Environmental and Trade Policies: Some Methodological Lessons

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Abstract

This paper describes the results of using a new computable general equilibrium model for the European Union that incorporates local and transboundary externalities to evaluate the effects of trade policy reform. In contrast to all past theoretical and empirical research, this model includes the morbidity effects of three criteria air pollutants as nonseparable arguments of household preferences. The model is based on the Harrison-Rutherford Wooton model that identifies 11 regions, six aggregate commodities and three factor inputs. Three modifications were made to the model: (a) Stone Geary utility functions were used to characterize preferences for each consumer; (b) nine morbidity effects due to the three air pollutants were introduced as translating effects; and (c) pollution generation and dispersion models were introduced and calibrated to the model's base solution.

General equilibrium welfare effects are evaluated with a balance of trade function. Overall, the evaluations of policy suggest that incorporating environmental effects as non-separable influences on preferences can have a marked impact on the evaluation of trade policy reforms.

Key Words: trade and environmental policy, CGE models

JEL Classification No(s).: Q20, H41

Table of Contents

List of Figures and Tables

Environmental and Trade Policies: Some Methodological Lessons[1]

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I. INTRODUCTION

Trade and the environment has been a front page issue for most of the nineties. Both popular and professional publications have offered lessons about how policies should be modified to harmonize both sets of objectives.[3] This interest has, in turn, stimulated a considerable body of new conceptual research [see Krutilla, 1991; Chichilnisky, 1994; Copeland, 1994; Copeland and Taylor, 1994, 1995a; and Lopez, 1994 as examples]. We have learned, as a result of the research to date, that domestic environmental regulations will either *increase or they will decrease* the international competitiveness of the products traded by the country undertaking them. By contrast, we know that removing trade barriers will either *improve or it will reduce* the level of well-being of the typical household in the country reducing trade barriers. Finally, while the verdict here is not as clear-cut as in these first two areas, it seems likely research currently underway will soon establish that efforts to link trade

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[1] Paper revised August 22, 1995.

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Thanks are due Glenn Harrison for providing the data and code to implement HRWI as well as for helping us to understand how to use it, to an anomymous referee, Edward Barbier and Charles Perrings for most helpful comments on an earlier draft, and to Paula Rubio for preparing and editing several versions of this paper. Partial support for Smith's contribution to this research was provided by the National Oceanic and Atmospheric Administration through Grant No. NA46GP0466. Espinosa's research was supported by Resources for the Future. The conclusions presented are those of the authors and not their affiliated organizations.

[3] For a good summary of this discussion as well as citations to empirical literature bearing on this topic see Repetto [1995].

and environmental policies will either *enhance or degrade* the current levels of well-being experienced in developed economies from the levels reached using the current independent approaches to these problems.

While this summary is presented, in part, to "amuse" the reader, it is nonetheless a reasonably accurate description of where we stand. Moreover, it is not an indictment of the research to date. Rather, it reflects what is learned from conceptual research in most areas -- *"the devil is in the details."* That is, the specific circumstances of each country economy in relation to the world markets relevant for its products must be considered before clear-cut conclusions can be offered. Thus, we can agree that . . .

> The international market transmits and enlarges the externalities of the global commons. No policy that ignores this connection can work. [Chichilnisky, 1994, p. 865].

Nonetheless, this agreement does not prevent policy makers from rejecting most proposals for greater linkage in these policies. Moreover, their caution may well be warranted based on the available empirical evidence. As Repetto [1995] observed, there is no solid empirical evidence that increasing the stringency of environmental regulations necessarily has detrimental effects on trade and investment. Of course, this does not mean that coordination should be ruled out. Rather, it heightens the importance of understanding the features of each case, before attempting to offer generalizations about when there will be the advantages to linking trade and environmental policies.

Research on these questions is also likely to have payoffs in other areas. Indeed, we will argue that important methodological issues have emerged from the intermediate results of the research to date on trade and the environment. In what follows, we summarize these insights, and illustrate their importance with a new CGE model that incorporates local and transboundary externalities. Using Krutilla [1991] and Anderson's [1992] adaptation of the conventional applied welfare framework, the first section illustrates how environmental and trade policies become intertwined. This graphical analysis also provides a platform for our description of how assumptions of recent theoretical and computational models influence these studies' conclusions about environmental and trade policy. The third section describes the Espinosa-Smith [1995] extension to the Harrison-Rutherford-Wooton [1989] model of most of the economies currently comprising the European Union to include environmental externalities and how that framework can be used to gauge the importance of several of the "simplifying details" of earlier research. While most of the empirical detail in this model considers developed economies, the generic lessons derived from examining the implications of incorporating environmental resources within preferences are equally relevant to the developing context. These relationships are discussed in the closing section of the paper as well as throughout our description of the findings. The last section also uses the results from our analysis to suggest a corollary to Krugman's [1991] arguments about the importance of geography for international economic interactions.

II. A SIMPLIFIED STORY OF INTERDEPENDENCE

Using the Krutilla and Anderson demand and supply format, it is possible to develop a straightforward categorization of the current literature's description of trade and the environment. Consider first, the case of a small, open economy exporting a product to the

Figure 1.

Figure is available from authors
and from Resources for the Future.

world market. This is represented in simple terms in Figure 1. $D\overline{D}$ and $S\overline{S}$ describe the domestic demand and supply and OP_w the world price. "Small" implies this country's actions alone will not affect the world market. Under autarky, the market equilibrium would be at the point X with domestic price, OP_x , and quantity OQ_x. If SS_E defines the supply function reflecting the full social cost of producing Q, (i.e., including both incremental private and any incremental social costs arising from externalities from the production of Q),[4] then the welfare loss associated with failing to adopt efficient environment policies is given by XEH. SHX is the added social costs due to producing Q_x. Most of these losses count against the economic surplus we would have attributed to producing OQ_x (i.e., the triangle SXD is economic surplus and SXE the amount subtracted due to added environmental costs).

If this economy is opened to the world market, producers now face the world price, OP_w and would export (i.e., $OP_w > OP_x$). They now produce Q_w, selling OQ_A on the domestic market and Q_AQ_w on the world market. Social costs due to environmental externalities increase by HXCG. Some of this increase displaces the increased rent (AXC) earned by producers and the net outcome depends on the relative size of ABE (the remaining rent) and BGC (the incremental environmental cost that does not displace the rent change). Any export restrictions intended to reduce incentives to participate in the world market that fail to reflect

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[4] This framework is the one often used in describing environmental costing. It is important to acknowledge that the "costs" added by private incremental costs represent the aggregate incremental willingness to pay to avoid the externalities associated with each level of production. Thus, this arises from the affected people's preferences for pollution abatement. To derive the link between $S\overline{S}$ and SS_E would require understanding how each sector responds to control as required to realize the net pollution arising from each level of output. See Smith [1992] for a discussion of some of these assumptions in the context of applying environmental costing to agriculture.

the presence of environmental costs may alter the judgment on rent losses versus environmental costs, depending on the incremental private and social costs.

There are a number of issues that cannot be addressed in this type of a simple, one-market evaluation. For example, this diagram does not take account of the effect of each policy on the position of the private supply, social cost, and private demand functions. The treatment of these general equilibrium effects is what distinguishes most of the new conceptual literature from this simple approach. There are also the "details" about the factors underlying these functions that have implications relevant to complex domestic environmental policies. As a result, we first consider the factors that can be important to the results with small open models and then turn to the effects of general equilibrium feedbacks.

A. Extensions to Krutilla-Anderson Framework

Copeland [1994] and Lopez [1994] consider the potential for multiple effects influencing either welfare or the pollution/income relationship in a single economy. General equilibrium adjustments are not considered. Copeland proposes a small, open economy where the primary focus of his evaluation is a generalization of the analysis to include several markets and programs. Thus, he uses a framework that provides a proper accounting of the price, policy induced rent, and amenity changes required to properly measure Hicksian gains and losses for exogenous effects. There are no feedback effects of domestic policy through either international markets or the global commons because the domestic economy is small relative to the world market, and pollution is localized.

While it is not described in these terms, Copeland's evaluation of policies uses a Hicksian compensating variation measure. He bases his evaluation on marginal changes in the Anderson-Neary [1992] balance of trade function with changes in either environmental (represented as effluent charges) or trade (import tariff and export subsidies) policies. This function reduces to the Hicksian compensating variation with adjustments for changes in income (or rents) due to existing policies.[5]

In terms of our diagram for the case of a small open economy, Copeland's model generalizes the analysis in three ways. It allows for multiple commodities, (consistently accounting for the effects of trade and environmental policy for each); expresses the welfare measures in Hicksian terms; and, perhaps most importantly from the perspective of our later discussion of general equilibrium effects of trade and environmental policy, allows for indirect consumer effects between pollution and marketed commodities. Thus, his framework allows a marginal change in pollution to shift the demand function for the marketed good. In terms of our diagram, this approach recognizes that the introduction of policies taking account of the externalities inherent in the SS_E function could, in principle, lead to shifts in $D\overline{D}$. This effect is ignored in virtually all the other analyses of trade and environment.

Lopez also considers a small open economy and provides a more detailed description of domestic pollution generation, as the equivalent of using an environmental input to produce

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[5] In practice, one would also need to include differential domestic taxation and subsidy policies as influences to the expenditure, GNP and rent changes. Our analysis incorporates these effects as well in the welfare measures described for the amended Harrison-Rutherford-Wooton model described below. All taxes collected in each region are redistributed back to the individual household representing all consumers in that region.

marketed output along with labor and capital. However, the environmental input is assumed to be weakly separable from conventional inputs. His focus is on how growth in income, whether due to technological change or trade liberalization, will influence environmental quality.

In the absence of stock effects on the environment, in his scheme income growth (and greater conventional factor usage) will initially increase pollution and then cause it to decline as income grows. This result allows for a role for the environment in preferences, but requires that Frisch 's index of the importance of income effects be separable from pollution.[6] This later point is important because income changes do not influence the rate of substitution between marketed goods and amenities. His model does allow income to increase willingness to pay for pollution reduction (or equivalently for amenities). In terms of Figure 1, the primary focus of his model is in the details underlying $S\bar{S}$ and the connection to SS_E.

These restrictions are also relevant to using the model to understand the role of coordination between trade and environmental policies in the developing as well as the developed contexts. For example, an important byproduct of Lopez's model is the demonstration that income effects can lead differences in the levels of environmental quality selected at different income levels. Developed and developing countries can appear as different points on a parabolic relationship between pollution and income, with pollution

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6 This condition relies on a partial equilibrium evaluation of a small open economy and assumes a CES (constant elasticity of substitution) production function for the single index of all market output in terms of a single marketed input and pollution services. With the assumption that the Frisch money flexibility of income is independent of the effects of pollution on preferences, Lopez shows that the relationship between pollution and income will depend on the inverse of the elasticity of substitution in production in comparison to the Frisch index.

initially increasing with income and then declining (comparable to the Grossman and Krueger [1993] empirical link between pollution and GDP). In the Lopez analysis, this result follows from a comparison of the importance of substitution in two contexts as the level of income grows. The first of these involves the environment's importance to people's preferences and the second considers its role in production at different levels of output.

These relationships become more complex if the environment influences people's demands for marketed goods and, simultaneously, affects some marketed inputs differently from others. Earlier research by Lopez with Nikletschek [1991], for example, illustrates how the positive contributions of environmental resources (e.g., natural biomass) to a traditional sector can have these types of effects on production. They found that direct production taxes to take account of trade's detrimental effects on the environment would be necessary to enhance welfare with trade liberalization.

With the Krutilla-Anderson framework, the inclusion of social costs requires considering the added incremental costs due to externalities so that they are proportional to increases in marketed outputs. Lopez's model focuses on the simplifications underlying the Krutilla-Anderson type of analysis and how they influence what is likely to be observed (across countries) from a process that views pollution levels as outcomes of the tradeoff between marketed goods and amenities as households experience growth in real income.

B. Incorporating General Equilibrium Feedbacks

The remaining papers in this area consider different approaches for treating the general equilibrium interactions between market and non-market outcomes. Chichilnisky's analysis uses a conventional general equilibrium framework with two countries, (designated the North and South). The North is intended to represent a developed economy with a well established system of property rights to all resources, while the South designates a developing economy with a different set of conditions describing the availability of factor inputs. Her model relies on the differences in access conditions between private and open access resources (as factor inputs) to alter the supply functions for tradable goods. Because endowments are not fixed and respond to prices, the supply of marketed outputs produced using the environmental resource's services will be greater under open access conditions. The model allows for the general equilibrium interaction between product and factor market conditions in both economies. Establishing private property rights to the environmental resource offers the only feasible policy response to the over-exploitation induced by the access conditions to the environmental resources. Trade simply increases the problem, even when policies designed to raise other factor costs are considered.

In terms of Figure 1 this framework is an analysis of how access conditions to environmental resources can influence $S\bar{S}$. There are no public goods or externalities, aside from the inefficiencies due to open access. While Chichilnisky's examples introduce amenities, the model does not. Indeed, private property rights succeed *because* there are no preference related effects served by protecting the environmental resource. Thus, SS_E does not exist in this framework.

Copeland and Taylor [1994] adopted a similar two country (North/South) setting but introduce externalities, local to each country's decisions. Thus, this model adds general equilibrium effects to the social cost issues identified in Figure 1 with SS_E. It allows for: interactions between the two countries, endogenous (to each country) pollution taxes, and a continuum of goods, differing both in their propensity to generate pollution and importance to consumers. The model assume Cobb-Douglas technology and Cobb-Douglas preferences in marketed goods. Domestic pollution is treated as strongly separable from marketed goods.

As with Lopez, income effects are the key source of differences in environmental policy and, in turn, lead to the motivation for trade. Increased pollution in the South provides the way it can increase the gains to be realized from trade. Lower incomes in the South assure that this trade is possible because pollution control is less highly valued. If the differences in the South's ability to absorb pollution correspond to income differences (e.g., the less developed country has both lower income levels and lower existing pollution) these differences in initial conditions would simply reinforce what the model displays. The Chichilnisky and the Copeland-Taylor models either ignore or assume separability between marketed goods and the environment. As a result, they fail to take account of the same substitution effects (i.e., arising through preferences) that were noted in our discussion of Lopez. Pollution itself may alter the composition of goods demanded.

The Copeland-Taylor framework shifts the focus of attention from the goods' markets and the effects of trade on them, as illustrated in Figure 1 for the one commodity case, to the "market" for pollution. In their first paper, the general equilibrium effects of trade are seen through the domestic "market" for pollution. Trade influences both the supply of pollution and exerts effects on income to shift the incremental value of pollution reduction. In a subsequent paper [Copeland and Taylor, 1995a] they allow for transboundary pollution and multiple countries. Separability (of preferences in aggregate pollution) implies that the pollution induced effects of greater production in one country now are not limited to that country. They act as an offset to the increased income and lower costs for marketed goods from trade. All pollution in any country is a pure public good (bad). But these effects arise with equal force to all countries. As the authors note, the results parallel what we find in the literature on charitable contributions [see Bergstrom, Blume, and Varian, 1986], policy changes that expand aggregate output do not reduce worldwide pollution.

Barbier and Raucher [1984] consider a framework that relates more specifically to the problems of developing economies by evaluating the effects of trade on incentives for tropical deforestation. Using an optimal control model they allow for stock externalities to influence trade policy for both small and large economies. As with Chichilnisky and Copeland and Taylor, the model assumes separable preferences, so there are no preference related substitution effects influencing how the externality in each model influences optimal trade policy.

C. Computable General Equilibrium Approaches

A framework with pure public goods has been the primary specification used for those computable general equilibrium (CGE) models that introduced non-market environmental resources [see Ballard and Medema, 1993, and Piggott, Whalley, and Wigle, 1992]. Environmental resources are allowed to influence the level of household well-being but not the preference-related substitutions between goods due to changes in these resources. Equally important, these models do not have an explicit spatial dimension. Their structure treats the environmental resource as a uniform public good. This specification is comparable to the form used in Copeland and Taylor's multiple country model with global pollution.

To our knowledge, the only model that has attempted to develop a more explicit treatment of local and transboundary pollution is Perroni and Wigle [forthcoming]. Their framework allows for both local and global effects. It incorporates separate regional abatement decisions, but assumes the same technology. A constant elasticity of transformation (CET) function is used to aggregate net local and net global pollution abatement activities. Within each region, local environmental quality is determined by the level of output of the sectors generating emissions, decisions about abatement activities, a region specific constant elasticity damage function linking aggregate net (i.e., after abatement) emissions to quality, and the initial stock of quality assumed present in the region. Control over the mix of global versus local environmental quality is realized through the abatement function. The emissions generation, damage functions, and environment quality endowments differ across regions. Global environmental quality is described in a similar way, but the parameters of damage functions are assumed to be the same across regions. It is difficult to evaluate how the model's implied response in the final mix of local and global damages to policy accords with the assumptions generally used in domestic policy evaluations.

Preferences are specified as a nested CES function with the pollution composite and goods aggregate in the top nest. This implies substitution between goods will not be influenced by the level of pollution (local or global). Nonetheless, the structure is an interesting step toward more realism.

D. Overview

Our review of the recent research on trade and the environment adopted the modeling perspective used in environmental economics to evaluate what "details" should be judged as important in evaluating the work to date. First, the models, both theoretical and computational, have consistently assumed separable preferences. This approach separates the effects of the environment on well-being from people's decisions made about different mixes of private goods. As we will discuss in more detail below, there are no preference related feedback effects of externalities transmitted outside markets on the outcomes observed in markets. This approach is inconsistent with all revealed preference methods for non-market valuation. It is the absence of separability, and indeed, specific assumptions linking private goods to public goods that have been the most important aspect of the preferred methods to estimate the economic values of non-marketed commodities.

Second, in actual applications, we generally find that environmental externalities arise through some type of spatial interaction. That is, activities in one location have effects on other activities in that location as well as on others outside the immediate area. Virtually all policy responses suggest that the details of both the activity and the transmission mechanism matter.[7] Recently, Copeland and Taylor [1995b] have demonstrated how spatial differences in the effects of externalities on production can give rise to nonconvexities akin to those due to increasing returns [see Helpman and Krugman, 1985]. From an applied CGE perspective, only Perroni and Wigle [forthcoming] acknowledged this type of connection. However, as we noted, their specification of these connections may oversimplify matters in important ways.

Finally, attempts to link trade and environmental policies must be evaluated within a framework that acknowledges the complexity of trade restrictions present in most countries. Equally important, they must allow welfare judgments to take account of the general equilibrium effects that change both relative prices and incomes (rents) that can arise from existing policies. As Chichilnisky (and others before her) acknowledge, these types of increases in complexity are difficult to incorporate in a meaningful way in theoretical models. While they can be accommodated in CGE analyses, they must be introduced so that the specification matches some existing baseline.

The reason for this approach is direct. It is relatively easy to acknowledge that complexity in the nature of regulations and policy induced price wedges will matter. Because each specific form will change outcomes, it makes little sense to catalog all possible distortions, many of which don't exist. Instead, the most productive route for model design

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[7] One example of this role for environmental resources is found in evaluating the net benefits of command and control versus incentive based regulations. See Oates, Portney and McGartland [1989].

would call for selecting a specific "realistic" description of a policy regime and calibrate the analysis to deal with it. Clearly, the specific calibration influences both the parameters and the conclusions drawn from that model. Nonetheless, by selecting an existing model and incorporating environmental effects within it, there is a ready benchmark for comparison. For this reason, we selected a re-specified version of an established model for the major economies in the European Union (EU). The model was re-calibrated to include local and transboundary pollutants as well as the health effects they cause using damage functions based on those currently used in regulating these pollutants in the U.S.

III. DEVELOPING A NON-MARKET CGE MODEL

In this section we describe the Harrison, Rutherford, Wooton model (HRW1) and the adaptations to it to incorporate three air pollutants -- sulfur oxides (SO_x), as a transboundary externality; and particulate matter (PM) and nitrogen oxides (NO_x) as sources of local externalities. The model links the pollutants to production in the relevant sectors of each country; incorporates a simple diffusion system for the transboundary pollutant; and introduces the morbidity related health effects from air pollution as non-separable effects on preferences. Mortality impacts are treated as separable effects on individual well being. The amendments were made to incorporate current estimates of health damages -- both morbidity and mortality from these air pollutants. The design also permits an evaluation of the implications of: (a) omitting the environment from evaluations of changes in trade policy; (b) ignoring the joint effects of local and transboundary pollutants; and (c) restricting preferences to be separable in environmental resources.

After describing the structure of the model and our amendments, we outline the welfare measure used to evaluate a scenario involving both trade liberalization with environmental degradation. Our analysis considers three different ways that environmental damages might have been introduced into the model. The first of these directly calibrates the preference and production structure to meet base year conditions, including health effects as translating parameters on a Stone Geary specification of preferences. The second treats the analysis of environmental damages as an *exogenous* valuation task with computation after the CGE model is solved for a market equilibrium in marketed goods. This follows the strategy recently proposed by Boyd, Krutilla, and Viscusi [1995]. The last considers health damages impacts on the source for household income that endogenously reduce effective labor endowment available to households.

A. The Revised Harrison, Rutherford, Wooton Model - HRW1

HRW1 was calibrated to represent conditions in the EU in 1985. It includes eleven regions with eight of the EU countries -- Germany, France, Italy, the Netherlands, Belgium, United Kingdom, Denmark, and Ireland, as well as the United States, Japan and an aggregate region that includes all other countries. The model distinguishes six aggregate commodities (agriculture and food; mining and energy; nondurable manufacturing; durable manufacturing; construction and transportation; and services) and three factor inputs (land, labor, and capital).

Factors are not traded outside the home region. Consumption goods trade using a nested Armington structure.[8]

Production is characterized using constant returns to scale, nested, production functions. These functions assume a constant elasticity of substitution in the primary factors (land enters only the agricultural sector) and a linear technology in intermediate inputs. Each region's (country) demand is represented by a single consumer with a Cobb-Douglas utility function in the six consumption goods. The budget constraint is specified by the aggregate consumer's exogenous endowment of primary factors, net revenues from taxes and level of foreign investment (assumed to equal a lump-sum transfer in the model). The model includes a detailed representation of domestic taxes, trade barriers, government and EU programs. For example, all regions (except the U.S.) have value added taxes on the primary factors represented as a fixed ad-valorem tax rate. Producers in the EU countries also receive subsidies on production aimed at fostering exports. The net EU transfers are equal to the value of receipts from intervention purchases and variable agricultural import levies (due to the Common Agricultural Policy) less the cost of export subsidies and the net contributions to the EU.

Our model uses the HRW1 structure in exactly the form developed and reported in various publications [i.e., Harrison et al., 1989, 1991]. We have made three modifications to the model: (a) replaced the Cobb-Douglas with Stone-Geary utility functions for the aggregate consumer in each region; (the Cobb Douglas specification takes the form $U = \Pi_i \, x_i^{\beta_i}$, while a

[8] With the nested Armington assumption importers are assumed to minimize import costs subject to an import aggregation function linking in the first nest domestic consumption of the commodity with a CES aggregate of the imports of the same commodity from all regions.

Stone-Geary displaces each commodity by a translation or subsistence parameter, γ_i, so $U = \Pi_i (x_i - \gamma_i)^{\beta_i}$); (b) introduced nine air pollution induced morbidity effects as translating effects on each household's subsistence parameter for services (this is the aggregate that HRW1 designates for health expenditures); and (c) introduced an explicit set of pollution generation and dispersion models for each of the three air pollutants identified earlier. As a result, air pollution will affect the marginal rates of substitution for consumption goods relevant to these services. Our specification for air pollution effects also allows for mortality effects as a separable shift in preferences. The magnitude of this effect is also directly linked to existing estimates of mortality-air pollution dose response models. Finally, monetary loss measures use estimates of the value of statistical lives. Each of these modifications has been introduced so that the model's initial calibration is maintained.

There are four important features of our adaptation to HRW1 to incorporate air pollution: (a) developing benchmark air pollution measures for each sector in each country; (b) specifying the air diffusion system for transfrontier pollutants (e.g. SO_x); (c) linking the ambient concentrations of pollutants to morbidity and mortality effects; and (d) monetizing these health impacts. We will summarize the highlights associated with each step.

Emissions of PM, NO_x, and SO_x are based on the *OECD Environmental Data Compendium 1989*. Each region was assigned the population weighted estimate of the average annual concentration for urban and rural locations. Because SO_x is assumed to be a transfrontier pollutant, we used 1991 estimates of the relationship between emissions and depositions to each country from each source [see Markandya and Rhodes, 1992]. The first three columns of Table 1 report the benchmark concentrations used for all three pollutants. The fourth column reports the share of SO_x deposition due to domestic sources. For local pollutants (PM and NO_x), the deposition is assumed to equal emissions and ambient concentration coefficients are constant multiples, converting deposition units to the appropriate ambient measures.

Table 1. Benchmark Air Pollution Levels and the Morbidity and Mortality Losses as Shares of Service and Total Expenditures

	Benchmark Air Pollution				Benchmark Morbidity Effects		Mortality Effects
Region	PM ($\mu g/m^3$)	SO_x (ppm)	NO_x ($\mu g/m^3$)	Own Deposition Rate	Share of Total Exp.	Share of Services Exp.	Share of Total Exp.
Germany	59.55	.024	49.50	.42	.028	.112	.172
France	24.32	.010	22.34	.42	.013	.049	.045
Italy	83.85	.029	46.98	.65	.031	.146	.157
Netherlands	60.28	.010	46.05	.15	.025	.131	.110
Belgium	91.40	.015	49.59	.31	.040	.216	.194
United Kingdom	19.85	.014	31.98	.83	.013	.046	.051
Ireland	16.32	.009	25.16	.51	.006	.023	.014
Denmark	60.61	.009	49.33	.15	.047	.255	.275
U.S.A.	32.78	.006	53.46	1.00	.012	.031	.047
Japan	35.02	.008	39.15	1.00	.023	.069	.058
Rest of World	48.40	.013	46.19	.95	.047	.128	.337

The allocation of emissions to specific production sectors was based on the U.S. emissions by production sector. These emission per unit of output rates were applied to each sector's output in each region and the resulting estimates of aggregate emissions were re-normalized by country, using the ratio of actual to predicted aggregate emissions.

The third component of the process of incorporating environmental resources into the HRW1 involves computation of the health effects. The nine morbidity effects are given by pollutant as follows: PM (bronchitis, chronic cough, croup, emphysema, upper respiratory disorders, and cough episodes), NO_x (lower respiratory disorders, eye irritation), and SO_x (chest discomfort). The dose-response functions were based on the Desvousges et al. [1994, Vol. 1] study of morbidity effects. Implementing these models requires the correct pollution measure (and we used conventional conversion ratios in these adaptations), along with a base population to apply the revised incidence rate, relevant for each health effect. In many cases these populations were specific demographic groups (often either older populations or young children). In general, it was not possible to identify populations at this level of detail. We used the overall population of each region to estimate a base incidence level. For NO_x, it was possible to adjust for the fraction of the population under 15 years of age in developing the health impact.

Monetization of the health effects requires estimates for the incremental willingness to pay for each health event. These were taken from Desvousges et al. [1994, Vol. 3]. Because all of the valuation estimates were in 1993 U.S. dollars, they were re-scaled to 1980 (the reference year used by HRW to deflate prices in their benchmark data set) and converted to each country's currency. Mortality effects were assumed due to particulate matter and used $3.5 million dollar estimate as the value of a statistical life (in 1989 dollars).

Changes in pollution are assumed to change the level of the subsistence parameter for the service aggregate [Pollak and Wales, 1981]. This translation was calibrated to meet the benchmark solution for HRW1 given our estimates of the ambient concentrations of each pollutant in each country and the dose-response functions. The subsistence parameters for the Stone Geary specification in each country were developed using Gamaletsos [1971] and Lluch and Powell [1975]. Based on these estimates, adjusted to reflect real GDP in the benchmark year for HRWI, total demand for each product was reduced by the value of its subsistence parameter for benchmark conditions (i.e., including estimates of air pollution). The remaining parameters of the Stone Geary functions were derived using HRW1's calibration method.

By allowing the subsistence parameter for services to be a linear function of estimated morbidity losses in the benchmark year, the intercept in the translating equation was used to adjust the impact of pollutants so the benchmark estimate corresponded for each subsistence parameter. Mortality effects were treated as a separable adjustment to utility.

B. Measuring the Welfare Consequences of Trade and Environmental Policies

To measure the welfare effects of changes in trade or environmental policies, it is important to acknowledge that existing trade policies (e.g., tariff, quota, and subsidy) generate income for some economic agents. Policy changes can lead to income changes. Thus, efficiency gains arising from efforts to remove distortions in product or factor prices or reduce environmental externalities can, in a general equilibrium framework, change these rents. To acknowledge them in applied welfare analysis implies we accept a second best situation in evaluating policy changes.

Following Anderson and Neary [1992b] we adopt a Balance of Trade function (BT) to evaluate the welfare effects of policy change. This is consistent with Copeland, except he assumed a balance of trade equilibrium and we allow for trade surplus and deficits (β). Equation (1) defines the BT function in terms of the Hicksian expenditure function, e(.), the GNP or aggregate revenue function, g(.), and tariff and quota rents.

$$\begin{aligned} BT(q,\phi,\bar{u}) &= e(p(q,\pi,\bar{u}),\pi,\bar{u}) - g(p(q,\pi,\bar{u}),\pi) \\ &\quad - (\phi-1)\,\pi^{*}\,m - (1-w)(p-p^{*})^{T}\,q - \beta \end{aligned} \tag{1}$$

where

q	=	quotas (vector)
ϕ	=	proportional markups due to tariffs
$\bar{u}$	=	level of well being for single household (assumed to represent all households in the economy)
π	=	domestic prices (i.e., $\pi_i = \pi_i^{*} + t_i$ so $\pi = \pi^{*}\phi$, with t_i = tariff on ith commodity, π^{*} a diagonal matrix and $\phi_i = 1 + (t_i / \pi_i^{*})$)
π^{*}	=	diagonal matrix of world prices on diagonal and zeros elsewhere.
m	=	vector of import demands ($m = e_\pi - g_\pi$)
p*	=	vector of foreign prices on quota restricted commodities (p = domestic price vector)
$p(q,\pi)$	=	virtual prices of quota restricted goods
(1-w)	=	fraction of quota rents that return to domestic residents (w is the share that goes to foreigners)
β	=	the trade surplus or deficit.
T	=	as a superscript identifies the transpose of a vector

Introducing environmental externalities regulated at some level Z_d for domestic and Z_f transboundary sources adds these two terms to e(.), g(.), and, therefore, to the virtual prices functions, p(.).

Consider now a simultaneous change in tariff restrictions from ϕ to $\bar{\phi}$ (with $\phi < \bar{\phi}$) and from Z^0_d to Z^*_d, Z_f^0 to Z_f^*. Using the balance of trade functions to evaluate the welfare implications of this policy change we have equation (2).

$$\Delta BT = e(p(q,\pi,Z_d^o,Z_f^o,\bar{u}),\pi,Z_d^o,Z_f^o,\bar{u}) - e(p(q,\bar{\pi},Z_d^*,Z_f^*,\bar{u}),\bar{\pi},Z_d^*,Z_f^*,\bar{u})$$

(conventional Hicksian compensating variation)

$$- \qquad g(p(q,\pi,Z_d^o,Z_f^o,\bar{u}),Z_d^o,Z_f^o,\pi) - g(p(q,\bar{\pi},Z_d^*,Z_f^*,\bar{u}),Z_d^*,Z_f^*,\bar{\pi}) \qquad (2)$$

(change in the value of factor endowments -- household income)

$$- \qquad \left[(\phi-1)\pi^* m - (\bar{\phi}-1)\pi^* \bar{m}\right]$$

(change in tariff income)

$$- \qquad (1-w)\left[(p-p^*)^T q - (\bar{p}-p^*)^T q\right]$$

(change in quota rents)

Re-organizing terms we see that the Anderson-Neary criteria for the restrictiveness of trade policy is completely consistent with Hicksian welfare theory in the presence of multiple restrictions. The first term in equation (2) is the Hicksian willingness to pay for the composite change, and the remaining terms adjust for income and rent changes due to the policy change. The zero profit condition along with an assumption that factors are immobile (a characteristic of the HRW model) assures that changes in the GNP function correspond to the change in value of domestic endowments.

This formulation also allows consideration of the effects of separability. With separable preferences, environmental resources would be yet another adjustment to the income changes. They would not influence the virtual price of quotas or the Hicksian WTP for the policy change independent of this income adjustment. In this general formulation they can, in principle influence the pure substitution effect captured in the first term as well as the other three "income" related changes.

A final issue that this expression illustrates concerns the role of the measures of environmental resources. We assumed in equation (2) that Z_d and Z_f enter both household expenditure and GNP functions in the same way. This specification implicitly embeds the role of the environment, as a mechanism converting emissions to ambient concentrations, in one of these two behavioral functions. Restrictions on domestic emissions are relevant to Z_d as well as to any contribution domestic emissions make to the level of the pollutants influenced by transboundary sources, and thus to the Z_f in the GNP function. The ambient environment and the transboundary transfer function influence what is relevant for the level of Z_f entering the expenditure function.

In practice the level of Z_d in the GNP function is not the same as that affecting the expenditure function. There is some conversion relationship. Because there is only one household in each country, the approach simply scales emissions in the current version of the model. It is nonetheless one of the ways spatial differences within each region could be introduced in a model without requiring preference differences. The diffusion functions serve as the equivalent of preference differences.

As we noted earlier, the Perroni-Wigle use of conventional CES functions to capture these differences is one of the ways of recognizing their importance. Unfortunately, we know very little about the correspondence between the use of this type of averaging function and the types of diffusion models used by environmental scientists to link ambient concentrations to emissions of different types of pollutants. Both influence excess demands and virtual prices. Thus, the simplifying assumptions highlighted earlier can in principle influence all aspects of a welfare evaluation of policy change. Separability assumptions incorrectly confine their impacts to the terms adjusting for changes in income.

C. Do the Assumptions Matter?

To evaluate whether the assumptions of the recent research on trade and the environment influence conclusions about welfare effects of liberalization, we have considered one composite scenario in four different ways. Our policy change introduces a reciprocal reduction in non-tariff barriers by 50% (from .20 to .10) for all trade between the UK and each of its EU trading regions in the goods from the durable manufacturing sector. It is combined with a 25% increase in the emission rates for all three pollutants for this sector in the U.K. We might consider the second component of the scenario as an approximate method for describing a relaxation in environmental standards to represent the entry of marginal plants in response to the trade liberalization.

The first approach for evaluating this change ignores the environmental effects completely. Labeled NE, it focuses on the market effects of the reduction in trade restrictiveness. The second approach adopts the Boyd, Krutilla, and Viscusi [1995] framework by keeping track of the changes in emissions due to the composite policy *after* the model is solved for a new vector of general equilibrium prices with the reciprocal reduction in non-tariff barriers in this sector for EU regions. The increment to the balance of trade function with environment effects is computed based on the scenario in comparison to the baseline. The changes in emissions, corresponding health effects (morbidity and mortality) are computed and valued at baseline incremental WTPs. These are treated as the equivalent of an exogenous income change using the fixed "prices" for the health effects. This approach (labeled BKV) imposes a stronger restriction than separability of preferences (in environmental and marketed commodities) because reductions in income due to the damages are not allowed to influence the composition of final demands for marketed goods and implicitly the general equilibrium levels of emissions. The third approach (labeled ENDOW) treats morbidity effects as reducing the available labor endowment. It might seem plausible to interpret this approach as a "pure" income reduction. This would not be correct. The reduced endowments alter factor and product prices. As a result, substitution effects do accompany the change in pollution. They arise in this case from the incremental cost increases due to increased labor scarcity rather than from a specified role of the environment in preferences.

Finally, the last evaluation framework (labeled ES for Espinosa-Smith) recognizes the effects of morbidity on threshold demands for services and as a result reflects the substitution effects induced for other marketed goods as well as any income effects through re-valuation of endowments or changes in rents (as given in equation (2)).

Table 2. A Comparison of Price and Trade Effects of Trade and Environmental Policy Changes

	-50% NTB for UK Durables			
United Kingdom	NE	BKV[a]	ENDOW[a]	ES[a]
I. Consumer Prices (%Δ)				
Agriculture and Food	.8515	.8503	.8618	.8591
Mining and Energy	.9018	.9003	.9119	.9113
Non-Durable Manufacturing	.8124	.8110	.8232	.8213
Durable Manufacturing	-1.1979	-1.1989	-1.1900	-1.1923
Construction and Transportation	-1.0877	1.0859	1.1010	1.0996
Services	1.1669	1.1651	1.1815	1.1790
II. Producer Prices (%Δ)				
Agriculture and Food	1.1074	1.1059	1.1210	1.1175
Mining and Energy	1.1681	1.1663	1.1813	1.1805
Non-Durable Manufacturing	1.0695	1.0677	1.0840	1.0813
Durable Manufacturing	.9984	.9967	1.0147	1.0098
Construction and Transportation	1.0988	1.0970	1.1123	1.1108
Services	1.1872	1.1854	1.2021	1.1996
III. Trade Durables				
%Δ Exports				
To -EC	16.195	16.199	16.159	16.169
To-Non-EC	-1.903	-1.886	-1.922	-1.899
%Δ Imports				
From EC	13.691	13.695	13.675	13.675
From-Non-EC	-4.139	-4.140	-4.168	-4.155

[a] When the 50% reciprocal reduction in non-tariff barriers for durables is implemented for these computations the emission rates for all air pollutants generated by the UK durable sector are increased by 25%.

Table 3. Welfare Implications of Policy Evaluations

	-50% NTB for UK Durables			
COUNTRY	NE	BKV[a]	ENDOW[a]	ES[a]
I. <u>United Kingdom</u>				
A. <u>Welfare Change</u>				
1. BT/GDP (%)	.1979	.1653	.1766	.1767
(excluding mortality)	[0.12]	[0.06]	[0.00]	--
2. BT/GDP (%)	.1979	-.1773	-.1660	-.1662
(including mortality)	[2.19]	[0.07]	[0.00]	--
B. <u>Environmental Effects (UK)</u>				
% Emissions				
PM	.161	6.714	6.687	6.693
NO_x	-.111	2.087	2.061	2.064
SO_x	-.098	2.427	2.402	2.406
% Health Effects				
Morbidity	-	1.654	1.645	1.647
Mortality	-	6.714	6.687	6.693
II. <u>Germany</u>				
A. <u>Welfare Change</u>				
1. BT/GDP (%)	.0134	.0123	.0120	.0121
(excluding mortality)	[0.11]	[0.02]	[0.00]	--
2. BT/GDP (%)	.0134	.0070	.0067	.0070
(including mortality)	[0.91]	[0.00]	[0.04]	--

[a] When the 50% reciprocal reduction in non-tariff barriers for durables is implemented for these computations the emission rates for all air pollutants generated by the UK durable sector are increased by 25%.

Tables 2 and 3 present the results for the trade/environment scenario evaluated with each of the four different strategies. Table 2 compares their impacts on producer and consumer prices and trade. Qualitatively, the results are similar with the direction of change in all the sectoral prices and trade similar regardless of how the policy is implemented (i.e., with and without environmental consequences as well as with and without various forms of separability imposed). Table 3 offers the most direct illustration of the effects of these later assumptions. To gauge the implications of separability, consider first the implications of taking account of the air pollution induced effects on morbidity. This is given in the first row of Table 3 labeled as IA.1. Taking the ES approach as the "correct" basis for evaluating the composite trade and environment scenario, we find that ignoring this aspect of the environment would cause a 12 percent overstatement of the gain relative to GDP. It should be noted that both the ΔBT and GDP (i.e., the numerator and denominator in the ratio reported in the table) are changing in these comparisons.

General equilibrium adjustments affect the composition of final demand, the level of emissions, and the value of factor endowments. The BKV approach would *overstate* the losses. This error is six percent, as seen in the bracketed term in the row labeled IA.1. This outcome is what should be expected because their approach ignores the prospects for substitution.

The results from treating morbidity effects as an endogenous adjustment to the labor endowment may at first seem surprising, but they should not be. The measure of welfare change as a percent of GNP is comparable to the ES case in part because of the specific form of the utility function and the role we assigned to pollution. With a Stone-Geary function, adjustments to the subsistence parameters reduce discretionary income, due to the increased demands for health services. This follows because the subsistence parameter for this sector increases with the increase in the morbidity effects due to air pollution. At the benchmark solution in the U.K, these morbidity induced service demands were about five percent of the expenditures on services (and one percent of total expenditures) .

The endowment approach allows the labor endowment to adjust down with increased morbidity effects due to air pollution. Because this adjustment is endogenous, factor prices and final goods' prices also adjust, changing the product mix, and ultimately, the pollution levels and associated morbidity effects. Welfare effects take account of the change in relative prices between the two scenarios and the associated adjustment in demands.

When we consider the mortality effects entered as a separable effect on preferences, the distinctions between the no-environment (NE) and other scenarios becomes more pronounced. Mortality effects were five percent of U.K. total expenditures in the benchmark solution. Here we find that it is possible to *misinterpret* the net benefits from the change in trade policy. Considering trade liberalization alone, the reduction in non-tariff barriers enhances well being. If, as we postulated, there is an accompanying increase in the emission rates for air pollution in this sector, then there is a net welfare loss considering both the separable and nonseparable health related effects. One reason for considering these elements in steps is to recognize that small omissions from the environmental consequences of trade policy may not be important to the measures of the welfare consequences of the change. Of course, this is not guaranteed. The nature of the change, sector affected, and character of environmental impacts all matter. This is illustrated with our example where even this relatively small increase in total emissions (from 2.0% to 6.7%) was sufficient to change the verdict on the policy.

Of course, it is important to acknowledge that we *postulated* the 25% increase in emission rates from this sector. Comparison of the entries in the first column under category B with the other three columns illustrate how trade liberalization affected emissions in the absence of this exogenously specified increase in emission rates for this sector. Particulate matter would have increased by about two tenths of a percent (in comparison to the 6.7% aggregate increase implied by the scenario).

While the primary focus of the analysis is on the U.K., the price effects and the environmental effects have impacts beyond this region. Germany experiences welfare gains for the trade liberalization which would *also* be overstated if the environmental effects are not taken into account. This overstatement arises primarily from the effects of increased output in the durable manufacturing sector on emissions and, to a more limited degree, from the transboundary effects of increased emissions from the U.K. for Germany.[9] The direction of these effects both for morbidity and mortality, and for methods of measurement, are comparable to what we found with the U.K. Here, we do not have the simultaneous increase in pollutants assumed to accompany trade liberalization in the U.K.'s durable manufacturing sector. Nonetheless there is a large difference in the evaluation of the policy depending on whether (and how much of) the environmental effects are recognized. The differences among evaluation methods, BKV, endowment, and our approach are much smaller because the overall importance of the nonseparable environmental effects is smaller as a fraction of GDP.

Overall, this comparison reinforces the issues identified in our review of the conceptual and CGE literature to date. Assuming that environmental resources make separable

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[9] Sulfur oxide is the only transboundary pollutant. Its effects are limited to one morbidity relationship (chest discomfort), not a mortality effect. The dispersion coefficient for 30x from UK to Germany is derived as the product of the share of the UK's 30x emissions received by Germany (0.015) and the S0x dispersion coefficient for Germany (.01128 ppm/ton).

contributions to preferences not only contradicts the logic used in revealed preference approaches to non-market valuation, it has an important effect on the relative price impacts and welfare measures derived for composite trade and environment policies. Equally important, there is a more subtle, but important role played by nonseparability. These specifications recognize the jointness in the general equilibrium solution between market *and* nonmarket interactions between economic agents. When environmental resources influence the marginal rates of substitution (in consumption) for market goods, we can expect that externalities will both *affect* and be *affected by* final good choices. The first of these influences is through the interaction outside markets and the second is the result of market based substitution on final production patterns and the level of emissions that result from them.

Preference related impacts provide a potentially important feedback loop that has to date been ignored by existing conceptual and computational models. In these approaches, the exclusive message seems to be one where international markets magnify external effects. However, in a more general approach, these external effects can *change* the demands for marketed goods and services and, thereby, transmit impacts outside markets that nonetheless change domestic and international resource allocation decisions.

IV. GEOGRAPHY, TRADE, AND THE ENVIRONMENT

Krugman's [1991] essays on the frontier issues in international economics argue that some of the most important research questions in trade theory, as well as in the analysis of trade policy, follow from greater recognition that geography matters to economic activities. In his models, the spatial or geographic concentration of economic activities arises from a collection of forces -- increasing returns to a common location in some production activities that must be balanced against transport costs to the larger markets required to take advantage of these economies, as well as by the degree to which production can be "footloose."

He uses two primary approaches to argue for greater attention in international economic models to economic geography. The first is a bottom-up framework that looks at the micro forces leading to different regional patterns of activity that may transcend separate economies as they are traditionally defined. He concludes with a top-down perspective, that postulates countries as the primary source of restrictions to the movement of factors and goods. In his analysis, national economies are simply sources of inefficiency in resource allocations.

In both situations, space (or location) matters in providing external economies, but the factors giving rise to either the advantages or the costs must be postulated by the analyst. Increasing returns exist -- their source is human capital or other forces often outside the model and thus not explained by it. An alternative explanation for the tendencies he finds is with the environmental resources that regionally and globally transmit external effects.[10]

Chichilnisky's analysis concluded that greater attention to trade and environment interactions was warranted because international markets *magnify* externalities. Our discussion of how environmental externalities can influence general equilibrium evaluations of trade and environmental policies emphasized the *feedback loop* or, more simply, the

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[10] Copeland and Taylor [1995b] have formulated a two country model with production externalities that encourage spatial separation of activities and trade that lends to environmental degradation. The logic of the analysis is comparable to Helpman and Krugman's [1985] analysis of the effects of increasing returns of trade.

implications of interactions between agents that arise outside markets because of one or more environmental resources. Through non-separabilities these interactions can play a direct role in the substitutions that influence outcomes within markets. To the extent non-marketed environmental resources make nonseparable contributions to production and preferences, they influence the signals for marketed goods from both sides of market transactions. These issues are likely to be at least as important for developing economies where the environmental resources often serve a key role in agriculture (e.g., Lopez and Nekletshek's natural biomass) or as extractive outputs but could also contribute (in a preserved status) to watershed protection, microclimatic functions, and amenities (e.g., Barbier and Rauscher).

What determines the importance of these interactions outside markets? One explanation is that environmental media define the relevant geographic extent of the positive and negative interactions outside markets. This was illustrated by the differences between local and transboundary pollutants. Differences in tariff, non-tariff barriers, and domestic taxes provide the basis for separating the "regions" within the HRW1 model. They provide the price "wedges" that define each economy. Without them some other exogenous constraint must be used to separate or distinguish activities within each country. Within CGE models, these restrictions provide the primary limit to "footloose" movement of production.

Once the restrictions are defined, however, it is possible to consider something completely different -- the diffusion of air pollution through transfer coefficients that define, in a simple way, the basis for local and transboundary feedbacks in the international economy.

But we could re-think matters and start with the environmental transfer function and, then, consider how the price wedges enter.

Thus, a key lesson that has more general implications beyond discussion of coordination of trade and environmental policies is the basic premise of Krugman's essays. Regional analysis can inform discussions of the issues relevant to international economic modeling because it helps to focus on the forces that create positive and negative interactions. In his approach there are still omitted factors, entering as "accidents" of historical interactions that gave rise to the regions. Perhaps starting with the role of the environmental resources serving as one source of services with positive and negative effects would help take the "mystery" out of the origins of economically meaningful regions. Transport costs and footloose behavior are not the whole story.

The relevance of this perspective is, of course, not limited to the interactions of trade and environmental policy. Analyses of regional economic issues and national environmental policies are equally plausible candidates. Here institutional restrictions providing for differences in prices are less relevant. The properties of diffusion systems, whether linking or separating activities, now have the opportunity to influence economic behavior. Thus, we are left with another source of endorsement for Krugman's recommendation to look at regional patterns of economic activities for the role of constraints (and incentives) whether institutional, technological, *or environmental*, for the scale and dispersion of economic activities.

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