An Empirical Study of the Economic Effects of Climate Change on World Agriculture

by

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Abstract. The economic effects of a doubling of carbon dioxide levels on world agriculture under what are termed "optimistic" and "pessimistic" crop response scenarios are empirically estimated. These effects include both changes in the prices of agricultural commodities as a result of changes in domestic agricultural yields, and changes in economic welfare following altered pricing and trade patterns of agricultural commodities. Under both scenarios, with a few exceptions, the effects on national economic welfare are found to be quite modest. However, prices of agricultural commodities are estimated to rise considerably under the pessimistic scenario. Increased agricultural prices reduce consumer surplus and diminish the benefits from climate change that some countries with predicted positive yield effects would otherwise receive.

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Introduction

The economic and social implications of global climate change are presently the subject of intense national and international political debate. In order to formulate policies to address this issue, the costs and benefits of potential climate change associated with increases in atmospheric trace gas concentrations must be identified. This paper focusses on the potential costs and benefits of climate change on world agriculture.

The study of the effects of climate change on agriculture is particularly important because of the high degree of sensitivity of agricultural systems to climate. Like most issues of global change, however, it presents researchers with a very difficult modelling problem. In an open economy, the effect of climate change on agriculture in any individual country cannot be considered in isolation from the rest of the world. This is due to the fact that changes in regional climates and agriculture in any individual country may affect global agricultural prices and trade flows. Thus, studies that infer the economic effects of climate change on agricultural producers and consumers on the basis of national yield change estimates alone are incomplete. They do not capture the important second round effects of changing world agricultural commodity prices and trade flows. This link between domestic crop yield effects and world agricultural markets is an area that has not been adequately explored in the literature to date.

The empirical analysis is conducted using a model of world agriculture and our survey of existing crop yield estimates under a doubling of atmospheric carbon dioxide levels. This work is part of the ongoing research efforts of the United States Department of Agriculture and the International Panel on Climate Change (IPCC).

Model Description

To derive the estimates of agricultural price and welfare effects of changes in agricultural yield we use the Static World Policy Simulation Model (SWOPSIM). SWOPSIM describes world agricultural markets through a system of supply and demand equations that are specified by matrices of own and cross price elasticities. A complete description of the SWOPSIM model can be found in Roningen (1986).

The SWOPSIM model is chosen for its ability to calculate the welfare effects of agricultural production disturbances. In contrast, most empirical models of agriculture ignore traditional welfare and resource efficiency measures (some widely used agricultural models in this category include FAPSIM (Gadson et al., 1982), WHEATSIM (Holland and Sharples, 1981), FAPRI (Meyers et al., 1986), and POLYSIM (Ray and Richardson, 1978)).

To estimate welfare changes SWOPSIM uses Marshallian measures of economic surplus. These can be considered true measures of welfare changes if it is assumed that consumer preferences are identical and homothetic, and that utility is held at the level that prevailed before the change in demand (that is, no income changes). For developed countries, where the income elasticity of demand and proportion of income spent on agricultural goods is low, the latter assumption is probably quite valid.

Even without satisfying these conditions, Willig's (1976) theorem provides support for the use of Marshallian consumer surplus as an estimate of compensating and equivalent variation--the true measures of welfare change.

By this theorem, under some fairly non-restrictive conditions concerning the income elasticity of demand and the ratio of consumer surplus to money income, Marshallian surpluses provide a very close approximation of the true changes in welfare.

In addition to the measurement of economic welfare, SWOPSIM also has the desirable feature of encompassing all regions of the world at a considerable degree of commodity disaggreation. The model contains 22 agricultural commodities, including eight crop, four meat/livestock, four dairy product, two protein meal, and two oil product categories. This level of country and commodity detail is useful for the present study because climate and yield changes vary across all regions of the world.

Finally, we should note that SWOPSIM is a partial-equilibrium model and does not capture agricultural interactions with other economic sectors. However, we do not believe that this a serious limitation. In industrialized countries agricultural production is only a small part of GNP and therefore has little cross sectoral impacts. Moreover, in a general equilibrium study of climate change in the United States, Kokoski and Smith (1987) show that the welfare effects of fairly large, single-sector impacts, can be adequately measured in a partial-equilibrium setting.

Climate Change Scenarios

The model is set up to separately identify the United States, Canada, European Community (EC), Australia, Argentina, Pakistan, Thailand, China, Brazil, the USSR, other Europe (Sweden, Finland, Norway, Austria, and Switzerland), and Japan. All other countries are grouped together. This level of disaggregation covers the major agricultural importing and exporting regions of the world and also highlights those areas projected to be the most strongly affected by climate change.

The agricultural yield effects specified in our model are consistent with some of the preliminary research being undertaken by the IPCC. They reflect the results of several recent studies of the effects of climate changes on crop yields (EPA 1989; Parry et al. 1988; and Santer 1985) which are presented in Tables 1-3. In general, these studies find that yields in middle latitude countries will fall and northern latitude yields will rise with a doubling of carbon dioxide levels (see Figure 1).

Crop yield response estimates to climate change embody a considerable degree on uncertainty which seems to derive from several areas. First, there is the scientific uncertainty associated with the climate effects of increases in atmospheric trace gas concentrations. As Tables 1 and 3 illustrate, the magnitude of yield effects varies widely by global circulation model (GCM). One important source of GCM variability, for example, is the complex interaction of cloud formation and ocean circulation. There are few if any regions where all the major climate models agree on the direction of change in terms of soil moisture (see Science Perspectives on the Greenhouse Problem, 1989).

A further limitation of present estimates of agricultural yield effects associated with GCMs has to do with the fact that GCM models specify only equilibrium climate changes associated with doubling of atmospheric carbon dioxide and other trace gases. Because it may take several decades to achieve climate equilibrium and because the dynamic climate change effects may not be linear, a more reliable analysis would ideally be capable of taking into consideration the dynamic climate effects of gradual increases in trace gas concentrations. For example, areas shown to be drier under an equilibrium climate in a doubled carbon dioxide environment may be shown to be wetter under a one-half or tripled carbon dioxide environment. In addition, although it is generally presumed that the long-run temperature trend will be a fairly persistent increase with year-to-year variations, the transient response of temperature change to increased trace gas concentrations is not well understood.

There is also considerable uncertainty regarding how predicted climate changes translate to yield changes. Present studies of the agricultural effects of climate change are limited by their inability to adequately incorporate several factors, including the effect of increased concentrations of atmospheric carbon dioxide on plant growth (the CO_2 effect); farm management response within the constraints of existing technology; hydrological changes affecting soil fertility and irrigation costs; and changes in the distribution of agricultural pests and diseases. These considerations may be important in determining the direction and magnitude of climate induced yield changes. At a recent conference of experts on the economic impacts of climate change, the CO_2 effect and farm management responses to climate change were taken into account in the estimation of likely crop yield responses to an effective doubling of the level of atmospheric carbon dioxide (National Climate Program Office, 1989). It was found that in all regions studied (US, USSR, Australia, China, Brazil, EC) there would likely be much more positive yield effects than those suggested by the literature that does not take these factors into account.

Thus, while the yield response literature that is used as a basis for our scenarios reflects the current state of knowledge of climate change and corresponding agricultural effects, it also embodies a considerable degree of uncertainty. For this reason, we specify what we term "optimistic" and "pessimistic" climate climate effects of predicted climate change (under a doubling of carbon dioxide levels) on global agriculture (see Table 4 and 5). They follow scenarios developed by the IPCC. They should not be viewed as uppper and lower bounds to potential outcomes, but rather as outcomes that illustrate the range of possibilities suggested by the existing literature. In that they do not attempt to capture the CO_2 effect or potential farm management responses to climate change, they are probably conservative estimates.

The estimated price effects of these crop yield changes generated by SWOPSIM are presented in Table 6. Under the optimistic scenario there is a small predicted decline in the price of primary products, and a small predicted increase in the price of secondary products. Corn and soybean prices increase by approximately 10%, but the price of all other primary commodities fall. This result is not surprising since most corn and soybean production occurs in countries located in regions of the world that are expected to be adversely affected by climate change. Of the secondary agricultural products, oil and meal prices increase by the highest percentage, representing their direct dependence on soybeans and other oilseed intermediate inputs. In contrast to the optimistic scenario, the pessimistic scenario predicts large increases in the world price of primary and secondary agricultural products--41 and 37 percent respectively.

Table 7 presents the complete breakdown of estimated changes in Marshallian consumer and producer surpluses for the pessimistic scenario, as well as the change in taxpayer costs ("other surplus") when there are distortions in agricultural markets from government intervention. For the optimistic case, only the net welfare change is presented. The net world welfare effect is positive under the optimistic scenario and is estimated at 0.01% of 1986 world GDP. Net welfare effects are negative but still very modest under the pessimistic scenario; they are estimated at 0.47% of 1986 world GDP.

The results in Table 7 illustrate two interesting features regarding the impact of climate change on agriculture. First, the considerable range of yield effects suggested by the crop response literature results in a similarly large range of potential economic effects. This uncertainity compounds the inherent difficulty associated with the development of international agreements to reduce greenhouse gas emissions, since countries cannot be certain of the magnitude and direction of the effect of climate change on their agricultural economies.

Secondly, they illustrate that relatively large domestic yield effects do not necessarily translate into large welfare effects. This supports our argument that a complete measure of the net costs and benefits of climate change on agriculture must include not only the direct domestic yield effects, but also the indirect effects which work through the open market.

Consider the pessimistic scenario. All countries are predicted to experience negative yield effects from climate change. However, in every case the change in producer surplus is positive. This is due to the fact that the positive price effect, which is transmitted through international markets, increases producer surplus and dominates the negative yield effect. In contrast, with demand curves unchanged, the same price effect reduces consumer surplus. The size of the positive producer surplus relative to the size of the negative consumer effect depends critically on the country's net trade position. The producer surplus gain will be large relative to the consumer surplus loss if the country is a large net exporter. Australia is an example of a very large net exporter with a gain in producer surplus dominating the loss in consumer surplus. In contrast, Japan is a large net importer with losses in consumer surplus very large relative to producer surplus gains.

These two cases are shown diagramatically in Figure 2. Consistent with the pessimistic scenario results, we assume that agricultural prices rise and agricultural production falls. Panel 1 represents the case of a large net exporter. The loss in consumer surplus is given by the area "A". The gain in producer surplus is given by (A + B) - (E + F). Thus, if the area "B" is greater than the area (E + F), there is a net gain in consumer plus producer surplus.

Panel 2 represents the case of a large net importer. The loss in consumer surplus is given by the area (A + B + C). The gain in producer surplus is given by (A - E). Thus, if (B + C) is greater than "E", there is a net loss in consumer plus producer surplus.

Concluding Comments

Our analysis provides a "snapshot" of the economic effects that a doubling of carbon dioxide levels might have on world agriculture, given present agricultural technologies, structure of production, and demand conditions. It makes clear that the evaluation of climate change gainers and lossers cannot be made on the basis of domestic yield effects alone. For example, although Australia is predicted to experience significant yield losses under the pessimistic scenario, the net consumer plus producer surplus effect is positive. In this case, the rise in world agricultural prices generates a large increase in producer surplus that dominates the yield decline losses and the loss in consumer surplus associated with a higher price of agricultural commodities.

Thus, when the effect of climate change on world agricultural prices is taken into account, a country's net welfare outcome depends not only on the relative size of domestic yield effects, but it also depends heavily on the relative size of the agricultural producing and consuming sectors, and the direction and magnitude of world price effects. Figure 3 summarizes the nature of the interpendence between yield changes, world price changes, and economic surplus studied in this paper.

These market relationships have important implications for the formulation of policy to address climate change. With respect to agriculture, policymakers' perception of the structure of incentives to reduce greenhouse gas emissions should not be based solely on predicted national agricultural production changes, but rather on how these yield effects alter global agricultural markets, and consequently, domestic producer and consumer welfare.

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Table 1

PROJECTED IMPACT OF CLIMATE CHANGE ON CROP YIELDS IN THE UNITED STATES BY CROP AND CLIMATE MODEL

CLIMATE MODEL	Corn (Dry)	Corn (Irrigated)	Soybeans (Dry)	Winter Wheat (Dry)
	----------------percent changes----------------			
GISS*	-23.7	-24.2	-34.6	-16.0
GFDL**	-54.7	-28.5	-59.7	-30.9

Source: EPA (1989).

*GISS is the Goddard Institute for Space Studies, National Aeronautics and Space Administration.

**GFDL is the Geophysical Fluid Dynamics Laboratory, National Oceonagrpahic and Atmospheric Administration.

Table 2

CLIMATE CHANGE AND IMPACT ON CROP YIELDS

Country/Region	Climate Change [°C; % precip.]	Hay	Pasture	Rye	Barley	Oats	S. Wheat	Rice
		Crop Yields						
		% change						
Canada								
Saskatchewan	+3.4°C, +18%	-	-	-	-	-	-18%	-
Iceland	+3.9°C, +15%	+64%		+48%	-	-	-	- -
Finland								
Helsinki	+4.1°C, +73%	-	-	-	+9%	+18%	+10%	-
Oulu	+5.0°C, +109%	-	-	-	+14%	+13%	+20%	-
USSR								
Leningrad	+4.2°C, +52%	-	-	-13%	-	-	-	-
Cherdyn	+2.7°C, +50%	-	-	-	-	-	-3%	-
Saratov	+3.3°C, +22%	-	-	-	-	-	+13%	-
Japan								
Hokkaido	+3.5°C, +5%	-	-	-	-	-	-	+5%
Tohoku	+2.9°C, +12%	-	-	-	-	-	-	+2%
Australia	+1°C, +50%	-	-	-	-	-	+(10-20)%	-

Source: Parry et al. (1988).

Table 3

PROJECTED IMPACT OF CLIMATE CHANGE ON CROP YIELDS IN EC COUNTRIES
(percentages of 1975-79 average yields)

Country	Average yield wheat and spelt** 1975-79 (dt/ha)	BMO* cumulative yield changes (%)	GISS cumulative yield changes (%)
Denmark	52.5	+18.7	+1.1
Netherlands	58.2	+1.2	+0.3
Luxembourg	30.9	+7.8	+6.1
Belgium	47.2	-9.5	-6.8
France	43.8	-9.8	-12.3
F.R.G.	46.6	-1.1	-8.6
Italy	25.8	-0.8	-1.2

Source: Santer (1985).

*BMO is a GCM developed at the British Meteorological Office
**Spelt is a cereal intermediate between wheat and rye.

Table 4
YIELD EFFECTS, OPTIMISTIC CASE

COUNTRIES/REGIONS	PERCENT CHANGE IN YIELD WHEAT	CORN	SOYBEANS	RICE	OTHER
UNITED STATES	-10	-15	-15		-10
CANADA	-15	+5	+5		-10
EUROPEAN COMMUNITY	-10	0	0		-5
OTHER EUROPE	+15	+30	0		+10
JAPAN	-5	0	+15	+10	+5
AUSTRALIA	+10	+10	+10	+15	+10
CHINA	+10	+10	+10	+10	+10
USSR	+10	+15	+15		+10
BRAZIL			No change		
ARGENTINA			No change		
PAKISTAN			No change		
THAILAND			No change		
REST OF THE WORLD			No change		

Table 5
YIELD EFFECTS, PESSIMISTIC CASE

COUNTRIES/REGIONS	PERCENT CHANGE IN YIELD WHEAT	CORN	SOYBEANS	RICE	OTHER
UNITED STATES	-20	-40	-40	-15	-20
CANADA	-20	-5	-5		-20
EUROPEAN COMMUNITY	-15	-10	-10		-10
OTHER EUROPE	+10	+15	0		+10
JAPAN	-5	0	0	-5	0
AUSTRALIA	-15	-10	-10	0	-10
CHINA	-15	-15	-15	-15	-15
USSR	-15	-10	-10	-20	-15
BRAZIL			No change		
ARGENTINA			No change		
PAKISTAN			No change		
THAILAND			No change		
REST OF THE WORLD	-10	-10	-10	-10	10

Table 6

PRICE EFFECTS
(PERCENT CHANGE IN PRICES, BY COMMODITY)

	SCENARIO	
GRAINS AND OILSEEDS	OPTIMISTIC	PESSIMISTIC
WHEAT	-0.9	50
CORN	9.2	75
OTH. COARSE GR.	-1.2	50
RICE	-8.1	36
SOYBEAN	10.6	79
OTHER OILSEEDS	-2.8	52
OTHER PRIMARY COMMODITIES		
COTTON	-4.5	40
SUGAR	-1.5	17
TOBACCO	-5.3	36
Composite Price Change, PRIMARY PRODUCTS:	-4.0	41

	SCENARIO	
PRODUCTS	OPTIMISTIC	PESSIMISTIC
BEEF	0.4	23
PORK	0.6	48
MUTTON, LAMB	0.7	29
POULTRY		31
SOYMEAL	4.9	50
SOYOIL	4.4	67
DAIRY:		
MILK	0.0	0
EGGS	0.6	28
BUTTER	0.2	50
CHEESE	0.1	45
MILK POWDER	0.2	51
Composite Price Change, SECONDARY PRODUCTS:	+1.0	37

Table 7

	PESSIMISTIC SCENARIO					OPTIMISTIC SCENARIO	
	Millions 1986 dollars						
	A Producer Surplus	B Consumer Surplus	C Other Surplus	Welfare Change (A + B - C)	Percent of 1986 GDP	Welfare Change (mill. 1986 $)	Percent of 1986 GDP
US	19212	-39990	-6464	-13027	-0.31%	194	0.005
CANADA	4167	-5450	-464	-738	-0.21%	-167	-0.047
EC	24270	-39162	-1214	-13677	-0.40%	-763	-0.022
OTHER E.	3848	-2550	1822	-524	-0.10%	-51	-0.010
JAPAN	4022	-9773	-333	-5614	-0.29%	-1209	-0.062
AUSTRALIA	1971	-1913	-14	75	0.04%	66	0.038
USSR	29198	-47377	-7426	-10753	-0.52%	658	0.292
CHINA	27500	-39874	0	-12374	-5.48%	2882	0.141
BRAZIL	9697	-8574	522	602	0.22%	-47	-0.017
ARGENTINA	5159	-3372	-437	2223	2.82%	95	0.120
PAKISTAN	2250	-2020	-313	528	1.63%	-50	-0.153
THAILAND	1596	-1076	29	490	1.22%	-33	-0.081
ROW	63835	-86349	0	-22513	-0.84%	-67	-0.002
WORLD	196725	-287480	-14292	-75302	-0.47%	1509	0.01

Figure 1

Effects of Climate Change on World Agriculture

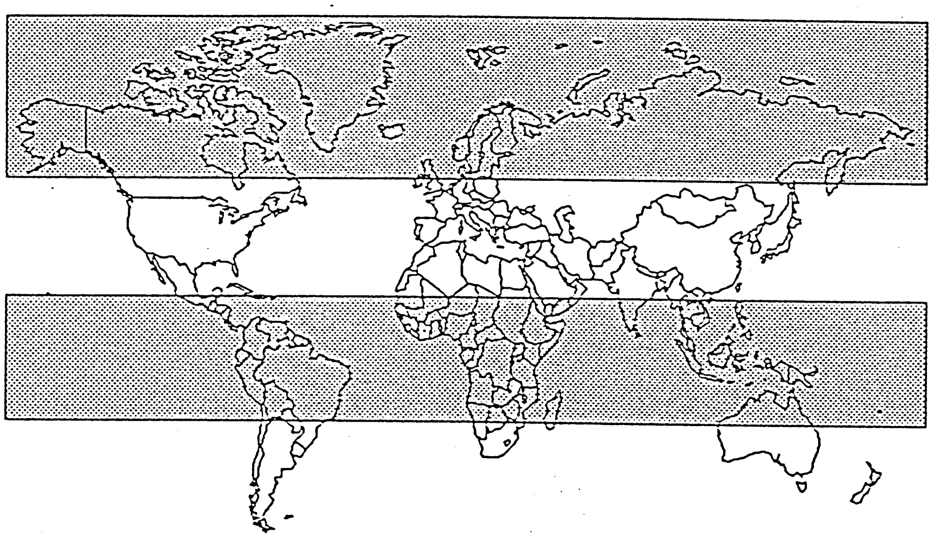
REGION

N. Latitudes

Northern Mid-latitudes

Tropics

Southern Mid-latitudes



N. Latitudes: warming and increased precipitation, increased yields

Mid-latitudes (north): warmer and dryer interiors, reduced yields

Tropics: little temperature change, uncertain yields

Mid-Latitudes (south): uncertain temp. and precipitation effects

Figure 2

The Effects of Climate Change on Welfare

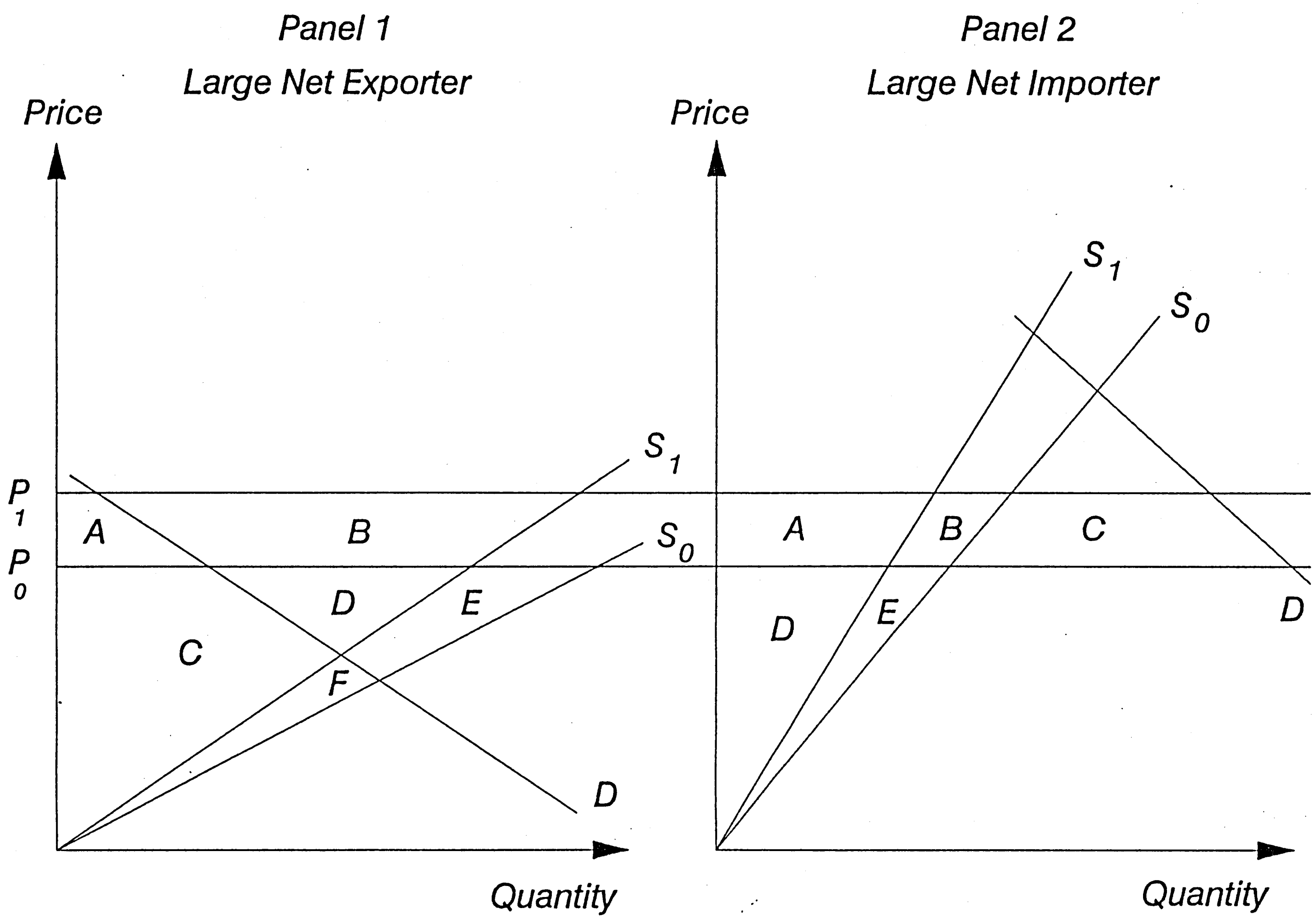


Figure 3

Net Welfare Effects of Climate Change Assuming An Increase in World Agricultural Prices

Yield Effect	Large Net-Importer	Large Net-Exporter
Strongly Negative	Negative Net Welfare Effect is likely	Ambiguous Net Welfare Effect
Strongly Positive	Ambiguous Net Welfare Effect	Positive Net Welfare Effect is likely