which environmental policy can be judged as trade-distorting. In this context, it will be important to identify indicators assessing the environmental performance of agri-environmental policies. So far, it has been difficult to agree on such indicators, given the complexity of the various agri-environmental effects and the diversity of agri-environmental programs (Primdahl *et al.* 2003). Some authors suggested that the importance of environmental concerns might be provided by opinion polls, by the level of activity of environmental NGOs, or by testing whether a government would be prepared to adopt an environmental measure if all the costs fell on domestic actors (Hooker and Caswell 1999; Runge 1999; Latacz-Lohmann and Hodge 2001). However, an appropriate assessment method for agri-environmental externalities would not only need to show evidence of the occurrence of agricultural non-market effects; it would also need to quantify the overall environmental effect of farming. An important future task will therefore be to value the overall value of agriculture's environmental impact in order to deal with the challenges that might be ahead with the use of strategic environmental policy in agriculture.

Notes

[1] Although demand functions are more likely to be convex than linear, they have been used in *theoretical* studies by, among many others, Tanaka (2001), Rath and Zhao (2001) and Gonzalez-Maestre and Lopez-Cunat (2001).

[2] Let one asterisk denote the tax/tariff rate at which domestic welfare is maximised. For calculation see Appendix.

[3] See Appendix.

[4] We assume a net-exporting trading partner, which has no incentive to implement a positive tariff rate ($T_j \leq 0$).

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Appendix

From (2) and (3), we can derive that

$$\frac{\partial X_i}{\partial T_i} = -\frac{\partial X_j}{\partial T_i}; \qquad \frac{\partial X_i}{\partial t_i} = -\frac{\partial X_j}{\partial t_i}; \qquad \frac{\partial X_i}{\partial T_j} = -\frac{\partial X_j}{\partial T_j}; \qquad \frac{\partial X_i}{\partial t_j} = -\frac{\partial X_j}{\partial t_j} \tag{a}$$

From (a) and (2), we can derive:

$$\frac{\partial P_{D_i}}{\partial t_i} = \frac{S_{iP}}{(\alpha_i + \alpha_j)} \qquad \frac{\partial P_{D_i}}{\partial T_i} = \frac{\alpha_j}{(\alpha_i + \alpha_j)} \tag{b}$$

Making use of (a) and (b), we obtain:

$$\frac{\partial X_i}{\partial T_i} = \frac{\alpha_i \alpha_j}{(\alpha_i + \alpha_j)}; \qquad \frac{\partial X_i}{\partial T_j} = -\frac{\alpha_i \alpha_j}{(\alpha_i + \alpha_j)} \tag{c}$$

Making use of (a) and (b), the partial derivatives of the domestic welfare function (equation 3) can be written as:

$$\frac{\partial W_i}{\partial t_i} = \frac{S_{iP}\left(X_i - (t_i + E_{iS})(-D_{iP} + \alpha_j) + T_i \alpha_j\right)}{(\alpha_i + \alpha_j)} \tag{d}$$

$$\frac{\partial W_i}{\partial T_i} = \frac{\alpha_j\left(-X_i \alpha_i \alpha_j^{-1} + (t_i + E_{iS})S_{iP} - T_i \alpha_i\right)}{(\alpha_i + \alpha_j)} \tag{e}$$

$$\frac{\partial W_i}{\partial t_j} = \frac{S_{jP}\left(X_i + (t_i + E_{iS})S_{iP} - T_i \alpha_i\right)}{(\alpha_i + \alpha_j)} \tag{f}$$

$$\frac{\partial W_i}{\partial T_j} = -\frac{\alpha_j \left(X_i + \left(t_i + E_{iS}\right) S_{iP} - T_i \alpha_i\right)}{\left(\alpha_i + \alpha_j\right)} \tag{g}$$

Setting equation (d) equal to zero and solving for t_i yields equation (4). Analogously, we can derive equation (5) by setting equation (e) equal to zero and solving for T_i. From (a), (b) and (1), we derive:

$$\frac{\partial X_i}{\partial t_i} = -\frac{S_P}{2}; \qquad \frac{\partial X_i}{\partial T_i} = \frac{\alpha}{2}; \qquad \frac{\partial X_i}{\partial T_j} = -\frac{\alpha}{2}; \qquad \frac{\partial X_i}{\partial t_j} = \frac{S_P}{2} \tag{h}$$

Making selective use of (b), (d)-(h) we obtain:

$$\frac{\partial^2 W_i(\theta)}{\partial t_i \partial t_j} = \frac{{S_P}^2}{4\alpha}; \qquad \frac{\partial^2 W_j(\theta)}{\partial T_i \partial t_j} = -\frac{S_P}{4} \tag{i}$$

$$\frac{\partial^2 W_i(t_i^*, T_i^*)}{\partial {t_i}^2} = \frac{S_P\left(-3\alpha + D_P\right)}{4\alpha}; \qquad \frac{\partial^2 W_i(t_i^*, T_i^*)}{\partial T_i \partial t_i} = \frac{3S_P}{4} \tag{j}$$