Chapter 3. National Adjustments to Climate Change

By altering temperature and precipitation conditions on a global scale, climate change threatens to shift national and world patterns of comparative advantage in the production of many crop and livestock products. The response of U.S. agriculture to climate change, then, will depend not only on how domestic farmers adapt to new environmental conditions, but also on a host of other factors that affect national and international commodity markets. In this chapter, we review recent research relating to potential impacts of climate change on U.S. agriculture and, to a lesser extent, the U.S. economy. Our objective is to see how results obtained in these studies can help address four questions of particular importance to national climate change policy.

- Are the aggregate economic impacts of climate change on U.S. agriculture and the U.S. economy likely to be positive or negative? As a related matter, which parts of the farm sector are most vulnerable to climate change?
- To what extent might negative climate change impacts on existing U.S. crop and livestock systems be mitigated or offset by farm-level adaptation and by international trade?
- How might climate change affect the allocation of U.S. land and water resources among competing uses?
- How can farm policy affect agriculture's response to climate change and are there actions the Federal Government might consider taking now?

Research Findings

Recently, Mendelsohn and others (1994), Adams and others (1995), and Darwin and others (1995) have investigated potential economic impacts of climate change on U.S. agriculture.[8] Adams and others develop estimates of climate change impacts on yields for specific crops; they then incorporate these impacts into a detailed analogous-regions model of U.S. agriculture. Mendelsohn and others and Darwin and others bypass explicit consideration of yield effects. These studies develop comprehensive measures of farm sector response to climate change from cross-sectional data on climate, economic activity, and resource endowments. Mendelsohn and others focus on the United States while Darwin and others take a global view.

Adams and others use quadratic programming to assess how climate change might affect the present structure of U.S. agriculture. Their spatial equilibrium model describes production and consumption of 42 primary and processed crop and livestock products. Production is modeled for 63 regions covering the contiguous 48 States; these are aggregated to 10 input supply regions for purposes of modeling agriculture's use of land, labor, and irrigation water. Demand is modeled at the national level and includes both domestic and foreign consumption. World commodity market conditions, however, are not endogenous to the model. Rather, changes in U.S. agricultural exports are keyed to forecasted changes in world food production from Rosenzweig and others (1993).

A base case scenario is obtained by running the model under 1990 climate, economic, and technology conditions. Crop yields, water supplies, and crop water use parameters in each region are then modified to reflect the $2xCO_2$ scenarios of the GISS, GFDL, and UKMO GCM's. Estimates of each scenario's impacts on crop yields are based on crop-response model results for corn, wheat, and soybeans from the U.S. sites reported in Rosenzweig and others (1994) (see chapter 2).

Among the three studies, the primary strength of Adams and others is its level of geographic and commodity detail. By disaggregating U.S. agriculture into 63 production regions and explicitly considering 30 primary crop and livestock commodities, the model indicates how regional producers might alter their output mixes in response to climate change. Viewed in total, these results indicate how climate change might shift national patterns of comparative advantage in the production of many crop and livestock products. A second strength of the study is that it explicitly considers CO_2 fertilization effects.

The main limitation of Adams and others is that its framework is partial equilibrium. Because it does not consider nonfood producing sectors, it assumes that agriculture's response to climate change is independent of the responses of nonagricultural sectors. In input markets, this means that climate change does not affect intersectoral competition for land and water resources. A second limitation is that farm-level adaptation to climate change is limited to choosing the most profitable output mix from a set of exogenously specified alternatives (and making the

[8] Similar approaches were used in earlier studies by Dudek (1989), Adams and others (1990), and Easterling and others (1992).

Table 3.1—Land class boundaries in Darwin and others (1995)

Land class	Length of growing season	Days with soil temperatures above 5^{o} C	Principal crops and cropping patterns	Sample regions
1	0 to 100	125 or less	Sparse forage for rough grazing	Northern Alaska
2	0 to 100	More than 125	Millets, pulses, sparse forage for rough grazing	Mojave Desert
3	101 to 165	More than 125	Short season grains, forage: one crop per year	Palouse
4	166 to 250	More than 125	Maize: some doublecropping possible	Corn Belt
5	251 to 300	More than 125	Cotton, rice: doublecropping common	Tennessee
6	301 to 365	More than 125	Sugar cane, tropical fruits; double cropping common	Southeast coast

Compiled by Economic Research Service from Darwin and others (1995), USDA.

implied adjustments in land and water use). Hence, many feasible farm-level adaptations have been overlooked.

Mendelsohn and others take a statistical approach and use regression analysis and county-level data for the contiguous 48 States to estimate marginal effects of various climate, economic, and other factors on farmland values. They assume that all land is in its highest valued use so that farmland values reflect all economic opportunities of farmland. Climate variables, reflecting mean monthly temperature and precipitation levels for January, April, July, and October, allow the model to distinguish economic costs and benefits associated with climate change depending on when in the year impacts occur. Warmer temperatures in October, for example, would favor agriculture by extending growing seasons and facilitating harvest operations. Warmer temperatures in July, however, would tend to hurt agriculture by increasing plant stress and irrigation requirements.

Regressions are run weighting each county by the percentage of its area in farmland and by its crop revenue; each regression is estimated using data from 1978 and 1982. The crop revenue weights emphasize irrigated lands, where production is intense with high-value crops (for example, fruits and vegetables). The cropland weights emphasize areas where cool-season grains dominate production.

Climate change is simulated by uniformly increasing mean county temperature and precipitation levels by 5 degrees F and 8 percent. Under this scenario, irrigated lands expand (particularly in the West and South) and cool-season grain production contracts. Reflecting these land-use changes, the value of U.S. farmland falls $119 - $141 billion using the cropland-weighted model and increases $20 - $35 billion using the crop revenue-weighted model. Mendelsohn and others conclude that the revenue model gives the better economic measure of climate change impacts on U.S. agriculture because it more fully reflects the value of farm-level adaptations to new environmental conditions. The cropland model, however, shows how focusing on major grain producing areas can bias assessments of climate change impacts on U.S. agriculture.

Aside from valuing seasonal effects of climate change, the major strength of Mendelsohn and others' framework is that it captures effects of farm-level adaptation without having to enumerate specific actions. Climate-induced changes in farmland values assume that farmers adapt to new environmental conditions by altering input choices, production technologies, and crop mixes. Hence, farm-level adaptation is both implicit and endogenous in the model. Additionally, the set of adaptations available to farmers is by definition everything currently done in U.S. agriculture. The framework also implicitly allows nonagricultural sectors to compete for farmland because if the value of land goes too high or too low, it will exit agriculture.[9]

Mendelsohn and others' model has two limitations. First, because it only considers farmland values, it cannot assess how climate change impacts might be distributed among agents (for example, producers and

[9] The model does not, however, let new land enter agricultural production.

Table 3.2—Current U.S. land and water endowments and percentage changes in endowments by climate change scenario

Resource	Present endowment	Percent change by scenario			
		GISS	GFDL	UKMO	OSU
	Million hectares		*Percent*		
Land class 1	120.45	-51.77	-54.84	-67.28	-43.57
Land class 2	300.97	-9.97	1.89	8.40	9.42
Land class 3	116.21	45.83	105.41	42.85	48.42
Land class 4	198.80	-14.84	-25.42	-27.96	-29.98
Land class 5	68.96	36.61	63.11	101.64	16.81
Land class 6	111.26	38.96	-49.54	-7.68	14.25
	Cubic kilometers				
Renewable water	2,478.00	-6.73	7.51	4.22	0.53
Water supply	467.00	-3.16	3.52	1.98	0.25

Climate change scenarios generated by the general circulation models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU).
Compiled by Economic Research Service from Darwin and others (1995), USDA.

consumers). The underlying assumption that prices do not change means that consumers are not affected and that the net affect on global production is zero. Regionally, some producers gain what others lose. Second, being a partial equilibrium analysis, interactions between sectors and regions are not accounted for. It is assumed, for example, that climate change will not affect output prices, nonland input prices, or world trade flows. While climate change can affect the price of a given tract of land, the price of land with a given set of characteristics is fixed. The analysis also abstracts from adjustment costs associated with changing structural features related to agriculture (for example, irrigation systems). Hence, differences between model simulations reflect movements between points of longrun equilibrium.

Darwin and others combine a computable general equilibrium (CGE) model and a geographic information system (GIS) to analyze potential climate change impacts on U.S. agriculture, taking account of interactions with nonagricultural sectors and other global regions. Their model has 8 global regions, each with an 11-sector economy that produces 13 commodities. Agricultural sectors include crops and livestock; agricultural commodities include wheat, other grains, nongrains, and livestock. All regions consume, produce, and trade all 13 commodities. General equilibrium refers to the fact that prices clear all input and output markets simultaneously.

The GIS describes regional land areas in terms of endowments of up to six heterogeneous land classes. Land classes are differentiated by length of growing season, which is computed from mean monthly temperature and precipitation data (table 3.1). The GIS also describes regional water resources and helps to define unique production structures (that is, technologies, input and output mixes) for crops, livestock, and forestry for each region/land-class combination. The production structures are developed from cross-sectional data on current land cover, land use, and production. In this way, the production possibilities associated with a region's agricultural resources depend directly on its land class and water endowments.

Climate change scenarios are imposed in the GIS by adjusting global temperature and precipitation data to reflect the 2xCO_2 simulations of the GISS, GFDL, UKMO, and OSU GCM's. By altering regional land class and water endowments, these scenarios shift the production possibilities facing regional crop and livestock producers. Table 3.2 shows how each scenario would affect U.S. land and water resources. Percent changes in regional land class and water endowments associated with each scenario are then entered into the CGE model as factor endowment

Table 3.3—Estimated annual economic impacts of climate change on the U.S. economy

Scenario[4]	Adams and others[1]			Darwin and others[2]		Mendelsohn[3]	
	with CO_2 and trade effects	no CO_2 or trade effects	CO_2 effects but no trade effects	Land use restricted	Land use unrestricted	Cropland weights	Crop revenue weights
				Billion dollars			
A. Aggregate U.S. economic impacts:[5]							
GISS	10.82	-11.33	10.21	5.9	5.8	- 9.2	16.4
GFDL	4.37	-19.09	4.57	-11.1	- 4.8	-35.6	33.1
UKMO	9.03	-67.01	-17.58	- 1.2	1.1	-36.6	8.9
OSU	NA	NA	NA	- 6.6	- 3.9	-28.1	- 5.8
B: Impacts on U.S. agricultural producers:							
GISS	12.56	10.79	12.74	2.8	-1.5	- 9.2	16.4
GFDL	6.61	16.84	7.22	8.3	-1.5	-35.6	33.1
UKMO	44.44	114.97	41.52	8.2	-1.7	-36.6	8.9
OSU	NA	NA	NA	5.9	0.4	-28.1	- 5.8

[1] Part A reflects changes in total surplus. Part B reflects changes in producer surplus. In 1990 dollars, the base scenario total (producer) surplus was $1,124 billion ($21 billion).
[2] Part A reflects changes in 1990 Gross Domestic Product (GDP). Part B reflects changes in returns to agricultural land, capital, labor, and water resources.
[3] Reflects changes in the annual stream of returns to farmland due to climate change.
[4] Climate change scenarios generated by the general circulation models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU).
[5] For comparison purposes, base scenario (Darwin and others) U.S. GDP was $5,497 billion (in 1990 dollars), and the annualized 1982 implicit return to agricultural land in 1990 dollars was $31.1 billion.
Compiled by Economic Research Service, USDA.

shocks. Given these shocks, the CGE model computes regional and world responses in commodity production, consumption, and trade.

The primary strength of Darwin and others is that the framework directly links land and water resources to climate conditions and economic activity on a global scale. Hence, estimates of climate change impacts on U.S. agriculture account for the full range of interactions with nonagricultural sectors and other global regions. As in Mendelsohn and others, farm-level adaptation to new environmental conditions is implicit and endogenous. When climate change forces a given tract of land into a new land class, that land assumes the production possibilities associated with its new region/land-class designation. Darwin and others also describe intersectoral competition for land and water resources explicitly. In model simulations, then, all input and output market impacts are internally consistent. Finally, Darwin and others do not consider adjustment costs and so, like Mendelsohn and others, their results also refer to points of longrun equilibrium.

Results of Studies

Part A of table 3.3 presents estimates of aggregate economic impacts of climate change on the U.S. economy as reported in Adams and others, Darwin and others, and Mendelsohn.[10] Because of the different methods used in these studies, direct comparisons of results must be qualified. Still, the studies agree that the economic impact of climate change on the U.S. economy is likely to be small. Whether this impact will be positive or negative, however, is uncertain.

For the GISS, GFDL, and UKMO climate change scenarios, Adams and others estimate total economic gains for the United States of $4.4-$10.8 billion (see "with CO_2 and trade effects" case). In this and each subsequent case, these are the figures reported in the executive summary and are considered to be generated by the appropriate statistical technique for

[10] Mendelsohn has redone the analysis in Mendelsohn and others using the GISS, GFDL, UKMO, and OSU scenarios. For Part B of table 3.3, Darwin redid the impacts in Darwin and others for U.S. agricultural producers only. The discussion here refers to these updated impacts.

analyzing overall impacts on the U.S. economy. For the same scenarios and the OSU scenario, Darwin and others estimate total U.S. economic impacts ranging from -$4.8 billion to $5.8 billion (see "land-use unrestricted" case). Results in both studies are reported in 1990 dollars, implying a net climate change impact somewhere between -0.2 and 0.2 percent of U.S. gross domestic product. Impacts in Mendelsohn tend to be larger, ranging from -$5.8 billion to $33.1 billion for the four scenarios (see "crop revenue weights" case). Additionally, the three studies generally agree with respect to the direction of impact associated with each of the change scenarios. The exception is the GFDL scenario, where the aggregate effect is negative in Darwin and others and positive in Adams and others and Mendelsohn and others.[11]

The effects of climate change on agricultural producers will be marginally negative at worst, and moderately to very beneficial at best (table 3.3, part B). Results from Adams and others reflect changes in producer surplus associated with climate change. Focusing again on the "with CO_2 and trade effects" case, producer surplus increases $6.6-$44.4 billion across the three scenarios analyzed. These gains reflect increases in baseline (1990) producer surplus of between 31.4 and 200.1 percent (baseline producer surplus was $21 billion).[12] Additionally, the increases in producer surplus exceed the gains in total surplus in each scenario, implying negative impacts for U.S. consumers.

Results from the other studies are generally less favorable for U.S. agriculture than those in Adams and others.[13] With respect to Mendelsohn, 1982 gross U.S. farm income in 1990 dollars was $191 billion. Hence, the results imply climate change impacts on annual farm income of -3.0 to 17.1 percent. Results from Darwin and others reflect changes in annual returns to agricultural land. Income from agricultural land in their base case is $25.4 billion; the results then, imply climate change impacts on returns to agricultural land of between -7.8 and 5.8 percent.

Besides indicating potential magnitudes and directions of climate change impacts on the U.S. economy and U.S. agriculture, two additional points should be highlighted from table 3.3. First, among the three studies, only Adams and others consider CO_2 fertilization effects. In their results, accounting for CO_2 fertilization positively affects estimates of climate change impacts on the U.S. economy by $20-$40 billion per year (see columns 2 and 3 of part A); Part B shows that these gains generally accrue to producers. This suggests that the results reported by Mendelsohn, and Darwin and others would almost certainly be more optimistic if CO_2 fertilization had been accounted for.

The other point to highlight from table 3.3 is the potential bias inherent in using a partial, as opposed to a general equilibrium, framework for analyzing economic impacts associated with climate change. Of the three studies, only Darwin and others explicitly account for interaction effects between sectors and between regions; Mendelsohn abstracts from interregion effects and Adams abstracts from intersector effects. With respect to magnitude, the Mendelsohn, and Adams and others results are always larger than those in Darwin and others. Additionally, interaction effects can capture important differences in the distribution of costs and benefits. For example, in three of four scenarios, Darwin and others find that the United States is better off when all global land is allowed to change land use in response to climate change than when it is restricted to its present use (part A, columns 4 and 5). U.S. agriculture, however, is always better off when land use is restricted (part B, columns 4 and 5). This is because much of the land that enters agricultural production under climate change is outside the United States and trade allows

[11] Adams and others do not consider the OSU scenario.

[12] Personal communication with R. Adams.

[13] Results in Parts A and B for Mendelsohn are identical because fixing output prices restricts impacts to agricultural producers.

Table 3.4—Changes in U.S. agricultural land rents under various constraints, by climate change scenario[1]

Scenario	Farm-level adaptations only[2]	Price changes occur: Land use fixed	Price changes occur: No land-use restrictions
	Percent change		
GISS	4.1	0.8	-7.8
GFDL	-16.1	21.9	4.3
UKMO	-4.4	12.6	-5.4
OSU	-10.0	11.5	5.8

Compiled by Economic Research Service, USDA.

[1] Agricultural land is composed of cropland and pasture land.

[2] No price changes.

Table 3.5—Base values and percentage changes in U.S. commodity production by climate change scenario

Commodity	Base value (1990)[1]	GISS		GFDL		UKMO		OSU	
		Rest.	Unrest.	Rest.	Unrest.	Rest.	Unrest.	Rest.	Unrest.
		Percent							
Wheat	74,475	8.191	5.986	14.761	12.392	10.518	9.374	6.087	1.479
Other grains	238,352	-5.177	-5.854	-10.638	-6.479	-9.804	-7.071	-9.298	-7.349
Nongrain crops	194,389	7.655	2.768	-3.454	-3.947	9.549	0.643	1.550	-0.317
Livestock	170,647	-0.464	-0.691	-1.476	-0.462	-1.512	-0.582	-1.819	-1.274
Forest products	498,000	0.566	0.713	-2.028	-0.818	-1.435	-0.470	-0.296	-0.253
Coal/oil/gas	215,073	-0.173	-0.010	-0.228	-0.063	-0.343	-0.042	-0.279	-0.166
Other minerals	24,786	-0.293	0.047	-0.050	0.136	-0.454	0.094	-0.284	-0.118
Fish/meat/milk	121,363	-0.081	-0.155	-0.837	-0.156	-0.736	-0.102	-0.987	-0.588
Other processed foods	292,850	0.380	0.130	-0.584	-0.372	0.072	-0.165	-0.327	-0.321
Text./cloth./footwear	155,999	0.091	0.091	0.021	-0.046	0.278	0.180	-0.082	-0.126
Other nonmetal. manuf.	1,067,890	0.048	0.099	-0.224	-0.027	-0.122	0.052	-0.207	-0.127
Other manuf.	1,266,520	-0.183	0.156	0.070	0.218	-0.213	0.258	-0.091	0.076
Services	6,103,870	0.050	0.077	-0.190	-0.075	-0.087	0.002	-0.156	-0.100

[1] For wheat, other grains, and nongrains, values are in 1,000 metric tons. For livestock, values are in 1,000 head. Forest products values are in 1,000 cubic meters. For all other commodities, values reflect total value of production (in million $U.S.).

Climate scenarios generated by the General Circulation Models of the Goddard Institute for Spaces Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU).

Rest. = cropland, pasture, forest, and land in other uses restricted to 1990 locations and quantities; Unrest. = all land can move between cropland, pasture, and other uses.

Compiled by Economic Research Service from Darwin and others (1995), USDA.

other regions to take advantage of this shift in comparative advantage.

An experiment undertaken for this report simulated the Mendelsohn and others approach using the Future Agricultural Resources Model (FARM). Table 3.4 shows percentage changes in agricultural land rents in the general equilibrium FARM when prices are assumed fixed. This is a closer direct comparison (than the one in table 3.3) of FARM and Mendelsohn's study that implicitly assumes that prices do not change. Comparing the first column of results in table 3.4 with columns 6 and 7 in table 3.3 indicates that FARM produces results closer to the crop revenue-weighted results than the cropland weights by Mendelsohn. When the fixed price assumption is relaxed in columns 2 and 3 of table 3.4 the results are more positive and somewhat similar to the crop revenue results obtained by Mendelsohn in table 3.3.

Table 3.5 shows climate change impacts on U.S. commodity production from Darwin and others. Focusing again on the "land-use unrestricted" case, impacts are small to moderate across commodities. These results also make clear that, regardless of the aggregate impact, climate change will likely have both positive and negative impacts within agriculture. In all scenarios, wheat production increases (the range is 1.5 to 12.4 percent), while output of other grains and livestock decline (the ranges are 5.9 to 7.3 percent and 0.5 to 1.3 percent). The drop in other grains is primarily due to reduced maize production in the Corn Belt under warmer and drier growing seasons, supporting results discussed in chapter 2. For nongrains, production increases or decreases depending on the scenario; the range is -3.9 to 2.8 percent. In food processing sectors, output generally declines; fish, meat, and milk decrease in all scenarios while other processed foods decrease in three scenarios.

Adaptation

The conclusion in Adams and others, Mendelsohn and others, and Darwin and others that climate change will not seriously threaten U.S. agriculture assumes that farmers will adapt their choices of inputs, production practices, and outputs to best suit their environments. The potential for farm-level adaptation to mitigate any negative impacts of climate change is highlighted by a series of simulations from Darwin and others (table 3.6). For each of the scenarios, Darwin and others estimate the impact on U.S. cereals (wheat and other grains) supply and production.

Table 3.6—Percentage changes in U.S. supply and production[1] of cereals under various constraints by climate change scenario

Scenario	Supply[2]		Production	
	No adaptation	With adaptation	Land use fixed	No restrictions
	Percent			
GISS	-21.5	-8.7	-2.0	-3.0
GFDL	-37.8	-22.3	-4.6	-2.0
UKMO	-34.1	-19.4	-3.2	-5.0
OSU	-31.9	-20.9	-5.6	-5.2

[1] Changes in supply show the additional quantities (positive or negative) that firms would be willing to sell at 1990 prices under the alternative climate. Changes in production show changes in quantities that firms would be willing to sell and consumers would be willing to buy at new market prices under the alternative climate.
[2] Land use is fixed in both supply cases, i.e., cropland cannot increase.
Compiled by Economic Research Service from Darwin and others (1995), USDA.

Supply effects represent changes in quantities (positive or negative) that producers would be willing to sell at 1990 prices under the alternative climates; production effects take into account changes in trade and consumer demand; that is, they show changes in what producers are willing to sell and consumers are willing to buy.

The "no adaptation" case in table 3.6 assumes that given new climate conditions, farmers do exactly what they are now doing. This case, then, shows how the four GCM's would impact current U.S. cereals production. Across scenarios, U.S. cereals supply decreases between 21.5 and 37.8 percent. The "adaptation" case allows farmers to alter mixes of inputs and outputs, but only on land currently in production and still holding prices fixed at 1990 levels. U.S. cereals supply now decreases between 8.7 and 22.3 percent. By adapting input and output choices on existing cropland then, cereals producers offset 35-60 percent of the initial climate-induced supply shock.

The "land-use fixed" case shows climate change impacts on current cereals production allowing for onfarm adaptation and changes in trade flows and consumer demand; total cropland, however, is still fixed at 1990 levels. Under these conditions, U.S. cereals production decreases between 2.0 and 5.6 percent. This implies that when all market-induced responses are accounted for, 82-91 percent of the initial climate change shock to U.S. cereals production is offset.

Finally, the "no restrictions" case allows global cropland to expand. Relative to the "land-use fixed" case, there are marginal reductions in the climate change shock on U.S. cereals producers in the GFDL and OSU scenarios. In the GISS and UKMO scenarios, however, the magnitude of the shock increases. This suggests that the global competitiveness of U.S. grain producers may depend on world agriculture's ability to expand in areas where cold temperatures now limit crop production.

Land Use Changes and Regional Shifts in Production

By altering temperature and precipitation patterns, climate change will shift the production possibilities associated with land and water resources in much of the United States. These shifts, combined with changing economic conditions, will alter the nature of competition for land and water resources. Resulting land-use changes are likely to alter domestic patterns of commodity production, particularly in land-intensive crops, livestock, and forest products. Results in Mendelsohn and others and Darwin and others provide a number of insights into which economic activities and which areas of the United States stand to be most affected by climate change.[14]

In Mendelsohn and others, the cropland-weighted model emphasizes counties where grains are important. Grains tend to favor cooler temperatures. Assuming land now in grain production is in its highest valued use, generally warmer climates would hurt many grain producing areas. The crop revenue-weighted model, on the other hand, emphasizes irrigated lands in the West and South. In Mendelsohn and others, these lands expand under uniformly warmer temperatures. Hence, the climate change scenarios favor agriculture in much of the South and West.

In Darwin and others, imposing climate change scenarios causes between 38.9 and 55.3 percent of all U.S. land to shift to a new land class. Table 3.2 shows the percentage changes in each land class by scenario; percentage changes in land use, by scenario, are presented in table 3.7. Across scenarios, land in crop production increases (the range is 1.6 to 9.7 percent), while in three scenarios, land in pasture also expands. From a national perspective then, these

[14] Adams and others discuss regional welfare effects but not regional production effects.

Table 3.7—Percentage of all U.S. land changing land use and net percentage changes in U.S. cropland, permanent pasture, forest land, and land in other uses, by climate change scenario

Climate change scenario	Percent of all U.S. land changing land use	Net percentage change in U.S.			
		Cropland	Pasture	Forest	Other Land
			Percent		
GISS	8.3	9.7	-0.1	2.9	-13.9
GFDL	14.1	3.9	0.7	2.3	-8.4
UKMO	15.1	4.9	7.0	0.6	-14.6
OSU	11.6	1.6	7.4	-0.8	-9.7

Compiled by Economic Research Service from Darwin and others (1995), USDA.

results suggest that climate change would increase the total amount of U.S. land in agricultural production.

At the same time, Darwin and others estimate that between 8.6 and 19.1 percent of existing U.S. cropland would leave production (table 3.8). Hence, some farm communities and agricultural industries are likely to be severely disrupted by climate change. The decreases in land class 4 (see table 3.1) in all scenarios in the Corn Belt and land class 6 (two scenarios) in the Southeast suggest negative impacts on existing agricultural systems. As for agricultural industries, results in Darwin and others suggest that climate change favors wheat production and restricts the output of other grains and livestock; effects on nongrain are uncertain (see table 3.5).

Uncertainty

Given all that is unknown about climate change, analysts and policymakers must accept uncertainty as given. Aside from the ultimate form of climate change, the impacts of several climate change events are much disputed; these include magnitudes of CO_2 fertilization effects, pest distribution effects, and the ability of agriculture to expand in the northern latitudes given warmer average temperatures. Finally, even if the aggregate national impact of climate change is small, sector and region impacts are uncertain and these could have more policy relevance than national effects. Economic analysis can help policymakers deal with climate change uncertainties in two important ways.

First, economic analysis can assess and compare impacts of different climate change scenarios as well as different policy responses. The quality of these analyses, however, depends on how well the economic models can reflect what is known about climate change or allow what is not known to be subjected to sensitivity testing. While economic models of U.S. agriculture under climate change have improved greatly in recent years, some capacities still need to be developed. Most important are developing the capacities to analyze climate change impacts: (1) among developing regions (since it appears that the most dramatic effects will be in these countries), and (2) in a dynamic framework (since climate change will evolve gradually over the next several decades).

The second way economic analysis can help climate change policy address uncertainty is by identifying those areas where uncertainty matters most; that is, areas where having the wrong information or understanding can most bias economic assessments of climate change. This allows resources to be targeted to areas where the payoff to reducing uncertainty is highest. One such area is improving our understanding of potential climate change impacts on regional water resources. The conclusion that climate change will not seriously threaten U.S. agriculture typically hinges on optimistic assumptions concerning the impact of climate change on water resources. The

Table 3.8—New and abandoned U.S. cropland by climate change scenario

Climate change scenario	New cropland		Abandoned cropland	
	Million hectares	*Percent*	*Million hectares*	*Percent*
GISS	34.8	18.3	16.2	8.6
GFDL	43.8	23.1	36.4	19.1
UKMO	42.4	22.3	33.2	17.5
OSU	32.2	17.0	29.1	15.3

Compiled by Economic Research Service, USDA.

large increase in irrigated acreage obtained in Adams and others, for example, assumes agriculture has a first-right to water resources. Similarly, the expansion of irrigation implicit in Mendelsohn (see table 3.3) assumes that if an area becomes more arid, farmers will have to pay what they now pay in arid places for water. It is possible that under a generally drier climate, the prices of alternative water supplies could also be bid up.

In Darwin and others, the allocation of water (among regional crops, livestock, and services sectors) and its price are market-determined. Regional water markets, however, embody several important simplifications. First, water resources can be transported anywhere within a region at zero marginal cost. Also, snowpack is not considered and too much water does not hurt production. Given these simplifications, Darwin and others find that water scarcity decreases for the United States under the GISS, GFDL, and UKMO scenarios (that is, the price of U.S. water falls between 1.52 and 3.22 percent). In the OSU scenario, the U.S. water price rises 8.97 percent, reflecting an increase in scarcity. Further, when land is restricted to its present use (that is, cropland, pasture, forest, and other), water scarcity increases for the United States in all four scenarios; associated price increases are between 4.05 and 11.73 percent.

Another area where uncertainty can be reduced in analyses of climate change and U.S. agriculture is improving our understanding of world agriculture's potential for expanding into areas where cold temperatures now limit production (mainly in northern latitudes). Some argue that this potential is small due to the prevalence of poor soils and other limiting factors in these areas (Ward and others, 1989), but the prevailing view is that a significant potential exists.

Darwin and others show impacts on the U.S. economy under the assumptions that all global land can and cannot shift into new uses (columns 4 and 5 of table 3.3, part A). Within the United States, the land-use restricted case implies that fewer adaptations are available to farmers and that consumers have less ability to offset negative impacts in world commodity markets. As a result, aggregate costs to the U.S. economy are higher for all but the GISS scenario; the magnitude of the cost increase is about double that in the unrestricted case. For the GISS scenario, aggregate U.S. costs are about the same when land use is and is not restricted.

For U.S. agriculture, however, the net effect of restricting land use is generally positive. Imposing climate change and restricting land to its present use insulates U.S. farmers from losses in comparative advantage in agricultural production relative to the case where land can freely shift into new uses worldwide. The primary effects of restricting land use are favorable shifts in domestic patterns of commodity production (see table 3.6). In all scenarios, for example, wheat production increases but the increases are larger when land use is restricted.[15] Similarly, production of other grains and livestock decreases in all scenarios but, in all but the GISS scenario, the decreases are larger when land use is restricted. Output of nongrains increases or decreases depending on scenario, but the effects are always more optimistic (that is, more positive or less negative) when land use is restricted. These results suggest the worldwide expansion of agriculturally suitable lands under climate change hurts U.S. agriculture (tables 3.3 and 3.6).

Government Farm Programs

The view that agriculture could offset many negative impacts associated with climate change assumes that the Government will not create *disincentives* for farmers to adapt to new climate conditions. Lewandrowski and Brazee (1993) analyze how farm price and income support programs affect U.S. agriculture's response to climate change.

Using a simple portfolio model, Lewandrowski and Brazee develop three decision rules regarding a farmer's crop mix. More resources are allocated to producing crop *i* when: (1) the expected returns to crop *i* increase relative to other investments, (2) the risks associated with crop *i* decrease relative to other investments, and (3) the covariance, or the amount that returns to crop *i* and the returns to other assets move together, decreases. These rules are used to consider how farmers would respond to three climate change scenarios with and without the present set of farm programs in place. The scenarios are: (1) an increase in atmospheric CO_2, (2) higher atmospheric CO_2 and an increase in average temperature and precipitation levels, and (3) higher atmospheric CO_2 and increases in both the means and variances of current temperature and precipitation levels.

[15] When land use is not restricted, large quantities of newly available cropland enter production in Canada and the former Soviet Union. This land is well-suited to growing wheat, so comparative advantage for wheat deteriorates for the United States and improves for Canada and the former Soviet Union relative to the case when land use is restricted.

Lewandrowski and Brazee conclude that farm price and income support programs discourage many obvious farm sector adaptations to climate change. Target prices and deficiency payments, nonrecourse loans, and multiyear penalties for reducing program acreage all dissuade farmers from switching crops. Disaster payments and subsidized crop insurance reduce consideration of crop failures in production decisions. In much of the West, Federal irrigation subsidies have discouraged investments in water-conserving technologies.

In the past, farm program costs have tended to be highest following very good harvests. This is because the Government must purchase (at above market prices) and store large quantities of output. Low prices also increase deficiency payments for some crops. Very poor harvests can also be costly. Federal disaster assistance to farmers following the 1988 drought totaled more than $3.1 billion. If climate change increases the occurrence of very good or very poor harvests, society could pay a high price for programs that discourage farmers from adapting to new environmental conditions.

A farm program adjustment to consider is how to encourage water conservation. Examples include removing institutional barriers to water markets in the West and promoting adoption of water-efficient irrigation technologies in general. Developing water markets and allowing water from Federal projects to move in those markets would facilitate the flow of water to its highest valued use. These markets, coupled with reform of water laws, would give farmers the resources and incentive to invest in more water-efficient irrigation systems. At present, the high cost of such systems makes their adoption unlikely by farmers who have access to adequate water supplies.

Aside from urban areas in the West, there may be other regions where promoting water conservation in agriculture is economically rational (for example, the Ogallala Aquifer in the Southern Plains and the Edwards Aquifer in Texas). Where irrigation is subsidized, where withdrawals exceed replacement, or where water has alternative uses, the social benefits of reducing agricultural water use may justify government programs to help farmers acquire more water-efficient irrigation systems. Farmers then, would also be in a better position to adapt to hotter and/or drier growing seasons.

Finally, disaster assistance payments could be tied to a moving average of yields over the past few years. Past disaster payments have been based on various measures of "average" production (for example, average county yields or average program area planted). In computing these averages, however, years with very low harvests have generally been omitted. The Disaster Assistance Acts of 1988 and 1989, for example, use similar definitions of "normal" production but the measures used in the 1989 Act do not include poor 1988 harvests. The effect then, is to bias upward the measure of "normal" production. Although aggregate agricultural impacts of gradual climate warming may be slightly positive, in any given area, growing conditions for the present mix of crops are likely to deteriorate slowly. We may perceive a series of crop failures before recognizing that the climate has changed. This modification provides a check against making a series of disaster payments when, in fact, yields are average given the new environmental conditions. Also, implementing the change would be inexpensive and would have no effect if the climate remained constant.

Along with the above changes in commodity programs, the Federal Government could help prepare the U.S. farm sector for possible climate change by promoting research aimed at maintaining agricultural productivity under possible future temperature and precipitation conditions. There is, at present, little economic incentive for private agents to undertake such research because its benefits typically will not be realized for several decades (if ever). Fuglie and others (1995) have estimated the average (historical) and marginal rates of return to public investments in agricultural research to be at least 35 percent. To date, this effort has focused largely on increasing yields.[16] Potentially large returns to research aimed at extending the temperature tolerances and/or reducing the water requirements of crops and livestock are indicated by the expansion of wheat production in the United States (particularly hard red winter wheat) and dryland corn production in Canada over the last 75 years (U.S. Congress, OTA, 1993).

Reilly and others (1996) provide a thorough review of these and other technological and socioeconomic factors that have been identified in the climate change literature as potentially important for adaptation to climate change. Chapter 2 discussed changing crop seasons and planting dates, developing new crops and

[16] Between June 1, 1984, and June 1, 1989, for example, USDA released 599 new plant varieties and germplasms; of these, 80 percent had improved disease resistance, 30 percent had better insect resistance, and 10 percent were more resistant to nematodes (Senft and McNeil, 1995).

crop varieties, and improving farm management practices. Other areas where public agricultural R&D could help prepare U.S. agriculture for possible climate change include developing new irrigation and tillage systems, improving short-term climate prediction, implementing training and education programs, and improving transportation and market integration systems.

Conclusions

This chapter has discussed recent evidence relating to the potential roles of farm-level adaptation, international trade, intersectoral competition for land and water resources, and government farm programs in shaping the response of U.S. agriculture to climate change. In response to the questions posed at the beginning of the chapter, five broad results have emerged from this work.

- Climate change is not likely to seriously disrupt the U.S. economy—most estimates suggest aggregate economic impacts of between -0.2 and 0.2 percent of gross domestic product. It is also unlikely that the ability of U.S. agriculture to meet domestic food needs will be threatened.

- Throughout the United States, climate change will alter the production possibilities associated with land and water resources. Farm-level adaptation (that is, adjusting input choices, technologies, and output mixes) will enable U.S. agriculture to mitigate most negative impacts that climate change might have on current production practices.

- Shifting production possibilities and changing economic conditions will alter the nature of competition for land and water resources among economic sectors. Resulting land-use changes will alter domestic patterns of crop and livestock production. While net impacts on U.S. agriculture are likely to be small, some regional impacts could be very disruptive.

- Major areas of uncertainty regarding U.S. agriculture and climate change include the form of climate change, potential impacts on water supplies, and the ability of global agriculture to expand into areas where production is now limited by cold temperatures.

- Government farm price and income support programs largely discourage farm sector adaptation to climate change, but water and disaster assistance programs and agricultural R&D could facilitate adaptation to climate change.