Chapter 2. Farm-Level Adjustments to Climate Change

Agricultural adaptation to climate change at the farm level depends on the technological potential (different varieties of crops, irrigation technologies); basic soil, water, and biological response; and the capability of farmers to detect climate change and undertake any necessary actions. As discussed in chapter 1, two approaches have been developed to analyze potential impacts and the ability of farmers to adapt to changing climate. The major advantage of the structural modeling approach is that it provides far more detail on the basic mechanisms of adaptation and provides the ability to integrate more directly scientific understanding of plant responses. Until recently, however, the biophysical detail of crop-response models had not been adequately linked with equally detailed models of the economic-technical options for adapting to climate change.

This chapter draws on a set of structural studies that integrate crop-response models with an economic management model. We focus on results that highlight the ability of individual farmers to adapt and respond to climate change. While it was not possible to consider results for many different farming systems at many different sites, it is possible to compare results with those of crop-response studies that do not fully consider the ability of farmers to adapt. These comparisons suggest considerable underestimation of adaptation potential in previous work. These results are sensitive to the time period over which the climate changes. Gradual climate change allows for a gradual shift in the mix of crops and to alternative farming systems (for example, a gradual trend toward a more arid and warmer climate might see the gradual introduction of a summer fallow period with spring and fall crops of shorter season grains). Gradual climate change could allow time for major infrastructure investments such as water projects and irrigation systems, transportation, and crop processing and storage systems to adapt to smaller or larger levels of production or to a different mix of crops (U.S. Congress (OTA), 1993; CAST, 1992). This chapter will answer the following questions:

- Are technological options available to U.S. farmers for adaptation to climate change? Some of the alternatives considered are adoption of later maturing cultivars, change of crop mix, and a timing shift of field operations to take advantage of longer growing seasons.
- Do studies that incorporate technology adaptations estimate smaller damages from climate change at the farm level in the United States than studies that do not allow for adaptations?

Climatic variability is a feature of current climate in most geographic areas. This variability may make it difficult for farmers to readily detect climate change and respond appropriately. Climate may also become more or less variable, or extreme climatic events may occur with more or less frequency. The second part of this chapter addresses the issue of farmer response to uncertainty.

Yield Changes of Major Crops on the U.S. Farm

Kaiser and others (1993) combine a crop-response model with a detailed structural model of the management and economic decisions farmers must make over a growing season for a site in Minnesota. Monthly temperature, precipitation, and solar radiation data are generated by a stochastic weather generator that is calibrated to produce ending values consistent with the 2xCO_2 results produced by the GISS GCM. Using the weather data, a crop-response model determines crop yields, grain moisture content, and field-time availability. Field-time availability considers whether fields have dried sufficiently in the spring to allow access of farm equipment. The three outputs from the crop model feed into an economic model that determines the optimal crop mix, scheduling of field operations, and expected net farm income. Farmers decide when to fall plow, spring plow, plant, and harvest based on expectations of four factors that are affected by the stochastic weather—field time availability, crop yields, grain drying costs, and crop prices.

Farmers' expectations are treated explicitly because farmers must make planting and other decisions before they observe the actual weather for the season. Their expectations are conditioned on the previous decade of weather simulated by the stochastic weather generator. Thus, farmers in the model are not ideally adapted to changing climate. Further, in any single year, actual weather may differ significantly from expected weather. Crop prices are determined by assuming that the crop yield on the individual farm is correlated with national crop yields and therefore the national price. Kaiser and others (1995) extend the Minnesota results to six additional regions: Georgia, Illinois, Iowa, Nebraska, North Carolina, and Ohio. Mount and Li (1994) extend Kaiser and others' (1993) integrated agronomic/economic results by developing response surfaces for yield, average production, and net returns using the integrated model for the range of temperatures and amounts of precipitation observed in the Midwest.

Sometimes, differences between research projects are only in the details, and this is the case for studies of climate change impacts on U.S. farms. On the surface, a U.S. EPA study by Rosenzweig and others (1994) is very similar to the work done at Cornell by Mount and Li, and Kaiser and others. Each study determines impacts on yields of maize, soybeans, and winter wheat for similar areas in Nebraska and Iowa. Because the weather data in the Cornell studies were slightly different than the GCM results used by other researchers, Li provided new simulations that give yield changes in his and Mount's response surface model for the same GCM results (GISS, GFDL, and UKMO) used by Rosenzweig and others (1994).[5]

Given the similarity of approaches and the use of identical climate scenarios, the percentage yield changes from Li's report and Rosenzweig and others (1994), presented in table 2.1, are surprisingly different. The only results that are reasonably similar are GFDL maize in both locations and wheat in Iowa. Differences may result from assumptions regarding soil type, crop response characteristics, and the effects of farmer adaptation.

Soil Types

Although the studies consider the same locations, they do not make the same assumption about soil type. Rosenzweig and others use a deep sandy soil with poor water-holding capacity in Nebraska, and a fine loamy mixed mesic soil with excellent water-holding capacity in Iowa. The results of Mount and Li reported here (from a model that is closely related to Kaiser and others, 1995) are based on a deep, clay soil with good water-holding capacity for both sites. Differences in soil characteristics may explain some of the yield difference in Nebraska, but not in Iowa. We would expect the poor water retention of the sandy soil in Rosenzweig and others to make the Nebraska crop more vulnerable to hot and dry weather than in Mount and Li (-31 percent vs. 14 percent for soybeans; -33 percent vs. -4 percent for wheat (UKMO)). However, since the UKMO climate scenario in Nebraska is 30-percent wetter after climate change, this factor cannot explain the pronounced difference between the percentage yield changes in table 2.1.

[5] Chapter 1 discusses these climate models in detail.

Crop-Response Models

The results shown in table 2.1 also follow from different crop models. Rosenzweig and others use the CERES-maize, CERES-wheat, and SOYGRO models validated recently by Egli and Bruening (1992) and Jones and Ritchie (1991). The GAPS model used in Kaiser and others (1993) and Mount and Li incorporates the earliest version of SOYGRO (Wilkerson and others, 1983), so any improvements made to SOYGRO are missing. GAPS itself was being refined over this time, which made soybean yields more robust under dry conditions. It is not possible to say whether GAPS or SOYGRO is a better model. The GAPS-maize (Stockle and Campbell, 1985) and the GAPS-wheat models (Stockle and Campbell, 1989) have identical owners. Differences in crop models, then, account for some of the differences between yield results.

The effect of differences in crop models may be demonstrated with Iowa soybeans. Under the GFDL scenario—a scenario that includes an almost 5-degree-Celsius temperature increase and a 36-percent decline in precipitation—Mount and Li show a 17-percent increase in yield for Iowa soybeans, while Rosenzweig and others show a 26-percent decline. In general, the results in Rosenzweig and others are far more negative than in Mount and Li. Even though some differences have been identified in the details of the crop-response models, none of these factors explain the pronounced and consistent difference in results between the studies.

Farmer Adaptation

The results in Rosenzweig and others are consistently more pessimistic than in Mount and Li because their estimated yield changes do not include farmer adaptation. Mount and Li include several adaptation alternatives, such as later maturing cultivars that permit farmers to take advantage of longer growing seasons, earlier planting dates resulting from climate change, and changes in other field operations. Farmers select specific practices to maximize profits given their expectations about future climate. Yield results presented by Rosenzweig and others assume that farmers will continue to plant the regional cultivars being planted now, implying that farmers will be unable to detect changing climate conditions even over a 50- to 80-year period. Another source of adaptation that does not directly affect crop yields, but that does affect profitability, is the mix of the three crops chosen by the farmer. The economic model in Kaiser and others (1993) and Mount and Li

Table 2.1—Major cash crops percentage yield change (1xCO_2 to 2xCO_2)[1]

State/crop	Kaiser and others (1995)/Mount & Li (1994)[2]			Rosenzweig and others (1994)		
	GISS[3]	GFDL	UKMO	GISS	GFDL	UKMO
				Percent		
Nebraska:						
Dryland maize	18	-22	19	-22	-17	-57
Dryland soybeans	24	19	14	-12	-18	-31
Dryland winter wheat	11	-3	-4	-18	-36	-33
Iowa:						
Dryland maize	22	-24	3	-21	-27	-42
Dryland soybeans	15	17	-1	-7	-26	-76
Dryland winter wheat	0	-6	-5	-4	-12	-15

[1] Results without CO_2 fertilization effect.
[2] To obtain results as comparable as possible to Rosenzweig and others (1994), a special report was generated by Li that runs the same GCM results used by Rosenzweig and others (1994) through Kaiser and others (1993) and Mount and Li's (1994) models. The results from this special report appear in this column. We are grateful to Li for generating the report and helping us to isolate the reasons for differences between the results of the studies.
[3] The acronyms in this row refer to general circulation climate model (GCM) results; Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO).
Compiled by Economic Research Service, USDA.

Table 2.2—Percentage yield change from 1xCO_2 to 2xCO_2 - dryland maize

	Kaiser and others (1995)		Rosenzweig and others (1994)		
	Warm/wet (2.5, 10)	Hot/dry (4.2, -20)	GISS	GFDL	UKMO
			Percent		
Sigourney, IA/Des Moines, IA	-12	-24	-21 (2.2, 10)	-27 (4.7, -36)	-42 (7.3, -16)
Urbana, IL/Columbia, MO	-10	-20	-28 (3.7,50)	-90 (3.8, -35)	-28 (4.8,12)
Lincoln, NE/Columbia, MO	0	-5	-28 (3.7, 50)	-90 (3.8, -35)	-28 (4.8,12)
Greenville, OH/Indianapolis, IN	-8	-16	-7 (2.2, 10)	-59 (3.8, -35)	-20 (5.5, 6)
Tifton, GA/Tallahassee, FL	-14	-28	-5 (3.1, 2)	-41 (2.8, -36)	-34 (9.2, -37)
Tarboro, NC/Lynchburg, VA	-4	-17	-58 (3, 41)	-61 (5.1, -51)	-21 (6.4, -12)

Numbers in parentheses are the change in temperature (degrees C) separated by a comma from the percent change in precipitation used in determination of percent change in yield. Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO) readings are for the crop heading month (July).
Compiled by Economic Research Service from Cooperative Agreements, USDA, ERS and Rosenzweig and others (1994).

allows for this source of adaptation not reflected in the yield figures in table 2.1.

While Rosenzweig and others (1994) do not report adaptation results, local estimates of supply shocks for different crops are developed as a basis for simulating national and global economic impacts of climate change. A set of Rosenzweig and others' (1994) results with adaptation are reported in Reilly and others (1993), but are not available for more than a few locations. Adaptation is able to reduce the yield losses, but the double-digit gains found by Mount and Li for all crops, except Iowa wheat, under at least one scenario, are still not evident. Adaptation offsets the yield losses at the most severely affected sites in Rosenzweig and others (1994), so it is surprising that the same adaptation does not lead to greater yield gains at the less severely affected sites (Reilly, 1994).

Tables 2.2-2.4 compare yield results from Kaiser and others (1995) with Rosenzweig and others (1994) for various sites. The climate scenarios differ and the sites, while generally less than 200 miles apart, are

Table 2.3—Percentage yield change from 1xCO_2 to 2xCO_2 - dryland winter wheat

	Kaiser and others (1995)		Rosenzweig and others (1994)		
	Warm/wet (2.5,10)	Hot/dry (4.2, -20)	GISS	GFDL	UKMO
			Percent		
Sigourney, IA/Des Moines, IA	3	0	-4 (2.6, 12)	-12 (3.6, 17)	-15 (6.2, 30)
Urbana, IL/Columbia, MO	-33	-23	-22 (3.5, 43)	-19 (3.4, 50)	-35 (5.7, 24)
Lincoln, NE/Columbia, MO	15	-9	-22 (3.5, 43)	-19 (3.4, 50)	-35 (5.7, 24)
Greenville, OH/Indianapolis, IN	-2	0	-3 (2.6, 12)	-6 (3.4, 50)	-16 (6, 11)
Tifton, GA/Tallahassee, FL	22	0	-56 (4.1, 4)	-80 (3.3, 42)	-100 (crop failure) (6.4, -15)
Tarboro, NC/Lynchburg, VA	6	10	-6 (4.3, 14)	-2 (3.6, 44)	-25 (6.8, 2)

Numbers in parentheses are the change in temperature (degrees C) separated by a comma from the percent change in precipitation used in determination of percent change in yield. Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO) readings are for the crop heading month (May).

Compiled by Economic Research Service, USDA from Cooperative Agreements, USDA, ERS and Rosenzweig and others (1994).

Table 2.4—Percentage yield change from 1xCO_2 to 2xCO_2 - dryland soybeans

	Kaiser and others (1995)		Rosenzweig and others (1994)		
	Warm/wet (2.5, 10)	Hot/dry (4.2, -20)	GISS	GFDL	UKMO
			Percent		
Sigourney, IA/Des Moines, IA	-10	-19	-7 (2.2, 10)	-26 (4.7, -36)	-76 (7.3, -16)
Urbana, IL/Columbia, MO	0	-20	-19 (3.7, 50)	-35 (3.8, -35)	-22 (4.8, 12)
Lincoln, NE/Columbia, MO	0	-24	-31 (4.4, -20)	-36 (4.5, 0)	-40 (4.8, 12)
Greenville, OH/Indianapolis, IN	14	-4	-12 (2.2, 10)	-37 (3.8, -35)	-43 (5.5, 6)
Tifton, GA/Macon, GA	-5	-55	-24 (3, 41)	-61 (4, -39)	-86 (9.2 -37)
Tifton, GA/Tallahassee, FL	-5	-55	-23 (3.1, 2)	-21 (2.8, -36)	-69 (9.2, -37)
Tarboro, NC/Lynchburg, VA	-3	-46	2 (3, 41)	-65 (5.1, -51)	-71 (6.4, -12)

Numbers in parentheses are the change in temperature (degrees C) separated by a comma from the percent change in precipitation used in determination of percent change in yield. Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO) readings are for the crop heading month (July).

Compiled by Economic Research Service from Cooperative Agreements, USDA, ERS and Rosenzweig and others (1994).

not identical; thus, the results are not directly comparable. Temperature and precipitation changes are presented in the tables for each GCM model at each location.

Table 2.2 repeats the pattern found in table 2.1, except for the Georgia/Florida location. Yield declines for corn in Rosenzweig and others (1994) are generally more severe than those in Kaiser and others (1995). The pattern continues for wheat and soybeans. For wheat, Illinois/Missouri is the only location showing a larger yield decline in Kaiser and others (1995) than in Rosenzweig and others (table 2.3). The Georgia/Florida location shows a 100-percent yield difference between the studies (from no effect to crop failure) and this may be due to farmer adaptation at high temperatures in the summer or because a chilling requirement (vernalization) is not part of Kaiser and others' (1995) crop model.[6] If the temperature does not fall low enough in the winter, the chilling requirement for winter wheat in the crop model in Rosenzweig and others is not satisfied, and crop failure results. For

[6] Personal communication with Susan Riha.

About the Studies

Comparison of results in tables 2.1-2.4 involves several technical modeling issues that do not depend on highly uncertain climate change estimates from global circulation models (CGM's). Scenarios are the same for both studies in table 2.1. In tables 2.2-2.4, the reader can control for the scenario by considering the changes in temperature and precipitation used in each study, given the yield changes on those tables. There are other differences in the studies that are harder to control for. The crop models are different and we cannot say which is better. The size of the yield differences that exist must to some extent be caused by differences in adaptation assumptions. As Rosenzweig and others admit, their yield change estimates would be more positive with stronger adaptation assumptions.

soybeans, locations generally show smaller yield declines in Kaiser and others (1995) than in Rosenzweig and others (table 2.4).

Kaiser and others (1995) show more moderate impacts than Rosenzweig and others (1994), with smaller negative and some positive yield changes for all three major crops. Kaiser and others (1995) include adaptation alternatives like later maturing cultivars and alteration of timing of field operations to take advantage of longer growing seasons. Kaiser and others (1993) point out that it is possible to fall plow later under a higher temperature regime, giving the crop more time in the field. Conservation tillage is a farming practice, not considered, that could be used to conserve soil moisture under a drier climate. None of the scenarios predict severe water stress, so optimistic conclusions about the possibilities for the dryland adaptation should be considered dependent on small changes in precipitation. Other adaptations, like irrigation, would become more important with larger rainfall deficits. Changes in crop mix, an adaptation to changing yields accounted for by Kaiser and others, feeds into the economic model and affects farm revenue and profitability.

All of the results presented are without the effect of CO_2 fertilization, so the comparison of results is not confounded by this effect. Although there is no consensus on the size of this effect, the yield changes would be more positive for all studies with this effect.

Additional methods of adaptation are considered in Hansen (1991), who tests whether or not there are significant yield effects associated with minor onfarm production adaptations to climate that are not captured in crop growth models. Using a statistical approach, and regression analysis and field-level data from 10 major corn-producing States, Hansen estimates a corn yield function. The model's regressors include six variables that reflect longrun average July temperature and precipitation levels (these capture longrun average climate effects on yields); six variables that reflect actual July temperatures and precipitation levels (these capture weather pattern effects on yields); and adaptation variables for tillage practice, irrigation, nitrogen use, planting date, seeding rate, soil erodibility, and soil loss tolerance.

Minor farm-level adaptations currently available to farmers are significant at the 99-percent level for all but tillage practice, which is significant at 95 percent. By showing the significance of these adaptations, Hansen highlights the importance of routine farm practices in adjustment to climate change. Assuming climate change takes the form of a 6.5-degree F increase in average July temperatures, Hansen estimates that corn yields would increase 43.8 percent where this variable is now 67.0 degrees F; yields would decrease 5.0, 38.7, and 69.6 percent where average July temperatures are now 70.0, 73.5, and 76.5 degrees F, respectively. A half-inch increase in average July precipitation increases corn yields between 1.1 percent and 10.7 percent, depending on current precipitation levels.

Hansen's results indicate that the Corn Belt could be particularly hard hit by climate change. Since average July temperatures in much of this area are at least 73.5 degrees F, Hansen's results imply that decreases in corn yields of at least 38 percent would be relatively common (that is, assuming a 6.5-degree F increase in average July temperatures). It may be possible in the future to assess the relative efficacy of these minor adaptations on corn and other crops, along with other adaptation alternatives like those considered by Kaiser and others.

Response models have also been used to assess potential impacts of climate change on U.S. livestock production. For summer months, studies tend to agree that in warmer areas, such as the South, climate change would hurt livestock; effects include reductions in animal weight gain, dairy output, and feed conversion efficiency (Hahn and others, 1990; Klinedinst and others, 1993; Baker and others, 1993). In cooler regions, impacts would be mixed; increased forage would improve grazing but capital-intensive operations, like dairy, would be hurt (Klinedinst and others; Baker and others). For fall and winter months, climate change is predicted to benefit livestock in all regions due to reduced feed requirements, increased survival of young, and lower energy costs.

The role of management and the potential for adaptation are also key in assessing the impact of climate change on livestock operations (Hahn and others; Baker and others; Klinedinst and others). The growth of dairy in the South is a testament to the creativity of farmers in finding ways to cool animals in hot climates (for example, shading, wetting, circulating air, and air conditioning). Other adaptations include herd reduction in dry years, shifting to heat-resistant breeds (for example, Brahman cattle), and replacing cattle with sheep.[7]

There are additional crop adaptations that have not been considered, like the development of new seed varieties that profit from longer growing seasons, the development of entire new crops, and other technological adaptations. Reilly (1995) finds that taking advantage of these additional adaptations involves significant time lags and long-term capital investment decisions, but including them could further reduce the negative impacts of climate change on crops.

The Capability To Adapt in Developing Countries

How the United States fares under climate change depends on the production impacts in the United States *relative* to those abroad. The capability of technologically advanced agricultural systems like those in the United States to adapt is thought to outstrip this ability in poorer developing countries. We focus on a single developing country to assess the potential for adaptation to climate change in Africa.

Jolly and others (1995) and Olowolayemo and others (1995) find that agricultural production in Senegal must be well planned and executed to avoid serious shortfalls from subsistence levels under climate change. Two of the country's three agricultural regions are expected to be self-sufficient, with one region producing three crops every year under irrigation, and the economy shifting from cash crops like cotton and peanuts (groundnuts) to maize, with the elimination of food imports. (Senegal presently imports over half of its food requirements, mostly rice.) Any surplus from two of the regions is expected to meet the shortfall in the third, mainly livestock, zone. The margin for error and uncertainty in the analysis is not discussed, but it is clear that few of the adaptation alternatives available to farmers in the Midwest are open to their counterparts in Senegal because of rainfall deficits.

Most production of crops is subsistence-level, with 75 percent of the population living in rural areas that rely on traditional or nonmechanized farming practices as their main source of income. The Government, with the aid of international organizations, has made substantial investments in agriculture over the last 30 years. During that time period, rainfall has declined at all Senegalese reporting stations, as it has across the Sudano-Sahelian region, and per-hectare production of food has fallen to almost half the level of the early 1960's. Over the last 50 years, the population of Senegal has more than doubled, with average per capita food production following per-hectare production. The studies conclude that Senegalese farmers should adapt by shifting from a cash to a staple system, requiring long-term and expensive investments in irrigation.

Uncertainty in Climate Change Impacts

Estimates of the effects of possible climate change on farm yields, much like annual estimates of farm productivity or estimates of the effects of an ongoing drought or flood, are uncertain (Schimmelpfennig, 1996). All farmers have a level of risk aversion, or willingness to bear risk. If climate uncertainty grows and the climate changes, this level of risk aversion may become very important. Yohe (1992), for example, demonstrates that if risk aversion is high, farmers may shift production from corn to sorghum, a more drought-tolerant crop, even though average corn returns are still higher under the new climate. Yohe's analysis highlights that farmers should not be expected to exhibit the same behavior after climate change that they do now. The farming system selects out farmers who are unwilling or unable to adapt to changing conditions by making those who do adapt more profitable. But how will the system respond to climate change?

It is because farmers are exposed to a significant degree of uncertainty in crop prices that hedging strategies, taking advantage of futures markets, have become a standard practice in the United States. The uncertainty of climate change, while not quantified, adds to the uncertainty that farmers and commodity markets routinely internalize. Existing markets for pooling price risk will expand and become even more

[7] Hahn (1994) reports, for example, that the upper end of the optimal temperature zone for growing ad-lib-fed lambs is 2-3 degrees C higher than that for growing ad-lib-fed feeder calves.

widely used, especially if farm support programs and crop insurance continue to be cut back.

Another way to help farmers adapt to increased risk is to improve the information they receive. Schimmelpfennig and Yohe (1994) have developed an index of crop vulnerability to changes in the distribution of weather variables. With investments in research to expand the locations covered by the index, and education and training through extension services, farmers may use the index to signal appropriate times to switch from usual practices.

The following are incremental risks from a changing climate that farmers and farm markets will need to account for:

- **Extreme event risks**—If the average temperature rises, the climate may foster more extreme weather events, even though the spread or variability of the temperature distribution itself may not increase. Although there is very little evidence whether the variability of temperature will increase or decrease, an increase in temperature variance has the same effect without an increase in the mean. Both together compound the probability of extreme-temperature events.

- **Field-time availability risks**—More extreme precipitation events, both wet and dry, affect the timing of field operations. Extremely wet weather in the spring, as experienced by midwestern farmers in 1995, delays planting, possibly causing corn farmers to switch to soybeans. Dry weather late in the season reduces crop drying costs.

- **Yield risks**—When temperature and precipitation are too high or low, crop yields suffer. For example, 1988 was so dry that 30 percent of the anticipated corn harvest did not materialize, and California recently began to recover from a 7-year drought. It is difficult to forecast these events, but decisions concerning when to employ adaptation alternatives can be supported by the best available information.

- **Interactions between risk factors**—All of these risks are interrelated. Increased climate variability affects field-time availability, which in turn influences yield.

Farm-Level Adjustments Policy Summary

Many options currently available to U.S. farmers would facilitate adaptation to climate change. These include adoption of later maturing cultivars, change of crop mix, and shifting the timing of field operations to take advantage of longer growing seasons. Planning is essential, because significant time lags often accompany the strongest form of these adaptations.

When farm-level adaptations and responses to uncertainty are included in the analysis, the impact of climate change on U.S. producers can be neutral or positive. These impacts are assumed to occur gradually over long periods of time, allowing adaptations in both practices and institutions. Regional effects can be negative, offset by positive effects in other areas. Developing countries are exposed to greater negative impacts than the United States because developing countries have fewer adaptation alternatives available to them, experience larger population growth, and have smaller income growth to fall back on.

It will be important to design policies that encourage adaptation. If farmers implement appropriate adaptations, the impact of climate change on U.S. agriculture can be a matter of reallocating farming resources to different regions. This topic will be discussed again in the next chapter when the U.S. farming system as a whole and farm programs are considered. Policies also need to foster the development of markets that allow farmers to hedge their risks as they respond to climate's inherent uncertainty–uncertainty that may be growing as climate changes.