Trade Liberalization as a Vehicle for Adapting to Global Warming

Timothy O. Randhir

and

Thomas W. Hertel*[1]

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[1] Assistant Professor, Department of Forestry and Wildlife Management, Holdsworth Natural Resources Center, University of Massachusetts and Professor, Department of Agricultural Economics, Purdue University

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ABSTRACT

This study assesses the interaction between climate change and agricultural trade policies. We distinguish between two dimensions of agricultural trade policy: market insulation and subsidy levels. Building on the previous work of Tsigas, Frisvold and Kuhn (1997) we find that, in the presence of current levels of agricultural subsidies, increased price transmission --as called for under the Uruguay Round Agreement on Agriculture-- reduces global welfare in the wake of climate change. This is due to the positive correlation between productivity changes and current levels of agricultural support. Increases in subsidized output under climate change tend to exacerbate inefficiencies in the global agricultural economy in the absence of market insulation. However, once agricultural subsidies have also been eliminated, price transmission via the global trading system contributes positively to economic adaptation under climate change.

Key words: Global warming, international agricultural trade, computable general equilibrium modeling, welfare decomposition, and Gaussian Quadrature.

I. Trade Liberalization as a Vehicle for Adapting to Global Warming

Much of the attention in the economic literature on global warming concentrates on policies directed toward emissions reduction. However, recently interest has turned to possibilities for *adaptation* to global warming. Schimmelpfenning *et al.* (1996) explore this issue in considerable detail for the case of agriculture. They review the studies which have examined adaptation at the farm level (changing the mix of crops as well as farming practices), adaptation at the national level (shifts in regional cropping patterns and the use of land and water resources, policy changes, and price adjustments), and international adaptation. They conclude that the early studies of climate change, which largely ignored adaptation, dramatically overstated the impact of climate change on agricultural production. This paper focuses on one particular dimension of the adaptation question -- international agricultural trade and trade policies.

Because the impact on agricultural production is expected to vary considerably by region (see Table 1 below), international trade offers an important vehicle for adapting to climate change. By permitting the geographic relocation of world food supplies according to changing comparative advantage, spatial diversification of the climatic risk associated with global warming may be achieved. This type of geographic diversification is hardly new to farmers, who sometimes seek to produce at dispersed locations in order to reduce their exposure to pest risks (Bromley, 1992). At a global level, the international trading system offers a similar risk-spreading opportunity. However, the potential for trade to play this buffering role is often hampered by restrictive trade practices. When individual countries insulate their domestic markets from developments in other regions they jeopardize the ability of world markets to lower global costs of climatic change. The value of this spatial diversification is then lost. In this paper, we explore the interactions between projected changes in agricultural production under climate change, and reforms to the international trading system initiated under the latest World Trade Organization (WTO) agreement.

II. Background

Global warming occurs due to the release of carbon dioxide (CO_2) and greenhouse gases into the atmosphere through anthropogenic activities and natural processes. This type of climate change, popularly known as the greenhouse effect, can result in significant environmental implications worldwide. Natural and social scientists have been actively involved in understanding the human sources of these global changes, the potential damage they cause to natural and economic systems, and the most effective ways to alleviate or remove the dangers (Nordhaus, 1993). Economic studies concentrate on impact assessment (Mendelsohn, 1994), the cost of slowing climatic change (Manne and Richels, 1990 and 1992; Kolstad, 1993), the relationship between environment and international trade (Chichilnisky, 1994), and management of climatic risk (Chichilnisky and Heal, 1993; Kurz, 1990 and 1993; Chichilnisky, et al., 1992).

Scientists predict that agriculture will be one of the most severely affected sectors. Exposure to new temperatures, rainfall patterns, and levels of CO_2 and other greenhouse gases can drastically alter the world agricultural productivity. Table 1 summarizes one set of estimates of crop productivity changes under a doubling of atmospheric CO_2 and accounting for the effects of CO_2 fertilization. Both Canada and the EU (cooler climates) show uniformly positive productivity gains for their major crop categories, with a regional average gain of 24% in Canada and 11% in the EU. The U.S., China and Australia also show positive average productivity gains. Mexico and ASEAN, on the other hand, show large adverse effects on crop productivity as a result of global warming, even in the presence of CO_2 fertilization. These diverse impacts on agricultural yields, by region, highlight the potential importance of international trade in any strategy to adjust to climate change. By facilitating the transfer of output from regions with increased yields to countries facing diminished productivity, international trade can play a valuable role.

Kane, Reilly and Tobey (1991), highlight the importance of international price transmission of the effects of climate change across countries. They find that the indirect effects of climate change on international prices and hence on national production and consumption, actually dominate the direct effects of climate change in the case of some economics. While those authors assume that international price changes are fully transmitted into domestic economies, the fact is that many countries have historically engaged in policies which blunt this link between world and domestic prices (Anderson and Tyers, 1992). Import quotas have been common on politically sensitive products (eg. rice in Japan, sugar in the United States) and the European Union has systematically shielded domestic producers from world market price changes by means of a system of variable import levies and export subsidies. In such an environment, the scope for international markets to spread the effects of climate change is greatly diminished.

In this context, the Uruguay Round Agreement (URAA), in Agriculture, concluded in 1995, represented an important step forward. It required countries to convert their border intervention to tariffs which substantially reduces the scope for market-insulation [3] (Martin and Winters 1996). However, full transmission of agricultural prices across international markets is only one aspect of trade liberalization. While this facilitates the spreading of risk across international markets, it still doesn't ensure an *efficient* allocation of production across countries. In particular, high income, OECD economies have tended to subsidize agricultural production, while the poorest economies have historically taxed the farm sector (Anderson and Hayami, 1986). The resulting misallocation of global resource use has been shown to be quite costly (Tyers and Anderson, 1992; Hertel, et al., 1999) To the extent that climate change reinforces this pattern of excessive agricultural production in the OECD economies, the consequences for global efficiency of food production could be even more severe. Indeed this paper shows that, unless significant reductions in OECD agricultural support also occur, the potential gains from increased price transmission in agricultural markets will be overwhelmed by the efficiency cost of current farm policies in the wake of climate change.

III. Methodology

Modeling approach: Several different approaches have been used to study global warming. Mendelsohn, *et al.* (1994) used a Ricardian approach to study the impact of global warming on land values in the US. They use geophysical variation in temperature to explain variation in local land prices and thus indirectly estimate the impact of global warming. This approach assumes that international trade has no role in dissipating the effects of climatic change across countries. They also abstract from commodity price changes and assume that all impacts in the US accrue to agricultural landowners. Several other studies use a production function approach to study the impact of climatic changes (Rosenzweig and Parry, 1994; Adams *et al.,*

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[3] The URAA left open the door for the use of tariff rate quotas (TRQs), for which a low tariff is charged for a fixed quantity of imports --the "quota"-- and a higher rate is charged for imports "over quota". If imports are exactly on-quota then price transmission will be blunted. Fortunately most countries are not currently using TRQ's for insulation purposes (Abbott and Morse).

1990; Rind *et al.*, 1990; Adams, 1989). General equilibrium analysis has been used in a number of single region studies (Goulder, 1993; Brinner *et al.* 1992; Jorgenson and Wilcoxen, 1991) as well as for the global economy (Burniaux *et al.* 1991, Darwin, *et al.,* 1995; Tsigas, *et al.*, 1997; Rutherford, 1992; Whalley and Wigle 1993; Babiker, Maskus and Rutherford 1997).

Many of the past studies emphasize a particular policy (carbon taxation), or concentrate on a particular country of interest and use partial equilibrium analysis, thereby limiting the scope of the results. Ricardian analysis that uses land values to value the impacts of global warming can be misleading if land values are affected primarily by omitted factors like the crime rate, urbanization, or aesthetic value. Another potentially serious limitation of this approach is that large and widespread climate change could cause a permanent shift in relative crop prices (Schimmelpfennig, *et al.*, 1996). When implemented on the basis of a few sites, the production function approach requires heroic inferences from relatively few sites and crops to large areas and diverse production systems (Schimmelpfennig, *et al.*, 1996). The use of a comprehensive model that derives benefits from each of these approaches can result in better estimation of climatic impact (Darwin, *et al.*, 1995; Tsigas, *et al.* 1997). Rosenzweig *et al.* (1993) have used such a model to simulate the impact of climate change, with and without trade liberalization. They find a small, positive effect production effect stemming from trade liberalization. Reilly, Hohmann and Kane (1993, 1994) have also explored this issue. They find that economic welfare losses tend to be more severe in developing countries, major agricultural exporters can gain significantly if world prices rise, and the carbon dioxide fertilization effect substantially offsets losses due to climate change alone. In one scenario, they report that CO_2 fertilization and adaptation leads to an increase in net global welfare. In this paper, we explore the role of trade liberalization in greater detail, by considering the issues of market insulation and subsidy levels separately. Unlike the Rosenzweig *et al.* study, we focus primarily on the welfare dimension of the problem.

We build on the earlier study by Tsigas, Frisvold and Kuhn (1997, henceforth referred to as TFK). They used the GTAP general equilibrium model of world trade and production (Hertel and Tsigas, 1997) in order to assess the consequences of the crop productivity changes owing to a doubling of CO_2 in the atmosphere, in the context of the current global economy. The productivity changes are summarized in Table 1 and they are interpreted as Hicks-neutral changes to the individual crop production functions. This permits the authors to capture several important layers of economic adaptation to climate change. First of all, yields are permitted to adjust optimally in the face of new production conditions as well as changes in commodity and factor prices. Secondly, the allocation of land across crops and between crops and livestock is permitted to adjust. Domestic commodity markets also facilitate further adaptation to climate change, as do international markets. The one important piece of economic adaptation which is missing in this approach is the potential for intra-regional adaptation. Because TFK do not distinguish differential climate impacts within a region, they miss this part of the adaptation process. In contrast, Mendelsohn (1994) and Darwin, *et al.* (1995) incorporate some of these intra-regional adjustments into their analysis.

TFK examine the consequences for production, consumption, trade and welfare in eight regions: Canada, USA, Mexico, European Union, China, Association of South East Asian Nations (ASEAN), Australia, and Rest of world (ROW, encompassing all remaining countries). TFK aggregate 37 commodities in the GTAP version 2.0 database into eight categories, preserving detail in crops. The resulting commodity groups are as follows: rice, wheat, other grains, other crops, livestock, processed agricultural commodities, manufactures, and services. We follow the aggregation used in TFK study and we also employ the GTAP model. We extend the TFK modeling approach by introducing uncertainty in the impact of climate change on crop productivity. Most importantly, we utilize recent techniques for decomposition of the welfare results (Huff and Hertel, 1996). When combined with an innovative experimental design, this permits us to shed new light on the links between trade liberalization and climate change.

Impacts on crop productivity: The estimates of climatic impacts on crop productivity used in the TFK study are presented in Table 1. These are based on the work of Rosenzweig and Iglesias (1994) as summarized in Reilly, Hohmann and Kane (1993). As is widely acknowledged, there is a great deal of uncertainty surrounding the impact of climate change on temperature and precipitation. Additionally, there is uncertainty about the way in which these changes will actually translate into productivity changes. To evaluate the robustness of their results, we have used the Gaussian Quadrature approach (DeVuyst and Preckel, 1996) to incorporate information on the distribution of productivity effects from climate change. This procedure approximates the distribution of climate change outcomes by using a discrete set of vectors of shocks and probabilities that have the same lower-order moments as the joint parameter distribution. In the context of a smaller global, general equilibrium model, DeVuyst and Preckel show that this technique dominates other approaches to systematic sensitivity analysis (SSA). An automated procedure for performing SSA using Gaussian Quadrature in GEMPACK (Harrison and Pearson, 1996) has recently been developed. This is used in this study, based on the Stroud procedure, as detailed in Arndt (1996), and Arndt and Pearson (1996).[4] In this way, mean welfare effects (as opposed to welfare effects of mean productivity shocks) as well as standard deviations for these outcomes can be evaluated.[5] This permits us to determine whether or not a given region's gain or loss from climate change is robust to the underlying uncertainty in productivity.

Building the underlying distribution from which to sample the productivity impacts of climate change represents a substantial challenge in its own right. By way of example, consider Figure 1. Here, the "w's" and “x's” show five different estimates of yield changes for dryland winter wheat and dryland maize in Iowa, under a doubling of atmospheric CO_2 (Schimmelpfennig *et al.*, Table 2.2). In order to implement our SSA, we must associate probabilities with each of the observations in Figure -- as well as any other possible outcomes. We have chosen use a symmetric triangular distributions in our analysis. Ideally, we would like to obtain comparable productivity distributions for all major crop-producing regions in the world. However, this is clearly beyond the scope of the present study. Therefore, we have opted for a simplified approach in which we work from the mean yield change, E(X), and the lower limit, which is assumed to be E(X)/2. While the lower limit can vary by crop and region, we approximate this level based on the Iowa data in Figure 1. In the case of Iowa's dryland maize in Figure 1, this procedure offers a relatively accurate portrayal of the situation, since 1/2 * E(X) = 13.5 and min(X) = 12. However, in the case of dryland wheat, this approach understates the potential variation, since one of the yield changes is of the opposite sign (positive). In the case of rice and other crops we have no

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[4] We implement a third order quadrature to approximate the yield distribution that required 64 sample points and probabilities. In their work, DeVuyst and Preckel show that a third-order approximation matched a higher nine-order approximation to four decimals. In contrast, they find that a 1000 run Monte Carlo approximation does not assure accuracy at one decimal point.

[5] Darwin *et al.* (1995) consider a range of climate scenarios, thereby generating a range of model outcomes. Our approach simply formalizes this idea by specifying a particular distribution of possible outcomes.

pertinent information at hand so this approach to specifying the productivity distribution is clearly *ad hoc*. Therefore, our approach should simply be viewed as a first attempt aimed at illustrating the value of formal sensitivity analysis with respect to the economic impacts of climate change on agriculture.

Design of the experiments**:** In order to assess the impact of alternative trading environments on the welfare effects of climate change, we conduct a series of simulation experiments. Our experimental design involves two distinct aspects of the international trade regime: degree of *price transmission* and extent of agricultural *price distortions*. The base case simulation (experiment E1) follows the approach of TFK, which assumes full price transmission (no market insulation) from world to domestic markets in the presence of substantial (pre-Uruguay Round) price distortions as described in the GTAP, version 2 data base (Gehlhar *et al.*, 1997). In practice, these two assumptions – price transmission on the one hand, and pre-UR price distortions on the other -- are somewhat at odds with one another. This is because one of the main accomplishments of the Uruguay Round (UR) agreement on agriculture was to begin the process of converting onerous non-tariff barriers to tariffs.[6] In the pre-Uruguay Round environment analyzed by TFK, many countries were effectively insulating domestic producers from changes in the world markets via quotas, variable levies and other border interventions. This is important, since the absence of price transmission eliminates the scope for trade to act as a buffer in the presence of climate change.

The preferred approach to examining the impact of incomplete price transmission in the face of climate change involves explicit modeling of all of the agricultural protection policies of all countries and all commodities. This is clearly not practical. Policies are simply too complex and volatile, and they also vary considerably across products. In light of these problems, we have opted to implement an alternative, simpler method of market insulation. In this way we are able to obtain an upper bound on the benefits of a liberal-trading regime in the presence of climate change.

The proposed approach to market insulation involves a change in model parameters. The GTAP model adopts the commonly used, Armington specification of trade behavior. Importers substitute among alternative sources of import supply according to a constant elasticity of substitution, σ_M, and they substitute composite imports for domestic production according to a smaller, constant elasticity of substitution, σ_D. The Armington equations are as follows:

$$qms(i,r,s) = qm(i,s) + \sigma_m(i)[pm(i,s) - pms(i,r,s)] \tag{1}$$

$$pm(i,s) = \sum_{r \varepsilon REG} \theta(i,r,s) * pms(i,r,s) \tag{2}$$

$$qm(i,s) = qc(i,s) + \sigma_D(i)[pc(i,s) - pm(i,s)] \tag{3}$$

$$pc(i,s) = \Omega(i,s) * pm(i,s) + [(1 - \Omega(i,s)] * pd(i,s) \tag{4}$$

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[6] While the Uruguay Round agreement in agriculture purports to eliminate non-tariff barriers, in fact it leaves many loopholes. Most notable are the widespread tariff rate quotas, which serve to eliminate world-domestic price transmission over the range of market conditions for which the quota is binding but the out-of-quota tariff is still prohibitive.

All variables are expressed in terms of percentage changes: $qms(i,r,s)$ corresponds to the bilateral sourcing of imports of commodity *i* from region *r*, into region *s*, $qm(i,s)$ refers to aggregated imports, and $qc(i,s)$ represents the composite quantity of domestic and imported goods. The prices associated with each of these quantity flows, again in percentage change form, are $pms(i,r,s)$, $pm(i,s)$, and $pc(i,s)$, respectively. The coefficient $\theta(i,r,s)$ refers to the import share from region *r* at domestic market prices in *s*. Likewise, $\Omega(i,s)$ is the share of imported goods in composite demand for commodity *i* in region *s*.

By setting $\sigma_m(i) = 0$ in equation (1), we effectively prevent bilateral imports from changing when the relative costs of supply from alternative exporters, $pms(i,r,s)$, are altered in the wake of climate change. However, via equation (2), such price changes in the exporting regions still affect the average import price, $pim(i,s)$. Therefore, we must also set $\sigma_D(i) = 0$ in order to prevent an expansion of import volume, $qim(i,s)$, when the average import price falls, relative to the domestic price. Therefore the only reason for imports to expand under this price insulation parameter setting is if the total composite demand for good *i*, $qc(i)$, expands. Re-implementation of the base case, with these modified parameter settings, comprises experiment E2. By comparing these results to E1, we are able to measure the buffering role of trade in the adaptation of the global economy to climate change, since E1 assumes full price transmission.

In addition to the tariffication of agricultural policies (aimed at reducing market insulation), the Uruguay Round began what many hope will be an ongoing process of reductions in the level of distortions in the world food system. Specifically, the UR agreement required average reductions of 36% in the tariff equivalents of agricultural protection (Hathaway and Ingco, 1996). However, as noted above, "dirty tariffication", in which estimated pre-UR tariff equivalents were overstated, limited the actual impact of these cuts (Ingco, 1996). Nevertheless, now that benchmark levels of agricultural support are established, future cuts are expected to be more effective (Martin and Winters, 1996). If the history provided by manufacturing tariffs is any indication, subsequent WTO rounds will likely have greater success in reducing support levels for agricultural products. Therefore, we are also interested in the interaction between climate change and diminished subsidies for agriculture.

To evaluate the effect of eliminating agricultural support, we implement two additional simulation experiments, E3 and E4. The third experiment (E3) removes all of the agricultural trade distortions and producer subsidies (these were present in E1 and E2 as *ad valorem* tariffs and subsidies). In so doing, we simulate an alternative, global economy, in which subsidized agriculture has been reduced in size and producers with a comparative advantage have expanded production. This experiment, in and of itself, is not of central interest to this paper, since there are already many comprehensive studies of the impact of trade liberalization on agriculture. Rather, we are interested in using the new equilibrium database, following this experiment, as the starting point for E4. This final experiment repeats E1, but now in the environment of undistorted agricultural trade. As will be seen below, the comparison of E4 to E1 is of considerable interest, as it identifies the interaction between agricultural support and climate change in a world of full price transmission for agricultural products.

A summary of the four experiments follows. (The first three experiments begin from the 1992 GTAP version 2 data base. E4 begins from a fully liberalized data base.)

E1: Base case: same as in TFK (1997), only now with uncertainty in agricultural productivity. Includes full price transmission in presence of pre-UR agricultural distortions.

E2: Same as base case, but now in the absence of world-domestic price transmission for farm and food products. Pre-UR distortions still present. *Compare this to E1 to determine the interaction between climate change and international price transmission.*

E3: Full agricultural trade liberalization. This involves elimination of import tariffs, export subsidies and output subsidies for agriculture. The purpose of this experiment is to establish the starting point for E4.

E4: Repeat E1 using the updated database from E3. Complete price transmission in the absence of agricultural border distortions and domestic subsidies. *Compare results to E1 to determine the interaction between climate change and agricultural subsidies.*

Welfare decomposition: In comparing the results of experiments E1 -E4, it will be important to make use of the welfare decomposition tool developed by Huff and Hertel (1996). This represents an extension of the decompositions offered by Keller (1980) and Baldwin and Venables (1995) to accommodate multiple regions, domestic distortions and non-local perturbations of the model. From the perspective of the present paper, the key features of the decomposition of regional Equivalent Variation (EV) for region "*s*" may be summarized as follows:

$$\begin{aligned} EV(s) = [mmscale(s)]*[&\sum_{i\varepsilon COMM}\sum_{r\varepsilon REG} MTAX(i,r,s)*qms(i,r,s) - \sum_{i\varepsilon COMM}\sum_{r\varepsilon REG} XSUB(i,s,r)*qms(i,s,r) \\ &- \sum_{i\varepsilon COMM} PSUB(i,s)*qo(i,s) + \text{remaining tax interactions} \\ &+ \sum_{i\varepsilon COMM} VOA(i,s)*ao(i,s) + \text{terms of trade effect}] \end{aligned} \tag{5}$$

The first term on the right-hand side of (5) represents a scale factor, which is applied to the terms inside the square brackets [·] in order to convert it to the EV. The latter terms provide an exhaustive decomposition of the change in welfare for region "*s*" as a result of the climate change experiment.[7] The first of these terms captures the second-best effects arising from the presence of import protection. In the OECD economies, there are high tariff rates on the importation of many crop and livestock products $(MTAX(i,r,s) > 0)$. Consequently, consumers purchase fewer imports than they would under an optimal allocation of global food supplies. To the extent that climate change causes imports to increase $(qms(i,r,s) > 0)$, this will contribute positively to welfare, *independently of* the direct effects of climate change on region *s*. Of course, if climate change causes a reduction in imports of heavily protected products $(MTAX(i,r,s) > 0$ and $qms(i,r,s) < 0)$ then this will increase the inefficiency associated with protection in this market, thereby reducing EV.

Similar logic applies to the next two terms in the decomposition offered by (5). The presence of export subsidies (from *s* to *r*) and production subsidies on many agricultural products in the OECD economies $(XSUB(i,r,s) > 0, PSUB(i,s) > 0)$ stimulates excessive production and export of these commodities. Therefore, *ceteris paribus,* anything that leads to an increase in

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[7] In the presence of non-homothetic preferences for private consumption, there is an additional term in this decomposition (Huff and Hertel, 1996). However, it is negligible in these simulations and is therefore ignored here. Other potential terms in this decomposition include endowment effects and biased technical change. However, these are held constant in the analysis presented here.

production, $qo(i,s) > 0$ or exports from s, $qms(i,s,r) > 0$, contributes to a decline in efficiency and hence welfare. To the extent that climate change boosts output and exports of heavily subsidized farm products in the OECD, while reducing output in the relatively low cost producing regions of the world, we can expect the global summation of these two terms to be negative. Of course other taxes and subsidies also come into play in a general equilibrium simulation -- although they are of second-order importance in the simulations presented here. When combined, we refer to the entire group of tax/subsidy terms as the "allocative efficiency effect."

Of course, we must also account for the direct effect of climate change, which is modeled as Hicks-neutral technical change in crops production at rate $ao(i,s)$. The decomposition pre-multiplies $ao(i,s)$ by the value of output at agent's (i.e., producer's) prices, $VOA(i,s)$, in order to assess this contribution to regional welfare. Finally, there is a terms of trade effect which summarizes the impact on Equivalent Variation of the change in prices of exports, relative to imports. If climate change raises the price of products for which a country is a net-importer, then this will contribute negatively to the EV for the region.

IV. Results

***Base Case**:* The aggregate welfare effects of global warming, as specified in Table 1, are presented in the first column of Table 2. Estimates are mean results, with standard deviations in parentheses underneath. For purposes of comparison, the TFK point estimates for aggregate welfare are also presented in square brackets to the right of the mean results from the present study. As with the TFK study, we find that Mexico and ASEAN (along with ROW) are losers from climate change. These are the regions where global warming has a negative average impact on crop yields, (recall Table 1). But why do our results differ from those of TFK? This is due to the fact that TFK simulate the impacts of climate change under only one set of productivity shocks (the “mean” shocks). In contrast, the present study computes a distribution of outcomes, based on the assumed underlying distribution of productivity changes, thereafter computing the mean of this distribution of results. With the exception of Canada, Australia, EU, ASEAN, and ROW, where the two sets of results are virtually identical, the expected values computed via Gaussian Quadrature are generally lower than the TFK estimates. This suggests that evaluation of benefits from climate change in the presence of uncertainty may be lower than those which only use a single vector of mean shocks to agricultural productivity.

The second point to note from Table 2 is that the apparent welfare gains for the USA and for China are uncertain, since the mean welfare improvement is less than one standard deviation from zero for the US, and less than two standard deviations from zero in the case of China. Overall, we find that the TFK conclusion that global welfare rises in the wake of climate change is also not robust. In fact, the standard deviation of \$6,856 million is six times as large as the mean, \$1,214 million change in world welfare clearly the estimated gain could just as easily be a loss.

In order to understand the source of these changes in welfare, it is necessary to use equation (5) to decompose the regional welfare changes into their component parts: the direct impact of climate change, the allocative efficiency or "second best" effects and the terms of trade (TOT) effect. These decomposition are reported in tables 2-5. As previously noted, the direct effects of climate change are captured as changes in technical efficiency associated with crop production. The greater the change in crop efficiency, and the more important the crop, the larger is this term.

From the second column of Table 2, we see that the contribution of climate change to world welfare is positive and equal to \$11,467 million. Furthermore, the regional impact is positive and significant for Canada, the EU and Australia. On the other hand, there are significant regional losses for Mexico, ASEAN and ROW. Impacts on USA and China are not significantly different from zero. Table 4 disaggregates these direct contributions of climate change to global welfare by region and commodity. As anticipated by equation (5), the sign pattern for these technical efficiency gains/losses follows from that of the productivity changes shown in Table 1.

The second part of the welfare decomposition in tables 2 and 3 measures the allocative efficiency effect. As noted above, this effect captures the creation or destruction of welfare owing to the reallocation of resources in the face of policy distortions, while holding technology, endowments and world prices constant. If there were no taxes or subsidies in the global economy, then this component of the welfare decomposition would be zero. However, this is hardly the case. In fact, industrialized economies have a long tradition of subsidizing agriculture relative to other sectors of the economy, thereby maintaining excessive capacity in that sector (Tyers and Anderson). In contrast, developing economies often penalize agriculture, and subsidize industry (Loo and Tower, 1990). As a consequence, the global allocation of productive resources is distorted, with too much farm production in the high-cost, OECD countries and too little production in the lower income economies. Any external shock which tends to exacerbate this problem by increasing production in the high-cost regions will lead to a further worsening of this global allocation of resources, and hence a decline in allocative efficiency. Table 5 breaks out the change in allocative efficiency by crop, with a residual category representing the net changes for all other commodities. The total efficiency effect associated with E1 is negative for Canada, Mexico, EU, and ROW, with the EU dominating the overall total of a negative \$10,118 million. The bulk of this loss derives from “other crops”, where subsidized output expands in the wake of climate change.

The last column of Table 2 reports the TOT effects associated with this climate change scenario. The EU and China both experience significant TOT gains in E1, while Mexico, ASEAN, Australia, and ROW show significant losses. On a worldwide basis the welfare contribution is zero, since one region’s terms of trade gain is another region’s loss.

When these three parts of the aggregate welfare effect are combined, on a worldwide basis, we observe that the sum of a large positive climatic contribution and large negative allocative efficiency contribution is slightly positive (\$1,214 million). However, this mean effect is dwarfed by the associated standard deviation (\$6,855 million), indicating that we really can’t say whether the global impact of climate change is positive or negative in the base case.[8] This illustrates the value of systematic sensitivity analysis of climate change. It permits us to identify which findings are likely to be robust and which are not.

Impact of price transmission: As noted above, we contrast the base case (E1) with a simulation in which the elasticities of substitution in agricultural trade (σ_m and σ_D in equations (1) and (3)) are all set to zero, in order to isolate the role of world price transmission in determining the

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[8] It may seem curious to some readers how it can be that the global welfare effect is insignificant, despite the fact that the majority of the individual regional gains and losses *are* significant. However, this is due to the fact that some regions gain while others lose. As a consequence, one standard deviation in the EU's equivalent variation, \$2,354 million, is only about 13% of the EU's mean gain, but it is twice as large as the global EV.

consequences of climate change. This is experiment, E2, and welfare results are reported in the corresponding rows of tables 3 – 5. *A priori* we would expect the welfare gains under E2 to be lower than E1, since the world economy can no longer adjust trade patterns to accommodate the revised pattern of comparative advantage. However, a comparison of the world welfare gains at the bottom of Table 3 reveals that these gains are *larger* in the absence of price transmission (E2 = \$6,727 million) than when world prices are fully transmitted into all of the domestic economies (E1 = \$1,214 million). Once again, insight into the source of this anomaly can be obtained by decomposing the welfare changes using equation (5). From the second column in Table 3, we see that the direct contribution of climate change to world welfare in E2 is indeed much higher under full price transmission (\$11,467 vs. \$7,579 million). Furthermore, this same pattern applies across all regions, excepting for ROW[9]. In short, with fixed world prices and an unchanging allocation of resources (no economic adaptation), price transmission does indeed enhance the welfare attainable following climate change.

The reason this outcome doesn't carry through to higher global welfare under E1 is due to the allocative efficiency effects detailed in Table 5. (Recall that the regional terms of trade effects cancel out at the global level.) In the absence of price-induced changes in trade flows $(qms(i,r,s) \approx 0, qim(i,s) \approx 0$ when $\sigma_D = \sigma_m = 0)$, there is less scope for high cost EU production to displace lower-cost production from other regions. Indeed, in E2, there is a small positive allocative efficiency effect (\$905 million) associated with "other crops" production in the EU, as output in the price-insulation simulation now contracts. Overall, the negative total allocative efficiency effect is almost eliminated (-\$603 million for E2 in the lower right hand corner of Table 5). Thus, even though this allocative efficiency effect is combined with a smaller direct effect of climate change, the total welfare gain in the absence of price transmission is still larger in the absence of price transmission (\$6,727 million in E2 vs. \$1,214 million in E1).

In summary, while price transmission, such as that required under the Uruguay Round's tariffication scheme, enhances the world economy's ability to respond to global climate change, this is not always a positive thing. Due to the high correlation between positive productivity effects and heavily subsidized agricultural crop production, we actually find that welfare is lower in the absence of price transmission – provided pre-Uruguay Round levels of protection are maintained. Of course that is a strong assumption. As mentioned earlier, we expect that future WTO negotiations will make significant headway in the reduction of border interventions for farm products. For this reason it makes sense to also consider the possibility of climate change in the next century in the context of a more liberal trading regime.

Trade Liberalization: It is impossible to predict with accuracy how much agricultural trade liberalization is likely to take place in the coming decades. However, in the interest of clearly identifying the interactions between such reductions in agricultural support and climate change, we adopt the extreme assumption of complete elimination of border protection and domestic support for agricultural products. Experiment 3 performs this simulation exercise. The consequences for regional crop production of this global liberalization experiment are reported in Table 6. World grain production shifts towards the U.S., Canada, Australia and ROW and away

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[9] In the case of ROW, the lower welfare from the direct effects of climate change, in E1 vs. E2, has to do with price changes, and hence differences in the value of "other crops" output under the two experiments.

from Mexico, the EU, China and ASEAN. Other crop production expands strongly in Australia and ROW.

These changes in the value of regional production following trade liberalization ($VOA(i,s)$ in (5)) have an impact on the sectoral value of climatic change. For example, compare the mean contribution to welfare of the anticipated "other crops" productivity changes in ROW under E1 vs. E4 as reported in Table 4. Prior to trade liberalization (E1), this gain is valued at $6,789 million. However, as seen from Table 6, trade liberalization results in a boost in the output of other crops in this region. With more of these crops planted, the 2% productivity boost shown in Table 1 becomes more valuable and the direct contribution to welfare is now increased in E4 to $7,856 million (see Table 4, ROW, E4). For most crops/regions the differences in direct contribution of climate change between these two experiments are very small.

The major source of welfare differences between E1 and E4 show up in Table 5, which compares the two sets of allocative efficiency effects associated with climate change. Rather than causing a drain on welfare (-$10,118 million in E1 shown in bottom right-hand part of Table 5), the allocative efficiency effects now contribute positively to aggregate welfare ($497 million in E4). This is because we now have free, undistorted trade in agriculture. Recall that a primary factor that contributed to the loss in welfare under E1 was the subsidized production in the EU, where other crops contributed to the loss in allocative efficiency. This was because of increases in subsidized output of these crops in face of climatic change ($PSUB > 0, qo > 0$ in equation (5)). Trade liberalization forces the equalization of marginal production costs, net of trade and transport margins, in all regions since $PSUB = XSUB = 0 = MATX = 0$. Therefore, a positive development in other crop yields in the EU, for example, does not displace lower cost production. Consequently, the global welfare gain from climate change reported in Table 3 under E4, $6,855 million, exceeds that in E1 ($1,214 million). Trade liberalization is indeed a vehicle for improving the world economy's ability to respond to climate change, but only if the tariffication of policies under the Uruguay Round is accompanied by substantial reductions in farm support under future rounds of WTO negotiations.

V. Conclusions

Concern about the potential effects of global warming on the world economy has continued to increase as awareness of the potential consequences has grown. While agreement has been reached in principle, under the Kyoto protocol, on stricter targets for greenhouse gas emissions abatement, given the anticipated costs of such restrictions, and the potential for growth in emissions from developing countries, it is unlikely that global increases in these gases be avoided (Edmonds, 1999). Thus it becomes important to consider how the world will cope with the resulting shifts in temperature and precipitation. This potential for *adaptation* in agriculture has recently received considerable attention (Schimmelpfennig *et al.*, 1996), and the present study represents a further contribution to this literature. By focusing on the interaction between climate change and agricultural trade policies, we highlight the potential role of a liberal-trading environment in facilitating global economic adjustment to a new pattern of temperature, precipitation, and hence agricultural productivity.

Our findings highlight the need for negotiating substantial cuts in agricultural tariffs and subsidies under future WTO rounds. As it stands, the Uruguay Round Agreement on Agriculture has contributed to increased price transmission (through tariffication), while leaving protection levels largely unchanged (Martin and Winters, 1996; Ingco, 1996). We find this to be a dangerous combination in the context of projected impacts of climate change on agriculture. Owing to the positive correlation between agricultural protection and the beneficial climate change effects (both tend to favor crop production in the temperate zones), world welfare is actually diminished by increased price transmission in world trade. This is because the global reallocation of farm output owing to climate change tends to encourage more supplies from the highly subsidized European agricultural sector. Removing distortions in global agricultural activity permits the world trading system to realize its full potential as a vehicle for facilitating adaptation to climate change.

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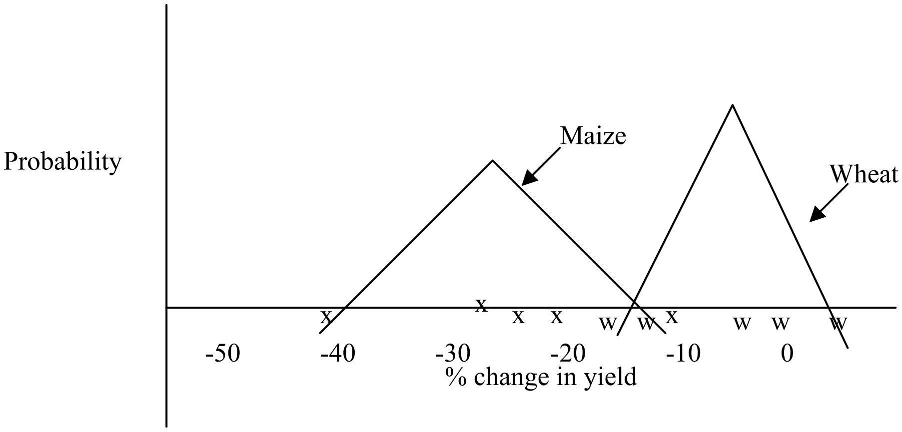
Figure 1. Distribution of Estimates of Yield Changes for Dryland Winter Wheat (w) and Dryland Maize (x) in Iowa, United States.



Observations marked 'w' (for wheat) and ‘x’ (for maize) are compiled from Schimmelpfennig, *et al.* (1996) Table 2.2 & 2.3

Table 1 Climate Change Impacts on Crop Productivity (%)

	Region								
Commodity	CAN	US	MEX	EU	CHN	ASEAN	AUS	ROW	World Average
Rice	0	1	-24	0	-3	-8	-12	-8	-7
Wheat	27	-2	-31	8	16	0	8	5	6
Other grains	15	-16	-35	1	-14	-33	5	-3	-9
Other crops	26	14	-18	15	13	-11	9	2	6
Regional average	24	2	-24	11	3	-11	8	-1	

Source: Tsigas, Frisvold and Kuhn, 1997, which is based on the work of Rosenzweig and Iglesias (1994) as summarized in Reilly, Hohmann and Kane (1993). These estimates take into account the direct effect of carbon dioxide fertilization on yields.

Table 2. Welfare Effects of Global Warming on the World Economy (Experiment 1: Equivalent Variation in millions of 1992 $US)

Region	Aggregate Welfare Effect [TFK]	Contribution of Climatic Impact	Contribution of Allocative Effects	Contribution of TOT Effects
Canada	2628* [2629]	4209*	-1093*	-487*
	(326)	(526)	(156)	(133)
USA	1927 [2026]	883	1002*	43
	(2356)	(2687)	(239)	(211)
Mexico	-8341* [-8273]	-7691*	-36	-520*
	(1602)	(1463)	(42)	(135)
EU	17225* [17253]	24519*	-9523*	2239*
	(2354)	(4057)	(2178)	(226)
China	2309 [2397]	1702	223	393*
	(1978)	(1823)	(224)	(109)
ASEAN	-6212* [-6216]	-6263*	491*	-417*
	(897)	(905)	(86)	(84)
Australia	682* [681]	737*	48*	-102*
	(116)	(114)	(8)	(34)
ROW	-9004* [-8958]	-6629*	-1230	-1143*
	(3611)	(3173)	(1095)	(330)
World	1214 [1539]	11467	-10118	0
	(6856)			

* indicates $|\mu| \geq 2\sigma$ is satisfied in the entry (μ is mean and σ is standard deviation); ( ) indicates Standard Deviation; [ ] identifies estimates of TFK study.

Table 3. Welfare Effects of Global Warming Under Alternative Trade Policy Regimes (Equivalent Variation in millions of 1992 $US)

Region	Aggregate Welfare Effect	Contribution of Climatic Impact	Contribution of Allocative Effects	Contribution of TOT Effects
Canada				
E1	2628*	4209*	-1093*	-487*
E2	1990*	3605*	-229*	-1383*
E4	1911*	3518*	-4*	-1609*
USA				
E1	1927	883	1002*	43
E2	-274	255	290*	-819
E4	71	173*	0	-102*
Mexico				
E1	-8341*	-7691*	-36	-520*
E2	-8337*	-8580*	-437*	820*
E4	-7977*	-8518*	-0*	782*
EU				
E1	17225*	24519*	-9523*	2239*
E2	23874*	23377*	673*	-160
E4	22821*	23767*	610*	-1605*
China				
E1	2309	1702	223	393*
E2	2144	1548	371	235
E4	2211	2052	0	83
ASEAN				
E1	6212	-6263*	491*	-417*
E2	-5681*	-6892*	-550*	1809*
E4	-5782*	-7440*	-80*	1795*
Australia				
E1	682	937*	48*	-102*
E2	536*	717	58	-239*
E4	682*	840*	54*	-212*
ROW				
E1	-9004	-6629*	-1230	-1143*
E2	-7526*	-6451	-779*	-294
E4	-7081	-7792*	-116*	836
World				
E1	1214	11467	-10118	0
E2	6727	7580	-603	0
E4	6855	6601	464	0

* indicates $|\mu| \geq 2\sigma$ is satisfied (μ is mean and σ is standard deviation).

Key:
E1 = Base case, distortions present, but with full price transmission
E2 = Distortions present, but no price transmission
E4 = Fully liberalized trade, with no distortions and full price transmission.

Table 4. Contribution of Climate to Welfare Change under Alternative Trade Policies (Equivalent Variation in millions of 1992 $US)

	Rice	Wheat	Other Grains	Other Crops	Total
Canada					
E1	0	1482	505*	2222*	4209*
E2	0	1154*	430*	2021*	3605
E4	0	1126*	424*	1968*	3518*
USA					
E1	38*	-434*	-8432*	9711*	883
E2	37*	-462*	-8607*	9287*	255
E4	37*	-472*	-8786*	9393*	173
Mexico					
E1	-97*	-325*	-4275*	-2993*	-7691*
E2	-104*	-405*	-4664*	-3407*	-8580
E4	-101*	-396*	-4624*	-3397*	-8518*
EU					
E1	0	2820*	331*	21369*	24519*
E2	0	2813*	319*	20246*	23377
E4	0	2764*	311*	20693*	23767*
China					
E1	-903*	1348*	-5480*	6737*	1702
E2	-903*	1331*	-5517*	6637*	1548
E4	-998*	1472*	-6148*	7725*	2052
ASEAN					
E1	-1532*	0	-1132*	-3599*	-6263*
E2	-1532*	0	-1281*	-4080*	-6892
E4	-1619*	0	-1376*	-4445*	-7440*
Australia					
E1	-17*	150*	40*	565*	737*
E2	-17*	149*	33*	552*	707
E4	-22*	178*	40*	644*	840*
ROW					
E1	-12519*	1392*	-2291*	6789*	-6629*
E2	-12548*	1400*	-2223*	6919*	-6451
E4	-14704*	1603*	-2547*	7856*	-7792*
World					
E1	-15030	6432	-20735	40800	11467
E2	-15067	5981	-21509	38174	7579
E4	-17407	6277	-22706	40437	6601

* indicates $|\mu| \geq 2\sigma$ is satisfied (μ is mean and σ is standard deviation).

Key: E1 = Base case, distortions present, but with full price transmission
E2 = Distortions present, but no price transmission
E4 = Fully liberalized trade, with no distortions and full price transmission.

Table 5. Welfare Contribution of Allocative Efficiency under Alternative Trade Regimes (Equivalent Variation in millions of 1992 $US)

	Rice	Wheat	Other Grains	Other Crops	All sectors
Canada					
E1	0*	-521*	-235*	-242*	-1093*
E2	0	3	-7*	-20*	-229
E4	0*	0	1*	2*	-4
USA					
E1	-70*	920*	445*	-563*	1002*
E2	0	25*	47	-13*	290
E4	0	0	0	0	0
Mexico					
E1	3*	29*	180*	43*	-36*
E2	0*	0	19*	4*	437
E4	0	0	0	0	-0
EU					
E1	-58*	29	-1387*	-7822*	-9523*
E2	-1*	33*	7*	905*	673
E4	-1*	-0	-7*	31*	611
China					
E1	1	1	22*	23*	223
E2	2*	-0	21*	-3	371
E4	0	0	0	0	0
ASEAN					
E1	9*	-5*	39*	429*	491*
E2	21*	-2*	2*	-59*	-550
E4	-6*	-0*	-0*	-0*	-80
Australia					
E1	0	-0	-4*	-7*	48*
E2	-0*	-1*	-0*	-1*	58
E4	-0*	-1	-0*	0*	54
ROW					
E1	-13	-126	3008*	2414*	-1230
E2	-21*	-19*	-155*	114*	-779
E4	0*	23*	-1*	-3*	-115
World					
E1	-128	326	-3947	-5724	-10118
E2	2	39	-66	926	-603
E4	-7	22	-8	30	464

* indicates $|\mu| \geq 2\sigma$ is satisfied (μ is mean and σ is standard deviation).

Key: E1 = Base case, distortions present, but with full price transmission
E2 = Distortions present, but no price transmission
E4 = Fully liberalized trade, with no distortions and full price transmission.

Table 6. Impact of Agricultural Trade Liberalization on Production of Crops by Region (Percent change)

	Rice	Wheat	Other Grains	Other Crops
Canada	-1.7	0.9	0.9	-0.2
USA	1.1	2.1	2.1	-0.2
Mexico	-2.7	-2.7	-1.6	-1.6
EU	-4.9	-4.60	-4.9	-5.7
China	-6.6	-6.3	-5.6	-4.3
ASEAN	-3.2	-1.4	-2.1	-0.9
Australia	15.4	9.1	9.1	6.7
ROW	5.0	4.0	3.8	1.7