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World Agriculture and Climate Change

Economic Adaptations

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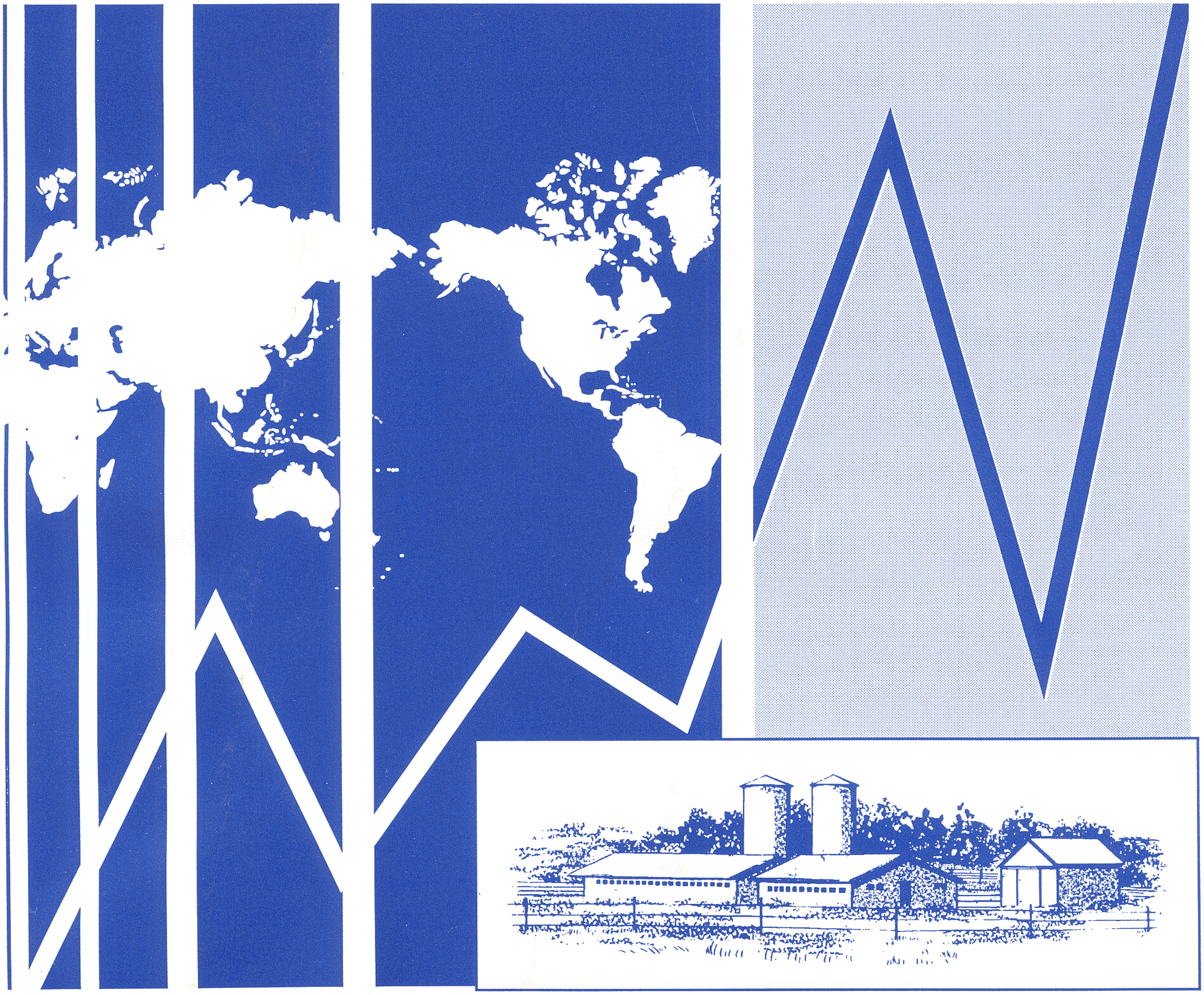

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Abstract

Recent studies suggest that possible global increases in temperature and changes in precipitation patterns during the next century will affect world agriculture. Because of the ability of farmers to adapt , however, these changes are not likely to imperil world food production. Nevertheless, world production of all goods and services may decline, if climate change is severe enough or if cropland expansion is hindered. Impacts are not equally distributed around the world. Agricultural production may increase in arctic and alpine areas, but decrease in tropical and some other areas. In the United States, soil moisture losses may reduce agricultural production in the Corn Belt and Southeast.

Keywords: Climate change, world agriculture

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Summary

Possible changes in climate may spur geographic shifts in agricultural production and structure, but should not significantly affect the level of U.S. and world food production. We evaluate the effects of global climate change on world agriculture with a model that links climatic conditions to land and water resources and to production, trade, and consumption of 13 commodities throughout the world. The model has three unique capabilities. First, it simulates the potential effects of global climate change on the availability and productivity of agriculturally suitable land. Second, it determines the extent to which farmers respond to climate change, such as by adopting alternative production systems and by expanding (or abandoning) agricultural lands. Third, it provides quantitative estimates of land and water use changes, because it simulates the competition between agriculture and the rest of the economy for these resources.

We evaluated four global-climate-change scenarios based on a doubling of atmospheric concentrations of carbon dioxide. These scenarios were derived from results projected by meteorological models at the Goddard Institute for Space Studies, the Geophysical Fluid Dynamics Laboratory, the United Kingdom Meteorological Office, and Oregon State University and embody a range of average global temperature and precipitation changes (2.8-5.2°C and 7.8-15.0 percent, respectively). Our principal results are:

(1) Global changes in temperature and precipitation patterns during the next century are not likely to imperil food production for the world as a whole. Although world production of nongrain crops is likely to decline (0.2-1.3 percent), production of wheat is likely to increase (0.5-3.3 percent) as well as livestock (0.7-0.9 percent). Changes in world production of other grains range from -0.1 to 0.4 percent, increasing in three scenarios. World production of processed foods, which is the primary source of food for households, would rise (0.2-0.4 percent).

(2) Farmer adaptations are the main mechanisms for keeping up world food production under global climate change. By selecting the most profitable mix of inputs and outputs on existing cropland, for example, farmers may be able to offset from 79 to 88 percent of the 19- to 30-percent reductions in world cereals (wheat plus other grains) supply directly attributable to climate change. Including adjustments in domestic markets and international trade (but still holding cropland fixed) mitigates more than 97 percent of the original negative impacts. Farmers also are likely to adapt by increasing the amount of land under cultivation (up 7.1-14.8 percent). This enables world cereals production to actually increase (0.2-1.2 percent) under climate change.

(3) Costs and benefits of global climate change are not equally distributed around the world. Warming in arctic and mountainous areas will increase the quantity of land suitable for farming and forestry, but warming in tropical and some other areas will reduce soil moisture, thereby causing decreases in farm and forestry productivity. These changes affect commodity production. In Canada, for example, output of wheat, other grains, nongrains, livestock, and forest products increases, while in Southeast Asia, output of these commodities generally decreases in all scenarios. Impacts on commodity production in mid-latitude regions are mixed. Real gross domestic product (GDP) tends to mirror agricultural and silvicultural activity. GDP in high-latitude regions, like Canada, increases under climate change, while GDP in tropical areas, like Southeast Asia, declines. Impacts on GDP in mid-latitudes vary by region, sometimes consistently increasing (Japan, other East Asia) or decreasing (European Community) across all climate change scenarios, and sometimes varying by scenario (the United States and a combined Australia and New Zealand region).

(4) Climate change is likely to affect the overall structure of agriculture and food processing in the United States. Land suitable for farming and forestry is likely to increase, but soil moisture losses may reduce agricultural possibilities in the Corn Belt and in the Southeast. Farmers are likely to adapt by increasing wheat production and reducing production of other grains, primarily maize. As a result of less feed available, livestock production also decreases. Output of nongrains and forest products increases or decreases depending on the scenario. Production of processed food commodities generally declines. U.S. shares of world production move in the same direction as changes in production. Across scenarios, effects on GDP range from -0.1 to 0.1 percent annually (in 1990 dollars, from -$4.8 billion to $5.8 billion).

(5) World GDP may decline if climate change is severe enough or if cropland expansion is hindered. Across the four climate change scenarios, net annual impacts on world GDP range from -0.1 to 0.1 percent (in 1990 dollars, from -US$24.5 billion to US$25.2 billion). These results indicate that world GDP may decline if increases in agricultural and food production are more than offset by losses in other sectors. Also, when land use is constrained to 1990 activities, world GDP declines by 0.004 to 0.35 percent annually (in 1990 dollars, from US$0.7 billion to US$74.3 billion). World output of processed food declines as well (from 0.002 to 0.58 percent). This implies that the new temperature and precipitation patterns under climate change are likely to reduce the average productivity of the world's existing agricultural lands.

(6) Land use changes that accompany climate-induced shifts in cropland and permanent pasture are likely to raise additional social and environmental issues. Although there are net increases in cropland for the world as a whole, from 4.2 to 10.5 percent of existing cropland is converted to other uses under the climate change scenarios. In the United States, from 8.6 to 19.1 percent of existing cropland is converted. Farm communities in areas where the only economically viable adaptation is to abandon crop production could be severely disrupted. Also, forest land is likely to decrease under global climate change (3.6-9.1 percent, net). This could cause more conflicts over the environmental consequences of agriculture in some areas. In tropical regions, for example, competition from crop production could aggravate direct climate-induced losses of tropical rain forests.

(7) Although water supplies are likely to increase for the world as a whole under climate change, shortages could occur in some regions. Across scenarios, world water supplies increase by 6.4 to 12.4 percent. In Japan, however, changes in water supplies range from -9.4 to 10.2 percent. In addition, the price of water in Japan increases by more than 75 percent in all scenarios. These results indicate likely conflicts over water in Japan. In the United States, the price of water increases in only one climate change scenario when farmers are allowed to fully adapt. If land use in the United States is constrained to 1990 activities, however, then water prices increase in all scenarios. This indicates that conflicts over water resources might increase in the United States.

A number of caveats and limitations remain. First, we do not consider the well-documented, beneficial effects of higher concentrations of atmospheric carbon dioxide on plant growth and water use. There remains considerable debate about the magnitude of this effect. Second, our simulations of water resources do not capture all potential impacts. The potential effects of too much water, such as flooding or water logging of soils, for example, are not evaluated. Finally, changes in socioeconomic conditions which might take place by the time climate changes occur were not considered.

World Agriculture and Climate Change

Economic Adaptations

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Introduction

Many studies project that Earth's climate will warm by 1.5 to 5.0°C during the next century (Manabe and Wetherald, 1987; Wilson and Mitchell, 1987; Hansen and others, 1988; and Schlesinger and Zhao, 1989). A substantial portion of this warming may occur even if global efforts are undertaken to reduce emissions of heat-trapping gases. Estimates of the economic and ecological effects of this warming and associated shifts in precipitation patterns are needed by policymakers to determine how much to control emissions and how best to adapt to unavoidable climate changes.

The agricultural consequences of these climate changes are twofold. First, climate change may affect crop and livestock productivity.[1] Second, ensuing economic responses may alter the regional distribution and intensity of farming. This means that, for some regions, (1) the long-term productivity and competitiveness of agriculture may be at risk, (2) farm communities could be disrupted, and (3) conflicts over environmental impacts of agriculture on land and water resources could become increasingly contentious.

A substantial amount of research has been conducted on the potential effects of climate change on agricultural productivity (especially crop yields). A few studies have used climate-induced changes in crop yields to estimate global economic impacts. These global studies, however, have generally failed to consider that climate change would affect the availability of agriculturally suitable land, that economic factors drive farm-level adaptations, and that farmers must compete with other economic agents for land and water resources.

This research effort is unique in that it directly links detailed climate projections with distributions of land and water resources. These distributions are then integrated within a global economic model that accounts for all market-based activity. This approach enables us to simulate how climate change might affect water supplies and the availability of agriculturally suitable land, and to analyze how these impacts might affect total world production of goods and services.

This effort is also unique in that it simulates the economics of how farmers respond to climate change (such as by adopting alternative production systems or expanding/abandoning agricultural land). Such a simulation reflects the fact that farmers are likely to consider the economic viability of their responses to climate-induced changes in yield, and it avoids the arbitrariness associated with projections of farmer responses that do not explicitly consider economic variables.

Finally, this effort is unique in that impacts in the major resource-using sectors (crops, livestock, and forestry) are estimated simultaneously. Crop, livestock, and forestry sectors often compete for land resources. Separate estimates of the land demanded by these sectors may implicitly lead to some land being counted twice, allowing the effects of climate change in these sectors to be underestimated. Treating land demands explicitly and simultaneously avoids such problems and enables one to provide quantitative estimates of land use changes. The combination of these unique features leads to the most comprehensive and economically consistent projections to date of how climate change might alter the location and intensity of farming.

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[1] In this report. climate change refers to an overall trend toward global warming and increased precipitation amounts.

Previous Research

Since the late 1970's, the literature addressing agricultural impacts of climate change has evolved from "expert opinion" surveys to dynamic multiregion, multisector economic models. Among the first major efforts to assess potential impacts of climate change on agriculture was that undertaken by the National Defense University (NDU) (1978). This study assembled an international group of climate experts and elicited their opinions concerning the probabilities of various climate change events and the resulting impacts on agriculture. NDU's most consistent finding was that the experts disagreed on most matters related to climate change,

Crop Production Studies

In the early and mid-1980's, research focused on the direct effects of climate change on crop production. Two complementary approaches were developed. The "analogous region" approach looked at potential shifts in climatic zones favorable to particular crops. These studies generally concluded that projected climate change would significantly alter regional patterns of crop production. Newman (1980), for example, estimated that the U.S. Corn Belt would shift 175 km north-northeast for every 1°C rise in temperature. Blasing and Solomon (1982) concluded that the U.S. Corn Belt would contract. particularly in its southwest region, under warmer and drier growing seasons. Rosenzweig (1985) found that climate change could greatly expand winter wheat production in Canada: while in the United States, the major effect would be regional shifts in the use of wheat cultivars.

More recently, Carter. Porter, and Parry (1991) used a geographic information system (GIS) to look at shifts in production of grain maize, sunflower, and soybeans in Europe. Eswaran and Van den Berg (1992), using a GIS-derived index of agricultural production based on length of growing season, analyzed the impacts of climate change on grain production and grazing in India, Pakistan. and Afghanistan. Leemans and Solomon (1993) used similar methods to match crop production with climate conditions globally. Both Carter, Porter, and Parry (1991) and Leemans and Solomon (1993) concluded that climate change could induce large spatial shifts in crop production patterns and that high-latitude regions would likely benefit as large areas become suitable to crops.

The second approach to estimating the effect of global climate change on agriculture was based on crop-growth models.[2] These mathematical models are intuitively appealing for analyzing the effects of change on crop yields because they incorporate daily data on temperature, precipitation, solar radiation, and (often) atmospheric carbon dioxide, as well as data on soils and management practices in their simulations of plant development. Earlier works (Warrick, 1984; and Terjung. Liverman, and Hayes, 1984) considered warmer temperatures and/or drier growing seasons and generally concluded that climate change would cause crop yields to decline. Later studies (Robertson and others, 1987; Ritchie, Baer, and Chou, 1989; and Peart and others, 1989) supported this result but found that many decreases in yield would be largely offset by positive impacts on plant growth associated with higher levels of atmospheric carbon dioxide.[3]

Livestock Production Studies

A relatively new line of research has started to analyze potential impacts of climate change on livestock. Virtually all examine current production practices given one or more specific climate change scenarios. A few studies also draw on the "analogous regions" framework to assess how likely farm-level adaptations might mitigate any negative impacts.

Results are consistent across studies. Studies tend to agree that, because of decreases in feed conversion efficiency, global climate change would reduce animal weight gains and dairy output during the summer months in relatively warm areas, such as the Southern United States (Hahn, Klinedinst, and Wilhite, 1990; Klinedinst and others, 1993; Baker and others, 1993). In relatively cool areas, grazed livestock generally do better (due to increased forage), but more capital-intensive operations, like dairy, are negatively affected (Parry, Carter, and Konijn, 1988; Klinedinst and others, 1993; Baker and others, 1993). The studies also speculate that reduced feed requirements, increased survival of young, and lower energy costs may benefit livestock in all regions during fall and winter. On the down side, a number of livestock diseases are likely to expand their ranges under global warming (Stem, 1988; U.S. Environmental Protection Agency, 1989).

Management techniques for adapting livestock operations to climate change are not formally analyzed but

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[2] Commonly cited crop-growth models are CERES (wheat, maize, and rice), EPIC (wheat, maize, and sorghum), GAPS (maize and sorghum). and SOYGRO (soybeans).

[3] Increases in atmospheric concentrations of carbon dioxide would probably act like a fertilizer for some plants and improve water-use efficiency for others (Intergovernmental Panel on Climate Change, 1990).

are generally assumed to be significant (Hahn, Klinedinst, and Wilhite, 1990; Klinedinst and others, 1993; Baker and others, 1993). Several relatively inexpensive technologies for cooling animals in hot climates (shading, wetting, increasing air circulation, and air conditioning), have contributed to the growth of dairy production in the Southwestern and Southeastern United States. Herd reduction during dry years is a key management technique in regions subject to frequent droughts, where livestock are often more resistant to severe weather events than crops and are, therefore, a better hedge for income protection and food security (Abel and Levin, 1981).

Other climate-induced responses include adopting new breeds or substituting species. Where warming is moderate, for example, Brahman cattle and Brahman crosses, which are more heat- and insect-resistant than breeds now dominant in Texas and southern Europe, might be adopted. In cases of extreme warming, sheep might substitute for cattle (Hahn, Klinedinst, and Wilhite, 1990; Klinedinst and others, 1993; Baker and others, 1993; and personal communications with B. Baker and G. Hahn).

Regional Economic Studies

The crop production studies discussed above did not consider farmers' responses to changing climate conditions. Without these responses, little could be concluded about likely effects on commodity markets. Crop-growth models became important in economic modeling, however, because yield effects were easy to incorporate into available economic models. The first research in this vein looked at farm-sector responses to specified climate change scenarios. In a series of case studies, Parry, Carter, and Konijn (1988) found that, for areas in Saskatchewan (Canada), Iceland, Finland, the former Soviet Union, and Japan, many negative impacts of climate change could be reduced by switching crop varieties, applying fertilizer differently, and/or improving soil drainage. They also found that projected climate change led to increased commodity production and farm income in some regions.

Subsequent country/region studies expanded economic analysis of climate change and agriculture to include more farm-level adaptations, input and output substitutions, effects on commodity prices, and impacts on welfare (see Adams and others, 1988; Arthur and Abizadeh, 1988; Adams and others, 1990; and Mooney and Arthur, 1990). Adams and others (1990), for example, focused on U.S. agriculture and climate-induced shifts in output mixes, input use, and welfare. Their model included 64 producing regions, 10 input (land, labor, and water) supply regions, and 1,683 possible output mixes for maize, wheat, soybeans, cotton, barley, sorghum, rice, alfalfa, and/or livestock. The inclusion of water stocks as a climate-dependent input was a major strength of the study. Water increases heat tolerance in many crops, so water availability is a key variable in assessing how climate change might affect agriculture.

Bowes and Crosson (1991) looked at the Missouri, Iowa, Nebraska, and Kansas (MINK) region under warmer and drier growing conditions (the conditions that prevailed in the 1930's) assuming zero, marginal, and significant levels of farm-level adaptation. More important, they considered how impacts in the agricultural, water, and forestry sectors would be transmitted to the MINK area's general economy. First, actions embodied in each adaptation scenario were incorporated into crop-growth models and simulations were run for 48 "typical" farms. Next, farm results were averaged and scaled up to obtain regional yield effects. Impacts for the total MINK economy were then estimated by converting regional yields to farm revenues and feeding these values into an input-output model. Bowes and Crosson (1991) found that a climate like that of the 1930's would likely reduce agricultural production in the MINK area by 0.3 to 1.4 percent (10 percent under a worst-case scenario). Because the climate-impacted sectors' share of the regional economy was small, total economic impacts were negligible in all scenarios.

Single country/region studies provided first estimates of how climate change might affect agricultural markets and input use. Results generally indicated small to modest reductions in crop output but net gains in producer welfare once adaptation, higher crop prices, and/or carbon dioxide effects on crop growth were accounted for (Adams and others, 1988; Arthur and Abizadeh, 1988; Adams and others, 1990; and Mooney and Arthur, 1990). Consumers and society usually fared somewhat worse under climate change, but not always. In Adams and others (1990), for example, economic impacts of climate change ranged from losses of $10.33 billion to gains of $10.89 billion per year for the United States, depending on the scenario. They concluded that climate change would not jeopardize U.S. agriculture's ability to meet domestic food needs but may shift domestic crop production patterns and (perhaps) reduce the role of U.S. producers in some world markets. More concern was expressed for natural ecosystems because of increased demands for irrigation water.

Global Economic Studies

Two important limitations of country/region studies are that they do not consider (1) effects of climate change in other regions (they assume climate outside the study area is constant) or (2) the role of world trade in dissipating effects across regions. As Reilly (1994) points out, such omissions are valid only when climate change occurs entirely within a country/region or under the assumption of a closed economy.

Recently, several studies have considered global impacts using agricultural market models (Kane, Reilly, and Tobey, 1991) or general equilibrium models (Rosenzweig and Parry, 1994). Kane, Reilly. and Tobey (1991) modeled world agriculture in a partial equilibrium framework using 13 regions and 20 commodities. Trade through global commodity markets linked the regions. The study's key finding was that, while climate change may significantly reduce crop yields in some regions, trade adjusts global patterns of production and consumption such that national and world economic impacts are small. Reported percentage changes in world gross domestic product ranged from -0.17 to 0.09 percent. For a "moderate impacts" scenario, world gross domestic product would increase by 0.01 percent.[4]

Rosenzweig and Parry (1994) examined the effects of climate change on world cereal production and the distribution of these impacts among developed and developing countries in the year 2060.[5] Their analytical framework is the Basic Link System (BLS) (Fischer and others, 1988), a set of 34 country/region models that interact through financial flows and trade. One commodity, "nonagriculture," links agriculture to the rest of the economy through competition for labor and capital inputs. Results are reported for climate change scenarios based on (1) temperature and precipitation changes only, (2) changes in temperature and precipitation plus increased crop growth due to greater concentrations of atmospheric carbon dioxide, (3) the former combined with farm-level adaptations (level 1 adaptations), and (4) the former combined with more extensive adaptations (level 2 adaptations). Level I adaptations include shifting planting dates by I month or less, using additional water on crops already irrigated, and switching to readily available crop varieties more suitable to the altered climate. Level 2 adaptations include shifting planting dates by more than 1 month, applying more fertilizer, installing new irrigation systems, and switching to new crop varieties specifically developed in response to the altered climate.[6] Without farm--level adaptations (but with carbon dioxide effects), Rosenzweig and Parry (1994) report decreases in world cereal production ranging from 1 to 8 percent. World cereal prices increase by 24 to 145 percent. Including farm-level adaptations helps to mitigate these impacts; changes in world cereal production ranged from -2.5 to 1 percent, while changes in the world cereal price ranged from -5 to 3.5 percent. Their results also suggest potential disparities in climate change impacts among developed and developing countries. Under the level 1 adaptation scenario, cereal production in developed countries increases 4 to 14 percent while production in developing areas falls 9 to 12 percent.

In summary, since the late 1970's, analysis of agriculture under climate change has evolved to include (1) a global perspective on the agricultural impacts of climate change and (2) adaptive responses at either the local or international levels. However, using changes in crop yields to simulate climate change has a number of limitations. First, because of the focus on crop production, impacts on other sectors have been partially or completely ignored. Global studies that include livestock, for example, limit their scope to impacts on grain-fed livestock; impacts on range-fed livestock have not been considered. Global studies that jointly consider crop, livestock, and forest products also have not been done. Under these circumstances, impacts of climate change would be underestimated. Second, only a few crops-wheat, maize, rice, and soybeans— have been modeled extensively. The validity of extrapolating yield effects from these models to other crops depends on the extent to which modeled growth processes reflect unmodeled crops.

Other limitations pertain to farmer adaptation. First, using yield changes to simulate how farmers around the world are likely to revise their production practices in response to climate change is a time-consuming, cumbersome, and somewhat arbitrary process. A near infinite number of potential adaptive responses (can be propagated with crop-growth models. The responses actually selected by farmers, however, will depend on whether they are economically viable. Second, climate-induced impacts on the availability of water and the distribution of agriculturally suitable land have been

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[4] This scenario was based on early research undertaken by Working Group 2 of the Intergovernmental Panel on Climate Change (Parry 1990).

[5] Some rebuilt discussed here are also in Rosenzweig and others (1993). Related work appears in Reilly, Hohmann, and Kane (1993).

[6] BLS has some dynamic economic adjustments related to agriculture, such as changes in agricultural investment (including reclamation of additional arable land) and reallocation of agricultural resources (including crop switching and fertilization) according to economic returns. However, BLS's regional stocks of potential arable land were not adjusted by Rosenzweig and others (1993) to reflect the altered temperature and precipitation patterns implicit in their climate change scenarios.

omitted from previous global studies. Hence, two major adaptive mechanisms have been neglected-using more abundant water resources for irrigation or expanding into new agriculturally suitable areas. Our approach was developed to address these limitations.

Procedures

The methodology employed in this research assumes that: (1) changes in climate will directly affect land and water resources and (2) changes in land and water resources will affect economic activity. The economic insight embodied in this approach is that climate change would affect production possibilities associated with land and water resources throughout the world, and the resultant shifts in regional production possibilities would alter current patterns of world agricultural output and trade.[7] By explicitly incorporating land and water resources, our framework enables us to simulate how climate change affects the availability of agriculturally suitable land and to allow economic factors to determine the nature and extent of adaptive responses to climate change by farmers.

Modeling Framework

The framework used in our research is embedded in the Future Agricultural Resources Model (FARM) (fig. 1). FARM is composed of a geographic information system (GIS) and a computable general equilibrium (CGE) economic model. The GIS links climate with production possibilities in eight regions (table 1). The CGE model determines how changes in production possibilities affect production, trade, and consumption of 13 commodities.

Environmental Framework

Climate, which is defined in terms of mean monthly temperature and precipitation, affects production possibilities by determining a region's length of growing season and its water runoff. Length of growing season is defined as the longest continuous period of time in a year that soil temperature and moisture conditions support plant growth. Growing season length is the primary constraint to crop choice and crop productivity within a region. Water runoff is that portion of annual precipitation that is not evapotranspirated back to the atmosphere.[8] Runoff limits a region's water supply, thereby constraining its ability to irrigate crops, generate hydropower, and provide drinking water.

Growing season lengths are provided in FARM's GIS. The GIS can be thought of as a grid overlaid on a map of the world. Grid cells have a spatial resolution of 0.5° latitude and longitude (360 rows by 720 columns) and contain information from various global data bases on climate and current land use and cover. Two data sets on growing season lengths are derived from current climatic conditions.[9] One data set is computed from Leemans and Cramer's (199 1) monthly temperature and precipitation data using Newhall's (1980) method. The other data set is derived from monthly temperature data only and is used to determine length of growing seasons on irrigated lands.

For any GIS grid cell, growing season length can range from 0 to 365 days. To obtain a broader picture of the distribution of growing conditions around the world, we divide the world's land into six classes (table 2). A region's distribution of land classes is a major determinant of its agricultural and silvicultural possibilities. Current distributions of land classes are presented pictorially in figure 2 and numerically in table 3.

Land Classes (LC's) 1 and 2 have growing seasons of 100 days or less. LC 1 occurs where cold temperatures limit growing seasons-mainly arctic and alpine areas. High-latitude regions (such as Canada and the former Soviet Union) contain 79.3 percent of the world's stock of LC 1. LC 2 occurs where growing seasons are limited by low precipitation levels—mostly deserts and semidesert shrublands and grasslands. Africa, Latin America, and western Asia contain 56.1 percent of the world's stock of LC 2. Crop production on LC 1 and rain-fed LC 2 is marginal and restricted to areas where growing seasons approach 100 days. LC 1 and 2 (without irrigation) are limited to one crop per year. Only 1 percent of LC 1 is cropland. LC 2, however, is an important crop-producing land class where irrigation extends growing seasons. Almost half of the world's land is either LC 1 or 2. Without irrigation then, 50 percent of the world's land is, at best, marginal for crop production due to cold temperatures and/or limited precipitation.

LC's 3, 4, and 5 are important agriculturally, especially in high-latitude (LC 3 and LC 4) and mid-latitude (LC 4 and LC 5) regions. LC 3 has growing seasons of 101-165 days; principal crops are wheat, other short-season grains, and forage. LC 3 is limited to one crop per year.

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[7] The economic principles behind our approach are demonstrated in Darwin and others (1994).

[8] Evapotranspiration is the removal of water from soil by evaporation from the surface and by transpiration from plants growing thereon.

[9] Growing season lengths were provided by the World Soil Resources Office of USDA's Natural Resources Conservation Service.

Figure 1
FARM modeling framework

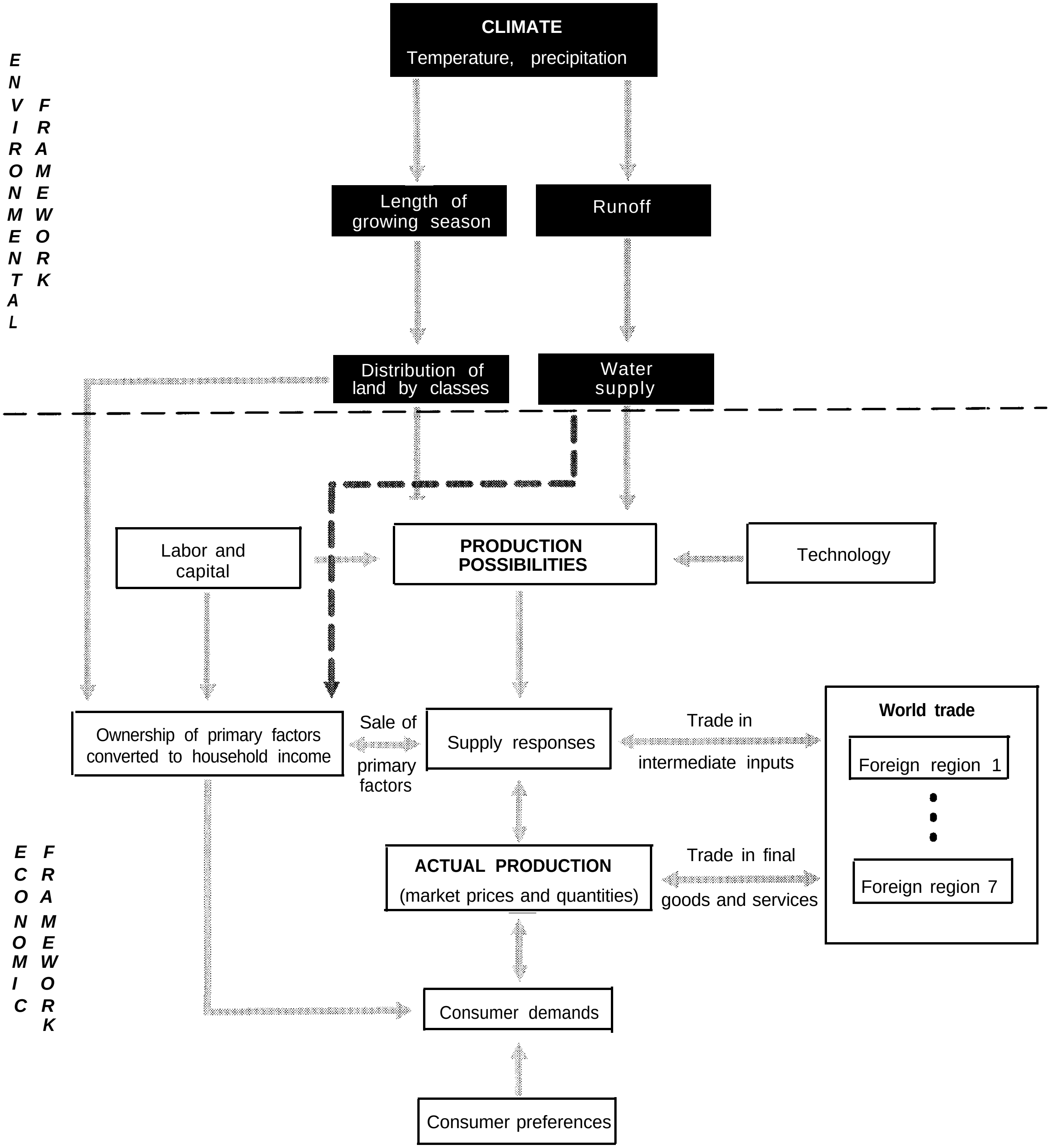


Table 1—Regions, sectors, and commodities in FARM

Item	World product
	Percent of total dollar value
Regions[1]	100.0
United States	22.2
Australia and New Zealand	1.6
Canada	2.7
Japan	14.8
Other East Asia:	
China, Hong Kong, Taiwan, and South Korea	4.2
Southeast Asia:	
Thailand, Indonesia, Philippines, and Malaysia	1.4
European Community:	
Belgium, Denmark, Federal Republic of Germany, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and United Kingdom	25.3
Rest of world	27.7
Sectors/commodities	88.1[2]
Crops[3]	2.5
Wheat	0.2
Other grains	0.9
Nongrain crops	1.4
Livestock	1.4
Forestry	0.4
Coal, oil, and gas	2.0
Other minerals	1.2
Fish, meat, and milk	1.8
Other processed foods	4.1
Textiles, clothing, and footwear	2.6
Other nonmetallic manufactures	11.8
Other manufactures	13.3
Services	47.0

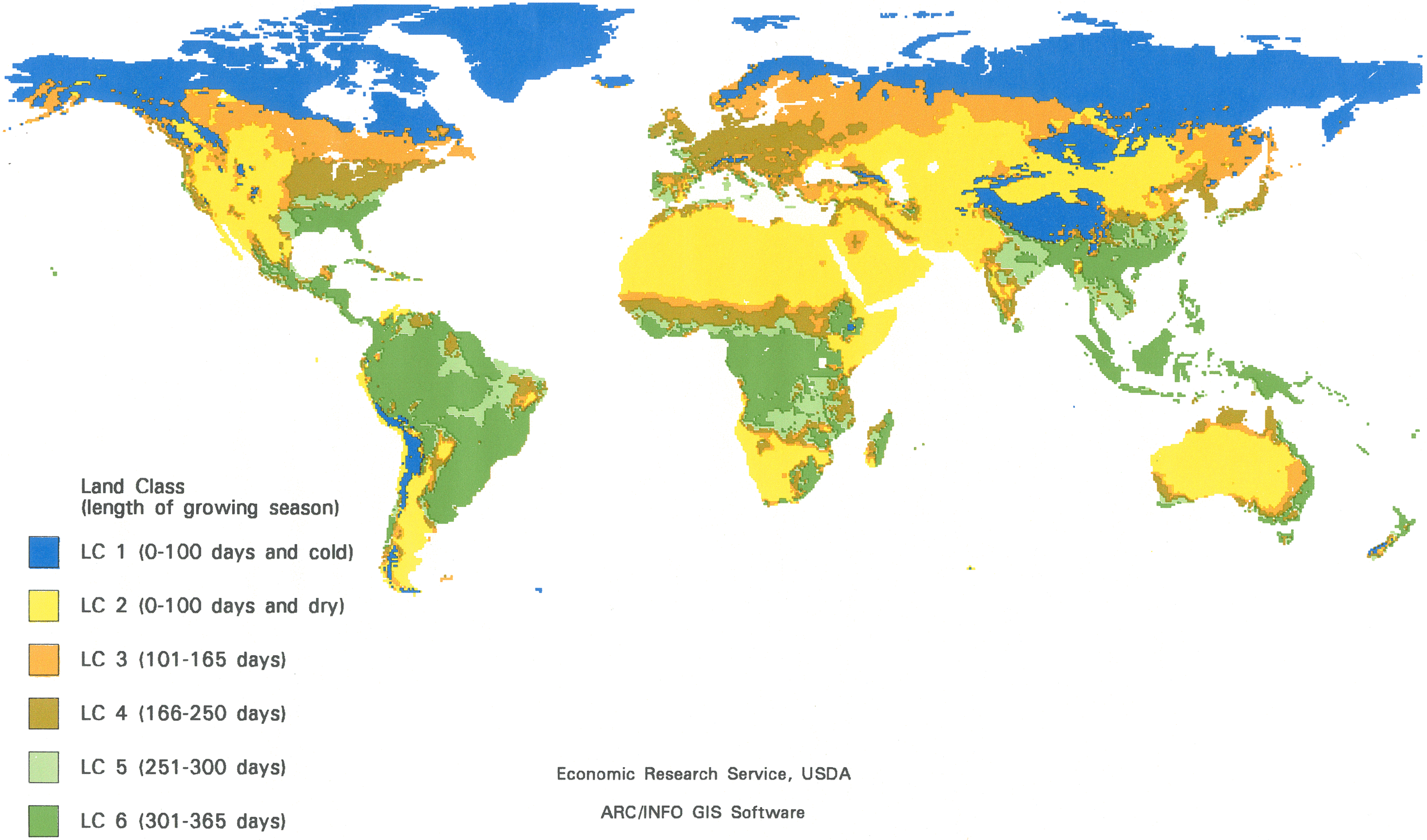
[1] The regions listed are for FARM's computable general equilibrium model. In FARM's geographic information system, rest of world is divided into the former Soviet Union (plus Mongolia), other Europe, other Asia and Oceania, Latin America, and Africa. [2] Saving (equal to investment) is 11.9 percent. [3] The crops sector produces three crop commodities, (wheat, other grains, and nongrains). Each of the other sectors produces one commodity.

Growing seasons on LC 4 range from 166 to 250 days and are long enough to produce maize. Some double-cropping occurs on LC 4. LC 5 has growing seasons of 251-300 days; major crops include cotton and rice. Two or more crops per year are common on LC 5.

Year-round growing seasons characterize LC 6, which is the primary land class for rice, tropical maize, sugar cane, and rubber. Two or more crops per year are common on LC 6. LC 6 accounts for 20 percent of all land. Most (87.2 percent) LC 6 land is located in tropical areas of Africa, Asia, and Latin America.

FARM's benchmark water runoff and water supplies are derived from country-level data compiled by the World Resources Institute (WRI, 1992) (table 4). Changes in a region's water supply are linked to changes in runoff by elasticities of water supply (table 4). These elasticities indicate percentage changes in regional water supplies that would be generated by l-percent increases in runoff. Runoff elasticities are positive, implying that water supplies increase when runoff increases. Regional differences in elasticities are related to differences in hydropower capacity. Production of hydropower depends on dams, which enable a region to store water temporarily. The ability

Figure 2
Land classes under current climate



Economic Research Service, USDA

ARC/INFO GIS Software

Table 2—Land class boundaries in FARM

Land class	Length of growing season	Time soil temperature above 5°C	Principal crops and cropping patterns	Sample regions
	------------*Days*------------			
1	0-100	< 125	Sparse forage for rough grazing.	United States: northern Alaska. World: Greenland.
2	0-100	> 125	Millets, pulses, sparse forage for rough grazing.	United States: Mojave Desert. World: Sahara Desert.
3	101-165	"	Short-season grains; forage: one crop per year.	United States: Palouse River area, western Nebraska. World: southern Manitoba.
4	166-250	"	Maize: some double-cropping possible.	United States: Corn Belt. World: northern European Community.
5	251-300	"	Cotton and rice: double-cropping common.	United States: Tennessee. World: Zambia, nonpeninsular Thailand.
6	301-365	"	Rubber and sugarcane: double-cropping common.	United States: Florida, southeast coast. World: Indonesia.

Table 3—Current land class endowments, by region

	Region								
Land class	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total
					Million hectares				
1	120.45	504.10	3.10	0.22	225.57	0.00	3.55	1,413.10	2,270.09
2	300.97	79.11	7.07	0.00	308.40	0.00	506.47	2,985.81	4,187.82
3	116.21	309.72	33.27	9.62	121.71	1.34	91.13	1,014.91	1,697.91
4	198.80	29.18	117.63	18.62	87.56	4.36	91.48	785.08	1,332.71
5	68.96	0.00	45.07	7.64	69.31	39.80	29.04	748.14	1,007.95
6	111.26	0.00	16.69	1.54	130.07	249.48	69.58	2,003.79	2,582.42
Total	916.66	922.10	222.82	37.65	942.61	294.98	791.24	8,950.83	13,078.89

[1]Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2]Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [3]Australia and New Zealand. [4]Rest of world.

to store water allows people within a region to consume water during both dry and rainy seasons.

Economic Framework[10]

Production possibilities interact with consumer preferences to determine a region's output (fig. 1). A region's production possibilities, that is, what it can supply, depend on its primary factor endowments (land, water, labor, and capital) and existing technology. We consider regional endowments of land, labor, and capital to be fixed; climate change scenarios, however, may alter regional water endowments and the distribution of land among the land classes. Although there are upper limits to what can be produced, the number of different product mixes is infinite. What actually gets produced depends on how firms and consumers interact in commodity markets. Consumer demands are driven by preferences and income. Firm supplies, consumer demands, and their interactions are embedded within FARM's CGE component.

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[10] A more complete description of FARM's economic framework is in appendix A.

Table 4—Water runoff, supply, and supply elasticities, by region

Item	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total
					Unit				
Runoff[5]	2,478	2,901	818	547	2,863	3,420	740	26,940	40,707
Supply[5]	467	42	254	108	471	88	19	1,791	3,240
Elasticity[6]	0.469	0.448	0.342	0.426	0.412	0.279	0.341	n/a[7]	n/a

n/a = Not available.

[1] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [3] Australia and New Zealand. [4] Rest of world. [5] Source: World Resources Institute (WRI), 1990. [6] Estimated from regression analysis. [7] Elasticities of rest of world include those for the former Soviet Union (0.453), Europe outside the European Community (0.299), western and southern Asia (0.324), Latin America (0.318), and Africa (0.223).

The CGE model contains eight regions. Each region has 11 sectors that produce 13 commodity aggregates (table 1). All 13 commodities are traded internationally and are used as both intermediate inputs and as consumption goods. This enables FARM to simulate how international trade offsets reduced production potential in some regions by gains in others. Finally, households own all primary factors and derive income from their sale as well as from net tax collections. Consumption and savings exhaust regional income. The main advantage of a general equilibrium approach is that it fully accounts for all income and expenditures and, therefore, provides comprehensive measures of economic activity.

To translate factor endowments into production possibilities, regional land and water resources are appropriately distributed as inputs to the production of goods and services. Land resources are distributed by land class. The distributions capture three economic realities: (1) land is used by all sectors; (2) water is used in the crops, livestock, and services sectors; and (3) different areas within a region are often associated with distinct product mixes. Within the CGE model, these assignments serve three purposes. First, major differences in the potential productivity of land are captured. Second, all sectors compete for the services of all land. Third, major water-using sectors compete for the services of water. A summary of the distribution of land and water resources to the economic sectors follows.

Owners of land within a land class provide productive services to all 11 sectors. Table 5 shows the distribution of land to cropland, permanent pasture, forest land, and other land by region and land class for 1990. Cropland, which includes land in permanent crops (orchards, rubber, etc.), is used by the crops sector. Permanent pasture, which includes range, is used by the livestock sector. Forest land is used by the forestry sector. Other land, which includes urban land, is used by the manufacturing and services sectors. Other land also includes deserts and ice fields. Within a land class, quantities of land supplied to the various sectors reflect the land class's productive capabilities. For example, LC's 3, 4, and 5 make up only 31 percent of all land but 58 percent of all cropland.

Water is used for irrigation by the crops and livestock sectors and is used for other purposes by the services sector (table 6). Table 6 also shows the distribution of irrigation water across land classes within each region. These distributions are based on the amount of irrigated land in a given land class and the amount of irrigation water required per hectare. Crops grown on desertlike LC 2, for example, use more irrigation water per hectare than crops grown on midwestern LC 4. Also, agricultural land on LC 2 is more likely to be irrigated than agricultural land on other land classes. Sixty-six percent of the world's irrigation water is allocated to LC 2 (table 6). Another 21 percent is assigned to LC's 5 and 6, which are heavily used for production of paddy rice and sugar cane.

Almost 40 percent of world production occurs on LC 4, which is comprised of the Northeast, Midwest, and part of the west coast in the United States; Great Britain, France, and the German Republic in the European Community; and much of the main island of Honshu in Japan (table 7). Almost all the rest is distributed on an approximately equal basis to LC's 2, 3, 5, and 6. Per hectare values also indicate the importance of LC 4 for the world as a whole. The broader range of per hectare values for LC's 3, 4, 5, and 6 more clearly

Table 5-Cropland, permanent pasture, forest land, and land in other uses, by region and land class

	Region								
Land use/ land class	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total
	Million hectares								
Cropland									
1	0.06	0.00	0.54	0.00	1.22	0.00	0.00	15.36	17.18
2	37.01	15.64	2.38	0.00	31.11	0.00	3.45	200.08	289.68
3	22.68	20.42	11.72	0.42	14.19	0.40	12.42	178.54	260.79
4	85.93	9.90	41.24	2.74	14.67	1.32	13.41	169.43	338.64
5	23.97	0.00	16.70	1.01	14.61	10.92	3.35	107.09	177.67
6	20.27	0.00	5.25	0.47	22.79	44.03	16.73	248.63	358.17
Total	189.92	45.96	77.84	4.64	98.59	56.68	49.36	919.14	1,442.12
Pasture									
1	13.49	10.48	0.00	0.00	66.82	0.00	3.16	210.01	303.96
2	137.11	8.34	2.23	0.00	149.30	0.00	341.24	896.82	1,535.04
3	18.18	6.64	9.38	0.11	45.81	0.36	29.63	241.59	351.71
4	39.71	2.73	29.86	0.39	31.64	0.91	27.54	264.79	397.56
5	13.71	0.00	10.88	0.13	32.07	2.41	10.53	214.53	284.26
6	19.26	0.00	2.72	0.02	74.45	10.16	19.58	404.35	530.52
Total	241.47	28.20	55.07	0.64	400.08	13.84	431.67	2,232.10	3,403.06
Forest									
1	36.07	136.89	0.59	0.00	12.73	0.00	0.08	658.38	844.75
2	48.76	21.77	1.45	0.00	7.71	0.00	33.78	115.90	229.37
3	56.20	184.22	7.40	8.34	38.85	0.17	28.96	436.40	760.54
4	58.48	15.12	29.14	11.44	26.63	0.60	26.97	204.20	372.57
5	26.77	0.00	9.50	4.88	17.24	14.99	9.36	340.89	423.63
6	67.62	0.00	6.33	0.44	29.86	142.22	14.17	1,143.22	1,403.86
Total	293.90	358.00	54.41	25.11	133.01	157.98	113.32	2,898.99	4,034.72
Other									
1	70.84	356.73	1.96	0.22	144.81	0.00	0.31	529.34	1,104.20
2	78.08	33.35	1.01	0.00	120.28	0.00	128.00	1,773.01	2,133.73
3	19.15	98.43	4.77	0.75	22.86	0.40	20.12	158.38	324.87
4	14.68	1.43	17.39	4.05	14.62	1.53	23.56	146.66	223.94
5	4.51	0.00	7.98	1.62	5.39	11.48	5.79	85.62	122.40
6	4.12	0.00	2.39	0.62	2.97	53.08	19.11	207.59	289.87
Total	191.38	489.94	35.50	7.27	310.93	66.49	196.90	2,900.61	4,199.00

[1] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [3] Australia and New Zealand. [4] Rest of world.

Table 6--Water use, by land class and region

	Region								
Land use/ land class	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total[5]
					Km³				
Agriculture	196	4	92	53	408	64	6	1,396	2,219
1	0	0	0	0	8	0	0	2	10
2	149	4	46	0	284	0	6	971	1,460
3	14	0	19	0	7	0	0	96	136
4	19	0	26	4	16	0	0	85	150
5	4	0	0	29	36	23	0	182	273
6	IO	0	0	20	57	41	0	60	189
Other uses	271	39	163	54	62	24	13	395	1,021
Grand total[5]	467	42	254	108	471	88	19	1,791	3,240

[1] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [3] Australia and New Zealand. [4] Rest of world. ‘Totals may not add up due to rounding.

Source: World Resources Institute (WRI), 1990.

Table 7-Value of commodity production, by region and land class

	Region								
Land class	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total
					Billion U. S. dollars				
1	65	21	68	3	27	0	0	199	385
2	1,887	360	291	0	503	0	48	2,244	5,333
3	1,146	505	1,473	505	240	3	155	1,959	5,986
4	4,136	232	5,377	3,361	256	11	174	1,911	15,459
5	1,148	0	2,210	1,355	257	99	46	1,237	6,352
6	1,095	0	694	612	402	433	221	2,906	6,363
Total	9,478	1,119	10,113	5,837	1,685	547	643	10,456	39,878
					U.S. dollars/hectare				
1	541	43	22,086	14,315	120	0	95	141	170
2	6,270	4,551	41,184	0	1,631	0	94	752	1,273
3	9,863	1,632	44,265	52,488	1,971	2,589	1,697	1,930	3,526
4	20,805	7,951	45,716	180,524	2,929	2,624	1,897	2,434	11,600
5	16,651	0	49,030	177,290	3,711	2,482	1,581	1,653	6,302
6	9,845	0	41,568	396,644	3,088	1,735	3,177	1,450	2,464
Total	10,340	1,213	45,387	155,014	1,788	1,853	813	1,168	3,049

[1] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia) [3] Australia and New Zealand. [4] Rest of world.

differentiates the contribution of these land classes to world production. It is clear from these per hectare values, for example, that production is more concentrated on LC 5 than on LC 6.

Each region in the CGE has three land-intensive sectors--crops, livestock, and forestry. Each of those sectors is divided into, at most, six subsectors, corresponding to the six land classes. In addition, crop producers may, on a given land class, produce up to three crop aggregates-wheat, other grains, and nongrains. There are substantial regional differences. In the United States, for example, maize is a major component of "other grains"; produce (fruits and vegetables), soybeans, and sugar crops are major components of "nongrains"; and cattle and pigs are major components of "livestock" (table 8). Most U.S. forest products are softwood products (derived from coniferous trees), and only 17 percent of the U.S. forestry harvest is used for fuel. In southeast Asia, however, "other grains" is primarily rice, "nongrains" is sugar cane and roots and tubers (such as cassava), and "livestock" is pigs, sheep, goats, and cattle. All forest products in southeast Asia are hardwood products, (derived from deciduous trees), and 69 percent of the harvest is used for fuel. Because of such regional differences in the composition of these and other commodities (including wheat), each region's commodities are treated as separate goods when traded.

Large portions of agricultural and silvicultural commodities (approximately 50 percent or more) are produced in the "rest of world" region (table 9). Other regions producing more than 10 percent of a given commodity include the United States (wheat, other grains, and wood), the European Community (wheat), and other East Asia (wheat, other grains, nongrains, and livestock). Crop production on LC I is very small. World wheat production is clustered (in descending order) on LC's 4, 3, 2, and 5. No wheat is produced on LC 6. However, LC 6 does produce 25 percent of the world's other grains (primarily rice and tropical maize) and 44 percent of the world's nongrains (primarily sugar, tropical roots and tubers, and tropical fruits and vegetables). Approximately 70 percent of world livestock production occurs on LC's 2, 4, and 6. The prevalence of both range and irrigated agriculture make LC 2 the most important land class for livestock production. Livestock production on LC's 4 and 6 is closely associated with grain production. World production of forest products is most prevalent (46 percent) on LC 6.

Per hectare production of FARM's agricultural and silvicultural commodities are presented in table 10.[11] For crop outputs, these values reflect productivity differences across land classes as well as differences in

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[11] Per hectare production values are calculated by dividing a land class's output by the total amount of land in that land class used by the sector. They are not yields. Yields are calculated by dividing a particular crop's output by the amount of land planted (or harvested) to the particular crop.

Table 8-Major components of agricultural and silvicultural production, by region[1]

	Crops			Forest products	
Region	Other grains	Nongrains	Livestock[2]	Hardwood	Fuelwood
				Percent	
United States	Maize	Produce, soybeans, and sugar	Cattle and pigs	34	17
Canada	Barley and maize	Oils, produce, and roots and tubers	Cattle and pigs	10	4
EC	Maize	Produce and sugar	Cattle, pigs, and sheep and goats	32	13
Japan	Rice	Produce	Cattle and pigs	34	1
OEA[3]	Rice and maize	Produce and roots and tubers	Pigs and sheep and goats	52	67
SEA[4]	Rice	Sugar and roots and tubers	Cattle, pigs, and sheep and goats	100	69
ANZ[5]	Barley	Sugar	Sheep and goats	42	9
ROW[6]	Rice, maize, and barley	Sugar and produce	Cattle and sheep and goats	69	62

[1] Commodities that make up more than 20 percent of the total are listed from most to least dominant. [2] Does not include poultry. [3] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [4] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [5] Australia and New Zealand. Rest of world.

Source: United Nations, Food and Agriculture Organization (FAO), 1992.

Table 9--Distribution of agricultural and silvicultural commodities, by region and land class

	Region								
Commodity/ land class	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total
					Million metric tons				
Wheat									
1	0	0	0	0		0	0	6	7
2	15	12	1	0	34	0	1	63	126
3	11	18	10	0	19	0	5	72	134
4	35	2	53	1	24	0	8	97	219
5	13	0	16	0	20	0	2	53	105
6	0	0	0	0	0	0	0	0	0
Total’	74	32	80	1	98	0	15	291	591
Other grains									
1	0	0	0	0		0	0	7	8
2	23	7	1	0	72	0	1	174	278
3	4	10	1	0	7	0	4	111	137
4	156	8	11	9	46	0	2	150	382
5	31	0	9	2	86	13	0	68	209
6	23	0	3	2	103	76	1	134	343
Total	238	25	25	13	315	89	9	644	1,357
Nongrains									
1	0	0	0	0		0	0	7	8
2	19	2	3	0	51	0	0	329	404
3	10	2	33	2	24	0	2	197	270
4	85	9	179	13	36	1	3	254	579
5	25	0	57	11	87	20	2	290	492
6	55	0	7	6	230	178	26	873	1,376
Total	194	13	280	32	429	200	33	1,949	3,129
All crops									
1	0	0	1	0	3	0	0	19	24
2	58	21	5	0	156	0	2	566	808
3	25	30	44	2	50	0	10	380	542
4	276	19	243	23	106	1	13	500	1,181
5	69	0	82	13	194	33	4	411	806
6	78	0	11	8	333	255	27	1,007	1,719
Total	506	70	385	46	842	289	57	2,884	5,081
					Million head				
Livestock’									
1	1	0	0	0	77	0	5	54	136
2	38	8	3	0	164	0	86	826	1,125
3	17	8	28	2	90	1	44	395	585
4	79	9	215	10	102	3	43	473	935
5	17	0	39	4	84	13	22	338	517
6	20	0	9		174	57	64	520	844
Total	171	24	295	17	691	74	264	2,606	4,142
					Million m^3				
Forest products									
1	17	39	1	0	3	0	0	254	313
2	31	6	2	0	0	0	3	27	69
3	62	101	19	9	56	0	6	304	556
4	93	9	91	16	60	1	7	147	424
5	66	0	30	4	51	23	4	251	428
6	230	0	28		114	237	12	902	1,525
Total	498	155	171	30	284	261	32	1,884	3,315

[1] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [3] Australia and New Zealand. [4] Rest of world. [5] Totals may not add due to rounding. [6] The numbers presented here do not include poultry production. Poultry production, however, is included in FARM.

Source: United Nations, Food and Agriculture Organization (FAO), 1992.

Table 10-Per hectare production of agricultural and silvicultural commodities, by region and land class

Commodity/ land class	Region								
	United States	Canada	EC	Japan	OEA[1]	SEA[2]	ANZ[3]	ROW[4]	Total
					Metric tons				
Wheat									
1	0.44	0.00	0.57	0.00	0.96	0.00	0.00	0.37	0.42
2	0.42	0.78	0.33	0.00	1.09	0.00	0.15	0.32	0.44
3	0.47	0.87	0.84	0.22	1.32	0.00	0.39	0.40	0.51
4	0.41	0.20	1.28	0.22	1.63	0.00	0.57	0.57	0.65
5	0.52	0.00	0.97	0.30	1.39	0.00	0.61	0.50	0.59
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.39	0.70	1.03	0.22	0.99	0.00	0.30	0.32	0.41
Other grains									
1	0.13	0.00	0.00	0.00	1.06	0.00	0.00	0.43	0.46
2	0.63	0.45	0.33	0.00	2.30	0.00	0.38	0.87	0.96
3	0.19	0.48	0.09	0.26	0.52	0.02	0.31	0.62	0.53
4	1.82	0.83	0.26	3.36	3.12	0.01	0.18	0.89	1.13
5	1.31	0.00	0.53	1.57	5.89	1.16	0.00	0.64	1.17
6	1.13	0.00	0.66	4.48	4.52	1.73	0.09	0.54	0.96
Total	1.25	0.54	0.32	2.80	3.20	1.57	0.18	0.70	0.94
Nongrains									
1	0.15	0.00	0.70	0.00	0.86	0.00	0.00	0.46	0.49
2	0.51	0.12	1.41	0.00	1.62	0.00	0.09	1.64	1.39
3	0.42	0.12	2.82	4.54	1.70	0.65	0.14	1.10	1.04
4	0.98	0.88	4.34	4.77	2.46	0.86	0.23	1.50	1.71
5	1.06	0.00	3.41	10.79	5.98	1.86	0.54	2.70	2.77
6	2.74	0.00	1.40	13.10	10.09	4.05	1.56	3.51	3.84
Total	1.02	0.28	3.60	6.90	4.35	3.53	0.67	2.12	2.17
All crops									
1	0.71	0.00	1.27	0.00	2.87	0.00	0.00	1.27	1.38
2	1.56	1.35	2.07	0.00	5.01	0.00	0.62	2.83	2.79
3	1.09	1.47	3.76	5.03	3.54	0.66	0.84	2.13	2.08
4	3.21	1.91	5.88	a.35	7.20	0.87	0.97	2.95	3.49
5	2.89	0.00	4.91	12.66	13.26	3.03	1.15	3.84	4.53
6	3.87	0.00	2.06	17.58	14.61	5.78	1.64	4.05	4.80
Total	2.66	1.52	4.95	9.92	8.54	5.10	1.15	3.14	3.52
					Head				
Livestock									
1	0.04	0.01	0.00	0.00	1.15	0.00	1.44	0.26	0.45
2	0.28	0.91	1.46	0.00	1.10	0.00	0.25	0.92	0.73
3	0.93	1.15	3.03	16.63	1.96	2.11	1.48	1.64	1.66
4	2.00	3.16	7.22	26.31	3.24	3.19	1.56	1.79	2.35
5	1.22	0.00	3.57	33.61	2.62	5.59	2.11	1.57	1.82
6	1.02	0.00	3.35	43.13	2.33	5.60	3.28	1.29	1.59
Total	0.71	0.85	5.36	26.48	1.73	5.35	0.61	1.17	1.22
					M^3				
Forest products									
1	0.47	0.28	1.07	0.00	0.24	0.00	0.35	0.39	0.37
2	0.63	0.29	1.62	0.00	0.00	0.00	0.09	0.23	0.30
3	1.10	0.55	2.53	1.03	1.45	0.67	0.21	0.70	0.73
4	1.59	0.60	3.13	1.43	2.24	1.44	0.26	0.72	1.14
5	2.45	0.00	3.14	0.84	2.96	1.51	0.43	0.74	1.01
6	3.40	0.00	4.47	2.18	3.82	1.67	0.84	0.79	1.09
Total	1.69	0.43	3.14	1.19	2.14	1.65	0.28	0.65	0.82

[1] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [2] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [3] Australia and New Zealand. [4] Rest of world.

the mix of crops planted and the use of nonland inputs. For livestock and forest products, these values also reflect differences in the extent to which grasslands and forest lands are used for agricultural and silvicultural purposes. For example, only a portion of South America's forests and Africa's savannahs are actively managed for timber and livestock.

Because of these distributions, each land class within a region is associated with its own production structure. Of the 301 million hectares of LC 2 in the United States, for example, 12 percent is cropland, 46 percent is pasture and range, and 16 percent is forest (table 5). LC 2 agricultural land (cropland and pasture) uses 149 km^3 of irrigation water (11,453 m^3 per hectare on average) (table 6); produces 15 million metric tons (mt) of wheat, 23 million mt of other grains, and 19 million mt of nongrains; and supports 38 million head of livestock. LC 2 forest land in the United States produces 31 million m^3 of wood (table 9). Output per LC 2 hectare is 0.42, 0.63, and 0.51 mt, respectively, for wheat, other grains, and nongrains; 0.28 head for livestock; and 0.63 m^3 for wood (table 10). Of the 199 million hectares of LC 4 in the United States, however, 43 percent is cropland, 20 percent is pasture, and 29 percent is forest (table 5). LC 4 agricultural land uses 19 km' of irrigation water (221 m^3 per hectare on average) (table 6); produces 35 million mt of wheat, 156 million mt of other grains, and 85 million mt of nongrains; and supports 79 million head of livestock. LC 4 forest land in the United States produces 93 million m^3 of wood (table 9). Output per LC 4 hectare is 0.41, 1.82, and 0.98 mt, respectively, for wheat, other grains, and nongrains; 2.00 head for livestock; and 1.59 m^3 for wood. These differences indicate that an increase in LC 2 coupled with a simultaneous decrease in LC 4 would reduce production possibilities overall, while pasture and range would expand at the expense of cropland and forest.

This structure supports the capability of FARM's CGE model to simulate a number of adaptive responses to climate change by farmers. With respect to outputs, farmers adopt the crop and livestock mix best suited to their climatic and economic conditions. If changing climatic conditions alter the growing season enough to shift their land to a new land class, farmers may adopt a different crop and livestock mix. (This is like incorporating the "analogous regions" methodology into a formal economic structure.) Farmers also may adjust their mix of crops and livestock in response to climate-induced price changes. If the price of wheat were to rise, for example, farmers would tend to increase both their cropland and the amount of wheat produced per hectare relative to other crops.

Farmers also adopt the mix of primary factor inputs best suited to their climatic and economic conditions.[12] If water supplies are adversely affected and water prices increase, for example, farmers may use less irrigation water and more land, labor, and/or capital. This might be done within a particular land class or, alternatively, by shifting production from land classes that require relatively large amounts of irrigation water to land classes that require less. Similarly, if climate change reduces the amount of land in an agriculturally important land class, farmers may use less of that land and more water, labor, and/or capital. They may also use more land in other land classes. Thus, FARM's framework enables us to analyze how climate change might alter the distribution and intensity of farming within a region.[13]

Simulating Climate Change

In FARM, climate change is simulated by altering water supplies and the distribution of land across the land classes within each region. These impacts shift the production possibilities associated with regional land and water resources. Given prevailing prices, shifts in production possibilities are simultaneously translated into changes in commodity supplies and primary factor income. Changes in primary factor income, in turn, generate changes in consumer demands, which are then reflected in new levels of production, trade, and consumption. This section focuses on how FARM's GIS transforms temperature and precipitation changes generated by general circulation models (GCM's) into changes in land and water resources.

General Circulation Models

Climate change scenarios are derived from monthly temperature and precipitation estimates generated by GCM's of the Goddard Institute for Space Studies (GISS) (Hansen and others, 1988), Geophysical Fluid Dynamics Laboratory (GFDL) (Manabe and Wetherald, 1987), United Kingdom Meteorological Office (UKMO) (Wilson and Mitchell, 1987), and Oregon State University (OSU) (Schlesinger and Zhao, 1989). The scenarios represent equilibrium climates given a dou-

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[12] Only primary factor inputs are substitutable for one another in production. Intermediate inputs (represented by the traded commodities) are assumed to be used in fixed proportions.

[13] Most model parameters that govern adaptive responses parameters were estimated for a limited number of countries but have been applied broadly. In other cases, parameters are based on expert opinion.

bling of atmospheric CO_2.[14] Summary statistics for the scenarios are presented in table 11. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that a doubling of trace gases would lead to an increase in mean global temperature of 1.5-5.0°C by 2090 (IPCC, 1992). The GCM scenarios considered here are at the upper end of the IPCC's range.

Land Resources

Revised data sets of monthly temperature and precipitation are obtained for each GCM by: (1) adding to Leemans and Cramer's (1991) temperature data, differences in mean monthly temperatures obtained in GCM runs with current ($1xCO_2$) and double ($2xCO_2$) atmospheric carbon dioxide levels; and (2) multiplying Leemans and Cramer's (1991) precipitation data by the ratio of precipitation in the $2xCO_2$ GCM run to precipitation in the $1xCO_2$ GCM run.[15]

Using the revised temperature and precipitation data, new sets of growing season lengths (one with and one without precipitation constraints) are computed for each GIS grid cell.[16] Each GIS grid cell is assigned the appropriate land class. The revised growing season length may alter the land class to which a given cell is assigned. In this way, climate change can alter regional endowments of the six land classes.

Two sets of land class changes are computed for each GCM scenario. One set contains regional net changes in land classes and is used to evaluate all potential economic impacts of global climate change, including impacts generated by changes in land use. The second set contains net changes in land classes on existing land use and cover patterns in the regions. Using both sets of changes enables us to evaluate economic impacts of climate change while constraining total quantities of cropland, permanent pasture, and forest land in each region to their 1990 levels. This has two purposes. First, it serves as a check on situations where land uses cannot change as easily as indicated in our model. Second, it measures climate change's potential effects on existing agricultural and silvicultural systems.

Water Resources

Changes in regional water supplies also are estimated with the revised temperature and precipitation data. First, estimates of water runoff under current climatic conditions are calculated using Leemans and Cramer's (1991) mean monthly temperature and precipitation data. Annual water runoff is the sum of monthly runoffs in an area. Monthly runoff is that portion of monthly precipitation that is not evapotranspirated back to the atmosphere. Monthly evapotranspiration esti-

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[14] Equilibrium scenarios presume that atmospheric concentrations of carbon dioxide, temperature, and precipitation have stabilized. At present, meteorologists are working to provide "transient" climate change scenarios that show how temperature and precipitation would respond to increasing levels of atmospheric carbon dioxide through time.

[15] Results from GCM simulations of current ($1xCO_2$) climate sometimes differ from actual climatic conditions. Comparing $2xCO_2$ GCM runs with $1xCO_2$ GCM runs minimizes the impacts of these errors while maintaining the overall integrity of the simulation results.

[16] Revised growing season lengths are provided by the World Soil Resources Office of USDA's Natural Resources Conservation Service.

Table 11-Summary statistics for the general circulation models used as the basis for climate change scenarios

Scenario[1]	Year calculated	Resolution	Carbon dioxide	Change in average global: Temperature	Change in average global: Precipitation
		*Lat. * long.*	*ppm*	*Celsius*	*Percent*
GISS	1982	7.83° I 10.0°	630	4.2°	11
GFDL	1988	4.44° I 7.5°	600	4.0°	8
UKMO	1986	5.00° * 7.5°	640	5.2°	15
OSU	1985	4.00° * 5.0°	652	2.8°	8

[1] 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).

Sources: For GISS, GFDL, and UKMO scenarios: Rosenzweig, Parry, Frohberg, and Fischer, 1993. For the OSU scenario: Dixit, 1994.

mates are obtained from monthly temperature data (Thomthwaite, 1948).[17]

Second, water runoff in each region is derived for the four GCM scenarios using the appropriate revised temperature and precipitation data. Third, regional percentage changes in water runoff are calculated by comparing the GCM-based runoff estimates with runoff estimates derived from the original Leemans and Cramer (1991) temperature and precipitation data.[18] Fourth, regional percentage changes in water supplies are computed using the runoff elasticities of water supply presented in table 4 ($\% \Delta W = \% \Delta R x E$, where $\% \Delta W$ is the percentage change in a region's water supply, $\% \Delta R$ is the percentage change in a region's runoff, and E is the runoff elasticity of water supply).

Limitations and Strengths

The FARM framework contains several strengths that significantly advance our ability to evaluate potential impacts of global climate change on regional and world agriculture. At the same time, a number of limitations should be made explicit.

Land and Water Resources

One limitation is that land classes are defined by climatic variables and do not account for soil characteristics or other factors that affect productivity. These nonclimatic factors may not accompany climate-induced shifts in length of growing season. While we assume that productivity per unit area follows the migration of growing seasons, it is more likely to decrease or increase in a given instance. This means that farmer adaptations simulated by FARM are somewhat uncertain and subject to independent verification. Per unit area productivity of natural ecosystems also is not likely to follow the migration of growing seasons. Some natural ecosystems will find it difficult or impossible to migrate, even with direct human assistance.

Procedures for simulating water resources are limited in three ways. First, water storage in alpine snowpack is not taken into account. Alpine snowpack is an important source of irrigation water in the Western United States, northern Africa, the Middle East, Indra, and China. Reductions in snowpack might cause shortages of irrigation water in some of these regions during critical times of the year. Second, water is treated as though it could be used anywhere within a given region; hence, water is considerably more mobile in our model than in reality. Third, water is always beneficial. In fact, too much water can wash away crops, waterlog soils, delay planting, or inhibit harvesting. These limitations suggest that our estimates of climate-induced changes in water supplies are probably optimistic and that negative impacts attributable to water supply changes are probably underestimated. We examine the sensitivity of our results to the specification of water shocks by simulating each climate change scenario with and without climate-induced water supply shocks.

Economic Impacts

Four limitations of FARM's economic framework need to be made clear. First, substitution between intermediate goods or between intermediate and primary factors is not allowed. This means that increases in fertilizer cannot be used to offset climate-induced productivity losses. Second, FARM considers only the commodity value of land. The value of land's environmental amenities is not included. This means, for example, that values of sawlogs, pulpwood, and similar forest commodities are tracked, but values for forest-related improvements in air and water quality are not. Third, the region "rest of world" includes Latin America, Africa, west Asia, much of South Asia, the former Soviet Union, and countries in Europe outside the European Community (EC). For a large portion of the world, then, it is difficult to obtain precise information about how the economic impacts of climate change would be distributed.

Finally, our benchmark is the world economy as it existed in 1990. This means that: (1) some potential adaptations (such as new cultivars or new livestock breeds) are not considered; (2) direct costs of physically converting land from one use to another (such as building roads, clearing trees, or burning brush) are ignored; and (3) current economic distortions in the form of subsidies and tariffs are in place."

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[17] McKenney and Rosenberg (1993) suggest that Thornthwaite's method produces estimates of potential evapotranspiration that are unrealistically high at warmer locations, In Thornthwaite's method, however, potential evapotranspiration generally (1) is equal to zero when temperature is less than or equal to 0°C; (2) increases at an increasing rate as temperatures range between 0°C and 26.5°C; (3) increases at a decreasing rate as temperatures range from 26.5°C to 37.5°C; and (4) is constant when temperature is above 37.5°C. McKenney and Rosenberg derive their results solely from the formula used to estimate potential evapotranspiration between 0°C and 26.5°C. Their results, therefore, do not accurately portray Thornthwaite's method at warmer locations.

[18] GIS estimates of water runoff computed with Leemans and Cramer's (1991) weather data differ from those derived from WRI (1992). Comparing estimates of runoff based on a standard weather database minimizes the impacts of these differences.

[19] The model embodies some technological innovation by assuming that productivity per unit area does not change when following a climate-induced migration of land classes even when the migration is to poorer quality soils.

Climate Change Scenarios

Our climate change scenarios are limited to how alternative global patterns of mean monthly temperature and precipitation affect land and freshwater resources. We do not simulate all potential impacts associated with climate change (such as possible rises in sea level or increased variability in weather).

We also do not consider physiological effects of greater atmospheric concentrations of carbon dioxide or other trace gases on plant growth. Based on results of many controlled-environment experiments, higher levels of atmospheric carbon dioxide act as a fertilizer for some plants and improve water-use efficiency for others (Kimball, 1983; Cure and Acock, 1986; IPCC, 1990). A number of studies that assess economic impacts of climate change on regional and world food systems positively adjust crop yields in their climate change simulations to reflect this "fertilizer effect" (Adams and others, 1988; Easterling and others, 1992; and Rosenzweig and Parry, 1994). The magnitude of any "fertilizer effect," however, is still very uncertain. Major sources of uncertainty include impacts of increased carbon dioxide on weed growth, interaction effects on crop growth among atmospheric carbon dioxide levels and other environmental variables (notably temperature and water availability), and negative impacts on crop yields of other gases (particularly ozone, sulfur dioxide, and nitrogen dioxide) released by burning fossil fuels (Wolfe and Erickson, 1993).

Strengths

Limitations aside, FARM extends previous research by linking land and water resources directly to climate conditions and economic activity; hence, our simulations of human responses to climate change are economically consistent with resource impacts, production technologies, and consumer preferences. FARM also integrates many advances made in earlier works. Specifically, FARM (1) uses GIS data similar to Leemans and Solomon (1993), (2) incorporates multisector impacts as in Bowes and Crosson (1991), and (3) simulates global impacts on production and trade as in Kane, Reilly, and Tobey (1991) and Rosenzweig and Parry (1994). The result is a framework that (1) includes climate effects on crops, livestock, and forestry simultaneously, (2) simulates endogenous adaptive responses to climate change by farmers, (3) explicitly simulates land and water resource markets, (4) includes detailed interactions with the rest of the economy, and (5) provides global coverage.

Results

We place special emphasis on the role of adaptation in adjusting to new climatic conditions. By necessity, many regional and sectoral effects are not discussed. Appendix B presents detailed results of climate-induced changes in land class endowments and economic effects by region and GCM scenario.

Impacts on Endowments

Changes in the distribution of land across land classes and changes in water supplies are used by the CGE model to simulate climate change. These and other results are used to evaluate economic responses to the climate change scenarios with respect to their overall magnitude, impacts on land and water resources, and implications for U.S. and global agriculture.

Land Resources

Twenty-nine to forty-six percent of the world's land endowment (outside Antarctica) faces changes in climatic conditions that are large enough to result in new land class assignments.[20] The scenario ranking, from lowest to highest, is OSU, GISS, GFDL, and UKMO (table 12). This ranking is not perfectly correlated with either GCM temperature or precipitation changes. We use this ranking when referring to the strength of climatic shocks generated by the four GCM scenarios; that is, we consider the OSU climatic shock to be "weaker" than the UKMO climatic shock. The shock pattern generally follows the same order in each region as for the world as a whole. The major exception is Australia/New Zealand. This indicates that the GCM's are consistently different with respect to each other.

Across scenarios, the global endowment of LC 1 (land with short growing seasons due to cold temperatures) decreases (table 13 and fig. 3).[21] In terms of growing season lengths, climate change is likely to increase the amount of land suitable for agriculture and silviculture, especially in arctic and alpine areas. However, LC 6 (land with growing seasons longer than 10 months, primarily in the tropics) decreases in each scenario and LC 2 (desert/dry grasslands) increases in three scenarios. This indicates that soil moisture losses are likely to reduce agricultural possibilities in many areas of the world. These results are consistent with Leemans and Solomon (1993).

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[20] Results are reported in ranges because we examine four climate change scenarios. Results for specific scenarios are shown in the tables or figures cited.

[21] Regional changes in the distribution of land across land classes are used by the CGE model to simulate climate change's impacts on land resources. These are presented in appendix B.

Agriculturally important land increases in high-latitude regions, but decreases in tropical regions (table 14). In mid-latitude regions, changes in agriculturally important land may be positive or negative. These results suggest that, under global climate change, agricultural possibilities are likely to increase in high-latitude regions and decrease in tropical areas.

Globally, 41.2 to 59.7 percent of existing cropland faces changes in climatic conditions that result in new land class assignments (table 15 and fig. 4).[22] Under each scenario, more than half of the cropland that does experience a change in land class shifts to a class with a shorter growing season ($LC_i < LC_0$). Using current rents, the total value of existing agricultural land declines under the land class distributions generated by the four climate change scenarios. These results imply that climate change will likely impair the existing agricultural system.

Water Resources

Water runoff for the world as a whole will likely increase with climate change (table 16). The scenario ranking, from lowest to highest, is UKMO, OSU, GISS, and GFDL. This ranking is not perfectly correlated with either GCM precipitation changes or the strength of climate change shock indicated by land class changes. Among the regions, the only scenario ranking that is the same as the world's is that for "rest of world." These results reveal the high levels of variability and uncertainty that accompany our knowledge about potential climate-induced changes in water resources.

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[22] The GIS can track, for example, how much LC 4 cropland in a given region becomes LC 2, LC 3, LC 5, or LC 6 as well as how much remains LC 4. This is done by combining the relevant land-use and cover data in Olson (1989-91) with the current and appropriate scenario-based land-class data sets.

Table 12-Percentage of total land changing land class, by region and climate change scenario

	Region								
Scenario[1]	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
					Percent				
GISS	40.0	37.7	71.8	65.9	34.9	21.9	18.5	31.2	32.3
GFDL	47.0	48.7	84.0	73.9	34.5	27.1	25.1	38.6	39.4
UKMO	55.3	58.8	85.7	78.8	43.9	34.3	24.6	45.6	46.2
OSU	38.9	35.3	59.3	63.8	26.1	16.0	26.4	26.8	28.6

[1] 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).
[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).
[4] Australia and New Zealand. [5] Rest of world.

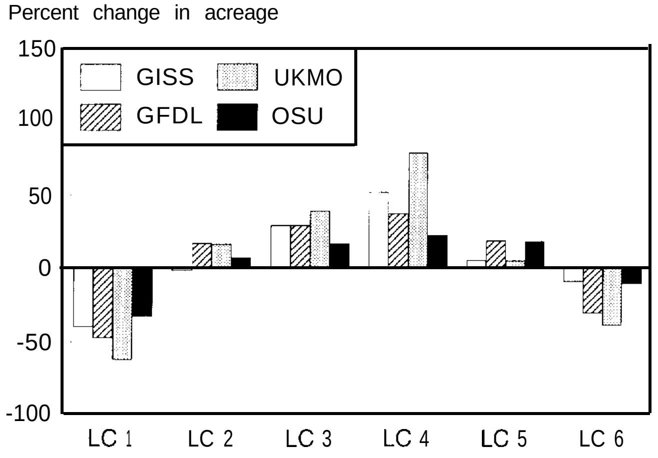
Table 13-Changes in world land class endowments, by climate change scenario

	Land class					
Scenario[1]	1	2	3	4	5	6
			Percent change			
GISS	-39.8	-1.4	28.7	51.6	4.7	-10.1
GFDL	-47.7	17.2	28.7	37.0	18.2	-31.1
UKMO	-62.5	16.4	38.8	78.1	4.4	-39.2
OSU	-32.6	6.9	16.7	21.9	17.8	-11.7

'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).

Figure 3

Effect of climate change on distribution of land among land classes (LC)



GISS = Goddard Institute for Space Studies.
GFDL = Geophysical Fluid Dynamics Laboratory
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

Table 14-Changes in agriculturally important land, by area and climate change scenario

Scenario[1]	High latitudes[2]	Tropics[3]	Other areas[4]
		Percent change	
GISS	58.6	-20.5	-0.5
GFDL	21.2	-39.7	1.2
UKMO	49.3	-52.0	-3.6
OSU	7.8	-18.6	6.8

[1] 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). [2] Land with growing season length from 101 to 250 days in Canada, non-EC Europe, and the former Soviet Union. [3] Land with growing season length greater than 300 days in Africa, Latin America, and Asia (except Japan, China, and South Korea). [4] Land with growing season length from 101 to 300 days.

Table 15-Global changes in land classes on existing cropland and in the value of existing cropland and agricultural land under existing rents

	Cropland land class changes		Value changes	
Scenario[1]	Total	To shorter land classes[2]	Cropland	Agricultural land[3]
			Percent change	
GISS	43.8	21.9	0.7	-0.3
GFDL	43.4	37.0	-3.2	-1.8
UKMO	59.7	41.3	-5.4	-3.5
OSU	41.2	25.1	-0.5	-0.8

[1] 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). [2] Shifts to land classes with shorter growing seasons. [3] Includes cropland and pasture.

All changes in regional water supplies follow the same direction as changes in runoff. Regional water runoff decreases in five cases (the United States, GISS; European Community, GISS; Japan, GISS and UKMO; and southeast Asia, OSU), indicating potential water shortages in some areas (table 16). Regional runoff also Increases by more than 20 percent in eight cases (Canada, UKMO; other East Asia, GISS and GFDL; Australia/New Zealand, GISS, GFDL, and OSU; and "rest of world," GISS and OSU). These results show that increased flooding or water logged soils could become more prevalent in some areas.

Our methodology does not include climate-induced changes in snowpack when determining changes in water supplies. This means that the water supply changes presented in table 16 are likely to be too high when supplies are estimated to increase and not low enough when supplies are estimated to decrease. In turn, estimated impacts on production possibilities will be too positive.

U.S. Resources

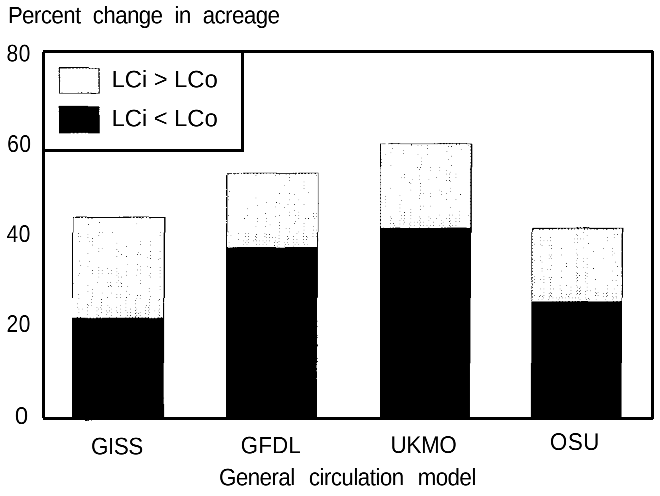
Across scenarios, 38.9 to 55.3 percent of U.S. land faces changes in climatic conditions that result in new land class assignments (table 12). LC 1 decreases in all GCM scenarios, indicating that total land suitable for agriculture and silviculture in the United States is likely to increase under climate change (table 17). Most of this impact will occur in Alaska. LC 4 decreases in all scenarios, suggesting potential negative impacts in the U.S. Corn Belt. Also, LC 6 (located primarily in the Southeast and an important source of fruits and vegetables) decreases in two scenarios and LC 2 increases in three scenarios. This implies that soil moisture losses may reduce agricultural possibilities in other areas.

Of existing U.S. cropland, 48.0 to 68.2 percent faces changes in climatic conditions that are large enough to result in new land class assignments (table 18). In two scenarios, more than half of the cropland that does change is assigned to land classes with shorter growing seasons. The total value of existing agricultural land using current rents would decline under the alternative land class distributions generated by three climate change scenarios (table 18). These results indicate that the effects of climate change on the existing U.S. agricultural system are uncertain.

Runoff and water supplies for the United States increase in three climate change scenarios (table 16). In one of the scenarios, however, water supply increases only 0.25 percent. Given the previous caution concerning our water supply estimates, these results indicate that climate change might exacerbate problems associated with allocating U.S. water resources among alternative uses.

Figure 4

Climate-induced land class changes that occur on cropland acreage



LCi = Land class after climate change.
LCo = Land class before climate change.
GISS = Goddard institute for Space Studies.
GFDL = Geophysical Fluid Dynamics Laboratory.
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

Table 16-Changes in water runoff and water supply, by region and climate change scenario

Scenario[1]	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
					Percent change				
Water runoff									
GISS	-6.73	12.46	-0.05	-1.82	48.24	8.43	68.47	38.79	31.47
GFDL	7.51	10.05	5.04	10.20	36.66	5.95	64.72	14.61	14.52
UKMO	4.22	23.27	8.61	-9.36	12.07	10.28	19.81	17.10	14.82
OSU	0.53	7.63	1.26	0.54	17.73	-2.19	59.32	28.77	21.85
Water supply									
GISS	-3.16	5.58	-0.02	-0.77	19.85	2.35	23.38	11.35	8.95
GFDL	3.52	4.50	1.73	4.34	15.08	1.66	22.10	16.52	12.35
UKMO	1.98	10.41	2.95	-3.98	4.97	2.87	6.76	9.08	6.38
OSU	0.25	3.41	0.43	0.23	7.30	-0.61	20.26	9.50	6.54

[1] 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).
[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).
[4] Australia and New Zealand. [5] Rest of world.

Table 17-Changes in U.S. land class endowments, by climate change scenario

	Land class					
Scenario[1]	1	2	3	4	5	6
	Percent change					
GISS	-51.8	-10.0	45.8	-14.8	36.6	39.0
GFDL	-54.8	1.9	105.4	-25.4	63.1	-49.5
UKMO	-67.3	8.4	42.9	-28.0	101.6	-7.7
OSU	-43.6	9.4	48.4	-30.0	16.8	14.3

[1] 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).

Table 18-changes in land classes on existing U.S. cropland and in the value of existing cropland and agricultural land under existing rents

	Cropland land class changes		Value changes	
Scenario[1]	Total	To shorter land classes[2]	Cropland	Agricultural land[3]
	Percent change			
GISS	48.0	15.0	4.1	4.1
GFDL	62.0	42.6	-20.4	-16.1
UKMO	68.2	29.7	-5.4	-4.4
OSU	54.4	31.2	-12.5	-10.0

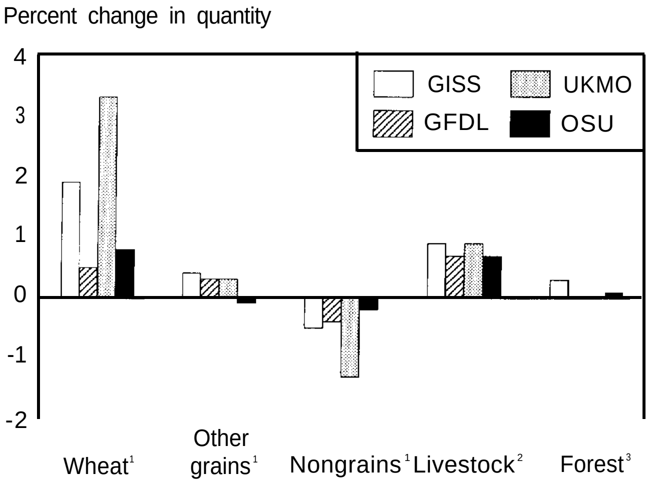
[1] Climate change scenarios generated by the general circulation models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU). [2] Shifts to land classes with shorter growing seasons. [3] Includes cropland and pasture.

Impacts on Commodity Markets

Climate-induced changes in natural resource endowments will affect the production of basic agricultural and silvicultural commodities around the world. Changes in agricultural production in turn will affect the output of various processed food commodities.[23]

Figure 5

Effect of climate change on world crop, livestock, and forest products



[1] Base unit = Million metric tons.
[2] Base unit = Million head.
[3] Base unit = Million cubic meters.
GISS = Goddard Institute for Space Studies.
GFDL = Geophysical Fluid Dynamics Laboratory.
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

We examine how the four GCM climate change scenarios affect production of these and other selected commodities when farmers are allowed to take advantage of newly available agricultural land as well as under the existing pattern of agricultural production. We also evaluate the role that onfarm adaptations might play in responding to climate change.

Agricultural and Silvicultural Commodities

Across scenarios, world wheat production increases, while production of nongrains falls (fig. 5 and table 19). Output of other grains increases or decreases depending on the scenario. Production of livestock and forest products generally increases. Average world prices for wheat, other grains, livestock, and forest products decline across scenarios, while the average world price of nongrains increases.[24]

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[23] The sensitivity of these results to 50-percent increases and decreases of selected model parameters in all regions is analyzed in appendix A. The analysis indicates that results presented here are robust.

[24] World price changes are weighted averages of the regional price changes. Regional price changes may vary considerably because each region's commodities (including wheat) are treated as separate goods (see table 8). This approach limits potential trade responses. The parameters used to simulate trade are included in the sensitivity analysis presented in appendix A.

Table 19-Changes in quantities and prices of agricultural, silvicultural, and processed food commodities, by region and climate change scenario

			Region								
Scenario[1]	Variable	Commodity	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
			Percent change								
GISS	Quantity	Wheat	6.0	2.4	-13.2	-49.8	-0.3	0.0	17.5	5.6	1.9
		Other grains	-5.9	12.4	29.2	11.3	0.6	-3.7	4.3	1.6	0.4
		Nongrains	2.8	35.6	-10.6	13.4	3.8	0.3	-3.8	-0.7	-0.5
		Total crops	-0.8	12.1	-8.6	11.5	2.1	-0.9	3.1	0.5	0.0
		Livestock	-0.7	8.6	-1.7	1.6	0.7	-0.9	-0.9	1.5	0.9
		Forest products	0.7	3.5	3.5	6.2	0.6	-4.6	-0.5	0.2	0.3
		Fish, meat, and milk	-0.2	4.9	-1.3	1.4	0.6	-1.2	-0.2	1.1	0.4
		Other proc. foods	0.1	3.1	-1.4	1.4	1.0	-3.4	0.3	1.5	0.4
	Price	Wheat	3.0	7.4	30.9	56.1	5.5	0.0	1.6	-14.9	-2.5
		Other grains	1.1	-11.7	-29.7	-13.1	0.0	10.0	-7.2	-6.7	-3.5
		Nongrains	-4.3	-19.8	6.6	-18.4	-5.9	-2.8	1.2	2.5	0.5
		Total crops	-0.5	-4.9	6.9	-15.4	-2.6	1.6	2.0	-2.0	-1.5
		Livestock	0.0	-9.2	1.1	-2.5	-0.8	-1.1	-0.5	-2.7	-1.9
		Forest products	-3.0	-6.2	-10.7	-5.3	-0.2	1.6	-0.4	-0.7	-1.7
		Fish, meat, and milk	0.0	-4.7	1.5	-1.0	-0.3	-0.1	-0.2	-1.2	-0.4
		Other proc. foods	-0.4	-1.8	0.7	-2.4	-0.5	2.7	-0.2	-1.7	-0.8
GFDL	Quantity	Wheat	12.4	9.5	-12.0	-60.3	-12.1	0.0	3.3	5.1	0.5
		Other grains	-6.5	16.8	21.9	12.5	0.9	-3.1	1.7	1.4	0.3
		Nongrains	-3.9	36.1	-6.5	17.2	6.6	1.3	-3.9	-1.2	-0.4
		Total crops	-2.7	17.0	-5.8	14.2	2.3	0.0	-1.1	0.0	-0.1
		Livestock	-0.5	8.4	-1.6	1.6	0.7	-0.8	-1.2	1.3	0.7
		Forest products	-0.8	3.9	3.4	9.1	1.3	-4.4	-0.3	-0.1	0.0
		Fish, meat, and milk	-0.2	4.9	-1.1	1.3	0.6	-1.0	-0.5	0.8	0.3
		Other proc. foods	-0.4	3.3	-1.2	1.4	0.8	-2.8	0.0	0.8	0.2
	Price	Wheat	-10.4	-4.1	19.3	0.0	59.1	9.2	-3.7	-18.9	-7.8
		Other grains	2.2	-14.6	-25.1	-14.3	-0.9	7.8	-5.2	-8.2	-4.3
		Nongrains	3.9	-16.9	6.1	-20.1	-6.3	-0.9	3.6	5.6	2.9
		Total crops	1.5	-9.5	5.8	-17.3	-2.7	2.0	0.2	-1.0	-0.9
		Livestock	-0.6	-9.0	1.4	-2.9	-1.1	-1.0	-0.5	-2.7	-1.9
		Forest products	-0.1	-4.4	-8.8	-6.7	-0.1	2.4	-0.2	0.9	-0.1
		Fish, meat, and milk	-0.4	-4.8	1.3	-1.0	-0.4	-0.1	-0.3	-1.1	-0.5

Continued-

See footnotes at end of table.

Table 19-Changes in quantities and prices of agricultural, silvicultural, and processed food commodities, by region and climate change scenario-continued

			Region								
Scenario[1]	Variable	Commodity	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
						Percent change					
UKMO	Quantity	Wheat	9.4	7.4	-14.7	-64.5	-0.7	0.0	2.8	a.7	3.3
		Other grains	-7.1	17.8	29.6	12.4	-0.2	-5.5	-3.3	2.4	0.3
		Nongrains	0.6	46.8	-9.3	17.9	3.1	2.3	-2.5	-2.0	-1.3
		Total crops	-1.7	18.5	-7.9	14.6	1.4	-0.1	-1.2	0.0	-0.3
		Livestock	-0.6	10.5	-1.9	1.4	0.5	-1.6	-3.3	1.9	0.9
		Forest products	-0.5	5.3	3.9	10.4	0.8	-6.6	-1.7	0.0	0.0
		Fish, meat, and milk	-0.1	6.0	-1.4	1.1	0.5	-1.9	-1.4	1.2	0.2
		Other proc. foods	-0.2	4.1	-1.6	1.3	0.8	-5.1	-0.3	1.5	0.2
	Price	Wheat	-3.5	1.8	31.9	79.9	0.9	0.0	2.0	-24.6	-9.7
		Other grains	0.0	-16.9	-31.4	-16.1	-0.1	14.4	-3.9	-12.4	-6.4
		Nongrains	-0.6	-21.5	7.8	-21.8	-3.9	-2.6	1.6	7.9	4.4
		Total crops	0.4	-8.9	8.1	-19.1	-2.0	2.9	1.4	-1.5	-1.1
		Livestock	-0.7	-11.0	0.9	-3.2	-1.0	-1.3	0.2	-4.0	-2.7
		Forest products	-1.7	-8.0	-11.2	-8.8	-0.2	3.1	0.6	0.1	-1.0
		Fish, meat, and milk	-0.5	-5.8	1.5	-1.0	-0.4	0.0	0.0	-1.7	-0.7
		Other proc. foods	-0.1	-2.3	0.9	-2.9	-0.7	4.1	-0.1	-2.4	-1.0
OSU	Quantity	Wheat	1.5	14.0	-6.6	-55.7	-5.2	0.0	17.7	2.9	0.8
		Other grains	-7.3	15.5	17.3	13.2	0.4	-1.0	11.7	0.9	-0.1
		Nongrains	-0.3	23.2	-5.2	14.9	4.7	-1.2	-2.0	-0.7	-0.2
		Total crops	-3.4	16.3	-4.0	13.0	1.9	-1.1	5.3	0.0	0.0
		Livestock	-1.3	7.1	-1.0	1.6	0.2	-0.1	3.5	0.9	0.7
		Forest products	-0.3	2.6	1.8	6.7	0.7	-2.5	2.2	0.1	0.1
		Fish, meat, and milk	-0.6	4.1	-0.6	1.4	0.1	-0.2	2.0	0.6	0.3
		Other proc. foods	-0.3	2.7	-0.6	1.3	0.2	-0.9	1.5	0.6	0.3
	Price	Wheat	-2.4	-3.8	8.7	55.9	4.1	0.0	-6.0	-11.3	-4.6
		Other grains	6.2	-11.3	-19.5	-12.2	2.4	2.8	-6.9	-4.2	-1.0
		Nongrains	-1.4	-13.9	3.0	-19.1	-6.3	-0.7	0.8	2.0	0.2
		Total crops	1.8	-8.3	2.2	-15.3	-2.1	0.6	-1.4	-1.1	-1.2
		Livestock	1.2	-7.3	1.3	-2.2	-0.2	-0.6	-2.2	-1.7	-1.2
		Forest products	-1.2	-2.7	-4.9	-5.1	-0.2	0.8	-2.6	0.3	-0.4
		Fish, meat, and milk	0.7	-3.8	0.8	-0.9	0.0	-0.2	-1.1	-0.7	-0.2
		Other proc. foods	0.0	-1.5	0.2	-2.2	0.3	0.6	-0.6	-1.0	-0.6

[1] 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).

[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).

[4] Australia and New Zealand. [5] Rest of world.

Global impacts mask more pronounced variations in regional impacts (table 19). In Canada, FARM's only unambiguously high-latitude region, output of wheat. other grains, nongrains, livestock, and forest products increases in all scenarios. In southeast Asia, FARM's only unambiguously tropical region, production of these commodities generally decreases in all scenarios (exceptions are nongrains in the GISS, GFDL, and UKMO scenarios). These changes in regional production of agricultural and silvicultural commodities reflect longer and warmer growing seasons at high latitudes and shorter and drier growing seasons in the tropics. Impacts on mid-latitude regions are mixed.

In the United States, output of wheat increases, while output of other grains (primarily maize) decreases across all scenarios (table 20). Production of nongrains increases or decreases depending on the scenario. Livestock production decreases in all scenarios, and forestry production decreases in three scenarios. U.S. shares of world production move in the same direction as changes in U.S. production. These results indicate that climate change is likely to have negative impacts on some important U.S. agricultural sectors.

Other Commodities

Although climate-induced changes in production possibilities will be most pronounced for agriculture and silviculture, other sectors will be affected as well. In general, world production of the goods and services in many sectors will increase (table 21). Output of fish, meat, milk. and other processed foods, for example, increases in all scenarios. This indicates that climate change's overall impact on world food production is likely to be beneficial. Not all sectors will increase output, however. Production of minerals such as metal ores, salt, and phosphate rock, for example, declines in all scenarios. Also, world production of services, which makes up 47 percent of world output in dollar terms, falls in the two strongest climate change scenarios (the GFDL and UKMO scenarios).

Regional production of processed food commodities tends to follow regional production of agricultural commodities. For example, production of processed food commodities increases in all scenarios for Canada and decreases in all scenarios for southeast Asia (table 19). In the United States, production of processed food commodities generally declines. The decreases in production of fish, meat, and milk are associated with decreases in output of other grains (primarily maize) and livestock in all four scenarios. U.S. production of other processed foods decreases in three scenarios. The increase in the GISS scenario is associated with a relatively large increase in nongrain production.

Comparison with Previous Research

Our results are more positive for world food production than those reported in earlier research, even in research that includes the beneficial effects of atmospheric carbon dioxide on plant growth. This can be illustrated in more detail by focusing on cereals (wheat and other grains). After taking carbon dioxide fertilization and various adaptations into account, climate-induced impacts on world cereal production in Rosenzweig and Parry (1994) are approximately 1.0, 0.0, and -2.5 percent, respectively, for the GISS, GFDL, and UKMO scenarios. However, our research indicates that, without carbon dioxide fertilization, world cereal production increases by 0.9, 0.3, and 1.2 percent, respectively,

Table 20-Changes in U.S. production and U.S. shares of world production of agricultural and silvicultural products, by commodity and climate change scenario

	U.S. production					U.S. share of world production				
Scenario[1]	Wheat	Other grains	Nongrains	Livestock	Forest products	Wheat	Other grains	Nongrains	Livestock	Forest products
					Percent change					
GISS	6.0	-5.9	2.8	-0.7	0.7	4.0	-6.2	3.3	-1.5	0.4
GFDL	12.4	-6.5	-3.9	-0.5	-0.8	11.9	-6.8	-3.5	-1.2	-0.8
UKMO	9.4	-7.1	0.6	-0.6	-0.5	5.9	-7.4	1.9	-1.5	-0.5
OSU	1.5	-7.3	-0.3	-1.3	-0.3	0.7	-7.2	-0.2	-2.0	-0.4

[1] 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).

Table 21-Changes in world production and prices of goods and services not produced in the agricultural or silvicultural sectors, by climate change scenario

	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
Commodity	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price
	Percent change							
Coal/oil/gas	0.182	-0.087	0.097	-0.071	0.101	-0.138	0.145	-0.022
Other minerals	-0.409	0.157	-0.280	0.108	-0.439	0.109	-0.089	0.091
Fish/meat/milk	0.371	-0.387	0.273	-0.489	0.310	-0.677	0.294	-0.224
Other processed food	0.382	-0.824	0.161	-0.758	0.225	-1.032	0.260	-0.616
Textiles/clothing/footwear	0.120	-0.049	0.049	0.104	-0.022	0.100	0.190	-0.016
Other nonmetal manufacturing	0.098	-0.047	0.062	-0.004	-0.006	-0.046	0.162	-0.005
Other manufacturing	0.114	0.036	0.060	0.042	0.001	0.046	0.156	0.043
Services	0.023	0.044	-0.003	0.013	-0.107	0.022	0.122	0.020
Global shipping services	-0.033	0.258	-0.202	0.168	-0.319	0.224	-0.052	0.113

[1] Climate change scenarios generated the by 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).

for the GISS, GFDL, and UKMO scenarios (table 22).[25]

The differences in impacts on cereals production could be due to a number of reasons. First, our direct climate-induced impacts on world cereals supply may be less severe than the impacts underlying Rosenzweig and Parry's (1994) analysis. Second, our methodology may assign a larger role to adaptation (switching to alternative crops, adjusting primary factor inputs, and taking advantage of new climatically suitable agricultural lands) when farmers respond to changing climate conditions. Third, other factors may be responsible.

Climate change will affect world supply as well as production of cereals (table 22). Changes in supply are the additional quantities (positive or negative) that firms would be willing to sell at 1990 prices under the alternative climate. Changes in production are the equilibrium quantities (positive or negative) that both firms and consumers would be willing to sell and buy at equilibrium prices under the alternative climate. The former can be represented as a shift in a supply curve. The latter results from simultaneous shifts in supply and demand curves. Land use is fixed (cropland is not allowed to increase or change location) in both supply cases. Land use also is fixed in one production case.

The degree to which farm-level adaptations are taken in response to climate change also will affect world supply and production of cereals (table 22). In one supply case, no farm-level adaptations are taken. These supply effects are comparable with results from Rosenzweig and Parry's (1994) no-carbon-dioxide-fertilization, no-adaptation scenarios. They capture the direct climate-induced effects on world cereals. In the other supply case, when land use is fixed, the primary farm-level adaptations are switching to alternative crops and adjusting primary factor inputs. These farm-level adaptations also occur in the production case with land use fixed. In the production case without land use restrictions, adaptation also includes expanding production into newly available agricultural lands.

Supply effects without farm-level adaptations are simulated in FARM's GIS by first assuming that crops are planted where they originally occurred no matter what the new land class turns out to be. Quantity harvested then depends on the average products of the crops on the new land class with one constraint-the average output cannot be greater than the average output of the original land class. Supply changes with farm-level adaptations are estimated with the CGE by fixing prices of all intermediate goods at their 1990 levels.

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[25] Rosenzweig and Parry (1994) do not report impacts on world cereals production for scenarios with their adaptation techniques but without carbon dioxide fertilization. The results would probably be negative and, hence, lower than ours.

Table 22-Changes in U.S. and world supply and production of cereals under various constraints, by climate change scenario[1]

	Supply[2]		Production	
Region/scenario[3]	No farm-level adaptations	Farm-level adaptations[4]	Land use fixed	No land-use restrictions[5]
	Percent change			
World				
GISS	-22.9	-2.4	0.2	0.9
GFDL	-23.2	-4.4	-0.6	0.3
UKMO	-29.6	-6.4	-0.2	1.2
OSU	-18.8	-3.9	-0.5	0.2
United States				
GISS	-24.4	-8.7	-2.0	-3.0
GFDL	-38.0	-22.3	-4.6	-2.0
UKMO	-38.4	-19.4	-3.2	-5.0
OSU	-33.3	-20.9	-5.6	-5.2

[1] Changes in supply represent the additional quantities (positive or negative) that firms would be willing to sell at 1990 prices under the alternative climate. Changes in production represent changes in equilibrium quantities (changes in quantities that firms are willing to sell and consumers are willing buy at new market prices under the alternative climate). [2] Land use is fixed (cropland is not allowed to increase) in both supply cases. [3] 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). [4] Includes switching to alternative crops and adjusting primary factor inputs. [5] Expansion in the new agriculturally suitable lands is allowed.

In our no-adaptation case, world cereals supply decreases 22.9, 23.2, and 29.6 percent, respectively, for the GISS. GFDL, and UKMO climates (table 22). For no-carbon-dioxide-fertilization, no-adaptation scenarios in Rosenzweig and others (1993). world cereals supply decreases 19.9, 24.5, and 30.0 percent, respectively, for the GISS, GFDL, and UKMO climates.[26] A comparison of these results indicates that direct climate-induced effects on world cereals supply are similar in the two modeling frameworks. With farm-level adaptations (and cropland fixed), world supplies of cereals decrease by 2.4, 4.4. 6.4, and 3.9 percent, respectively, for the GISS, GFDL, UKMO, and OSU scenarios. Comparing these changes with the no-adaptation farmer supply changes indicates that from 78 to 90 percent of the initial climate-induced reductions in world cereals supply might be offset by allowing farmers to select the most profitable mix of inputs and crops on existing cropland.

After allowing for trade and changes in demand (but still holding cropland fixed), changes in world cereals production range from -0.6 to (0.2 percent, thereby mitigating more than 97 percent of the original negative impacts. Finally, after allowing farmers to take advantage of new agriculturally suitable lands, changes in world production of cereals range from 0.2 to 1.2 percent. These results indicate that farmer adaptations are likely to offset many of the economic losses that global climate change may otherwise induce.

The relatively small impacts on cereals production are also due to how FARM's CGE component simulates consumption of final goods and services. Simply put, consumption of nonfood items will vary more than food consumption during economic upturns and downturns. For example, after allowing for land use movements, changes in the world supply of cereals are much larger (ranging from 10.9 to 26.5 percent) than changes in world production of cereals.[27] In FARM's simulations, climate-induced impacts will be shared by all sectors of the economy, not just those related to food production. This is also illustrated by decreases in the services sectors in two climate change scenarios.

Adaptation in specific regions may be more difficult for a number of reasons. First, initial regional impacts may be more negative. Under our no-adaptation sce-

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[26] These values arc derived from changes in simulated wheat, rice, and maize yields presented in Rosenzweig and others (1993) combined with production data for 1990 in United Nations, Food and Agriculture Organization (1992).

[27] See appendix table B7 for changes in world supplies of wheat and nongrains.

narios, initial impacts on U.S. cereals supplies are more severe than for the world as a whole (table 22). Second, farm-level adaptations may not be as effective. Selecting the most profitable mix of inputs and crops on existing cropland in the United States mitigates from 37 to 64 percent (rather than 78 to 90 percent) of initial climate-induced shocks to cereals supply. Further allowing for trade and changes in demand mitigates from 83 to 92 percent (instead of more than 97 percent) of these shocks. Finally, greater availability of potential cropland in foreign regions could have an adverse affect on domestic agricultural production. After all the world's farmers take advantage of newly available agricultural land, U.S. production of cereals would be smaller in the GISS and UKMO scenarios than if agricultural land were fixed (table 22).

Impacts on the Existing System

By restricting land uses and covers to their current patterns, we get an idea of how climate change might affect existing agricultural systems. World production of selected commodities is generally lower than when land use movements are allowed (table 23). This phenomenon is most striking with regard to processed foods. When land use changes are not allowed, world production in the processed foods sectors decreases in all four GCM scenarios-the opposite of what we found when farmers were allowed to take advantage of newly

Table 23-Changes in world and U.S. production of selected commodities when land use changes are and are not allowed, by climate change scenario

	Commodity						
Location/ Land use changes/ scenario[1]	Wheat	Other grains	Nongrains	Livestock	Forest products	Fish, meat, and milk	Other processed foods
	Percent change						
World							
Land use changes:							
Allowed							
GISS	1.9	0.4	-0.5	0.9	0.3	0.4	0.4
GFDL	0.5	0.3	-0.4	0.7	0.0	0.3	0.2
UKMO	3.3	0.3	-1.3	0.9	0.0	0.2	0.2
OSU	0.8	-0.1	-0.2	0.7	0.1	0.3	0.3
Not allowed							
GISS	0.6	0.0	-1.3	0.6	0.1	0.0	-0.1
GFDL	-1.0	-0.4	-0.6	0.3	-0.2	-0.2	-0.4
UKMO	1.2	-0.8	-2.6	0.4	-0.3	-0.3	-0.6
OSU	-0.4	-0.5	0.4	0.8	0.0	0.0	-0.1
United States							
Land use changes:							
Allowed							
GISS	6.0	-5.9	2.8	-0.7	0.7	-0.2	0.1
GFDL	12.4	-6.5	-3.9	-0.5	-0.8	-0.2	-0.4
UKMO	9.4	-7.1	0.6	-0.6	-0.5	-0.1	-0.2
OSU	1.5	-7.3	-0.3	-1.3	-0.3	-0.6	-0.3
Not allowed							
GISS	8.2	-5.2	7.7	-0.5	0.6	-0.1	0.4
GFDL	14.8	-10.6	-3.5	-1.5	-2.0	-0.6	-0.8
UKMO	10.5	-9.8	9.5	-1.5	-1.4	-0.7	0.1
OSU	6.1	-9.3	1.5	-1.8	-0.3	-1.0	-0.3

[1] 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).

available agricultural land.[28] This suggests that climate change is likely to reduce productivity on Earth's current agricultural land. This result also points out the importance of incorporating impacts on the availability of potential agricultural land into climate change analysis.

U.S. production of other grains and livestock, as well as output of fish, meat, and milk, falls in all scenarios (table 23). Wheat production increases in each scenario. Production of forest products, nongrains, and other processed foods varies from one scenario to another. These results are not very different from those that occur when farmers can take advantage of newly available agricultural land.

Land and Water Use

The ability of farmers to take advantage of newly available agricultural land will help to offset the negative effects of global climate change on the world's current agricultural and food processing system. Some of the land use changes that such activity is likely to generate might alter the distribution and intensity of farming.

Net Land Use Changes

Global climate change causes more land to be used for agricultural purposes (table 24 and fig. 6). Across GCM scenarios, world cropland and pasture land in-

Table 24-Net changes in cropland, permanent pasture, forest land, and other-use land, by region and climate change scenario

	Region								
Scenario[1]	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
					Percent change				
Cropland									
GISS	9.7	63.0	6.8	17.9	10.1	19.4	2.8	10.1	11.7
GFDL	3.9	78.8	8.7	26.7	7.0	21.9	1.6	6.7	9.2
UKMO	4.9	112.3	9.3	40.7	12.1	30.8	-5.3	12.7	14.8
OSU	1.6	49.1	4.0	17.6	7.5	9.5	22.0	5.3	7.1
Pasture									
GISS	-0.1	2.6	-9.0	-9.5	1.5	57.1	-2.3	3.8	2.5
GFDL	0.7	15.8	-4.0	-13.8	6.5	48.1	-2.0	4.3	3.7
UKMO	7.0	35.0	-11.9	-17.7	6.3	66.4	1.7	4.3	4.7
OSU	7.4	4.4	5.8	-12.0	1.6	20.7	-10.6	3.0	1.5
Forest									
GISS	2.9	6.9	8.8	-21.1	5.6	-8.6	5.8	-6.1	-3.6
GFDL	2.3	-1.9	-0.6	-26.4	-6.3	-9.5	5.5	-9.6	-7.5
UKMO	0.6	-0.1	7.7	-33.8	4.0	16.4	-0.3	-11.8	-9.1
OSU	-0.8	2.4	-4.5	-21.2	6.1	-4.5	18.5	-6.8	-4.4
Other land									
GISS	-13.9	-11.1	-14.5	62.3	-7.5	-7.9	1.1	0.0	-2.6
GFDL	-8.4	-6.9	-11.9	75.4	-7.8	-6.1	0.7	4.2	1.1
UKMO	-14.6	-12.5	-13.9	92.2	-13.7	-1.1	-2.1	4.5	-0.1
OSU	-9.7	-6.7	-10.9	63.0	-7.1	-1.8	7.1	2.8	0.5

[1] Climate change scenarios generatea 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). [2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia). [4] Australia and New Zealand. [5] Rest of world.

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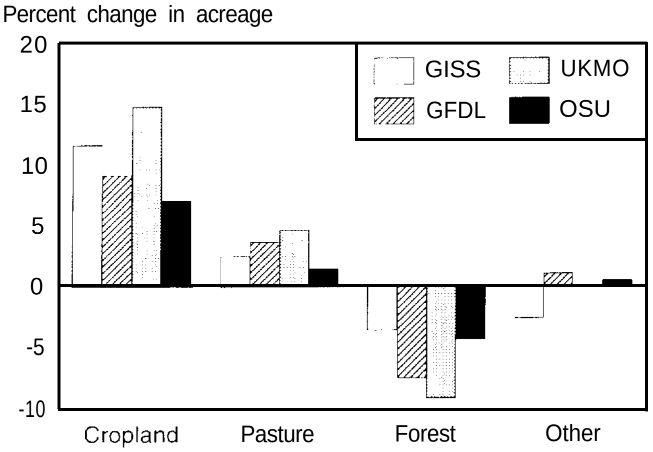
[28] Results in table 23 indicate that world production of fish, meat, and milk falls even though livestock numbers increase. This anomaly is due to increases in world output of small livestock (such as goats and sheep) and simultaneous declines in world production of large livestock (such as cattle). In the United States. the livestock and fish, meat, and milk sectors move together.

Figure 6

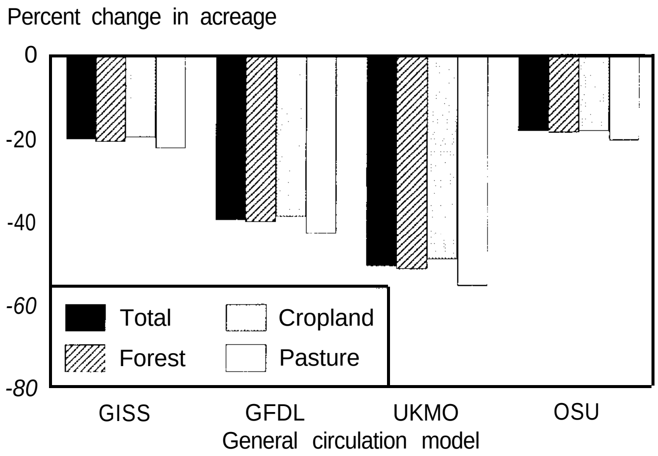
Net global changes in land use



GISS = Goddard Institute for Space Studies.
GFDL = Geophysical Fluid Dynamics Laboratory.
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

Figure 7

Climate-induced land use changes that occur on LC 6 in tropical areas



GISS = Goddard Institute for Space Studies.
GFDL = Geophysical Fluid Dynamics Laboratory.
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

crease by 7.1 to 14.8 percent and by 1.5 to 4.7 percent, respectively. Changes in total crop and livestock production, however, range from -0.3 to 0.0 percent and from 0.7 to 0.9 percent, respectively (table 19). Total crop production remains approximately the same in all scenarios (table 19). This implies that crop and livestock yields will decline, on average, under climate change.

Cropland generally increases in all regions and scenarios. In percentage terms, the largest net increases of cropland occur in Canada, ranging from 49.1 to 112.3 percent (22.6 to 51.7 million hectares) across scenarios.[29] Other regions with relatively large net increases in cropland are Japan and southeast Asia. In the United States. cropland increases by 1.6 to 9.7 percent.

Coinciding with the global expansion of cropland, forest land decreases by 3.6 to 9.1 percent (table 24). Thus suggests that expansion of cropland into new areas is likely to be at the expense of existing forest. Although this may be true in the aggregate, it might not be true for all forests. Because of tropical rain forests' biodiversity and large stores of carbon, we conducted a more detailed analysis of climate-induced impacts on those areas.[30]

Rain forests are located primarily on LC 6 in tropical areas. The amount of land classified as LC 6 in tropical areas declines by 18.4 to 51.0 percent (fig. 7). As estimated by FARM's CGE, forest land on LC 6 in tropical areas declines by 18.7 to 51.6 percent, cropland by 18.3 to 49.3 percent, and pasture land by 20.5 to 55.7 percent. Decreases in forest are larger (while decreases in cropland are smaller) than decreases in total LC 6 in all scenarios. These results indicate that competition from crop production could aggravate climate-induced losses of tropical rain forests.

Land Use Movements

Behind the net land-use changes lie various conversions of land from one use to another.” Minimum estimates

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[29] Most of the cropland increases in the rest of world region also occur at high latitudes, such as the former Soviet Union and non-EC Europe, ranging from 7.5 to 33.3 percent. respectively, for the OSU and UKMO scenarios.

[30] Tropical rain forests store large quantities of carbon in tree trunks. If the area covered by rain forests decreases. some of this carbon would be released into the atmosphere as carbon dioxide. This could cause the strength of global climate change to increase.

[31] Estimates of the quantities of land converted are derived by comparing the CGE model's land-class pattern of land uses with the land-class pattern of current land uses under alternative climatic conditions. The latter are generated by the GIS. If, for example. the CGE-estimated acreage for a particular land use in a given land class is less than the GIS-estimated acreage, then one can assume that the difference was converted to other uses.

of global land movements range from 6.4 to 11.3 percent of total acreage (table 25). In most regions, minimum estimates of land converted from one use to another are less than 15 percent (table 25 and fig. 8). In the European Community (EC) and Japan, however, estimated land use changes range from 10.5 to 20.4 percent and from 15.2 to 23.9 percent, respectively. Minimum estimates of land use changes in the United States range from 8.3 to 15.1 percent of total acreage.

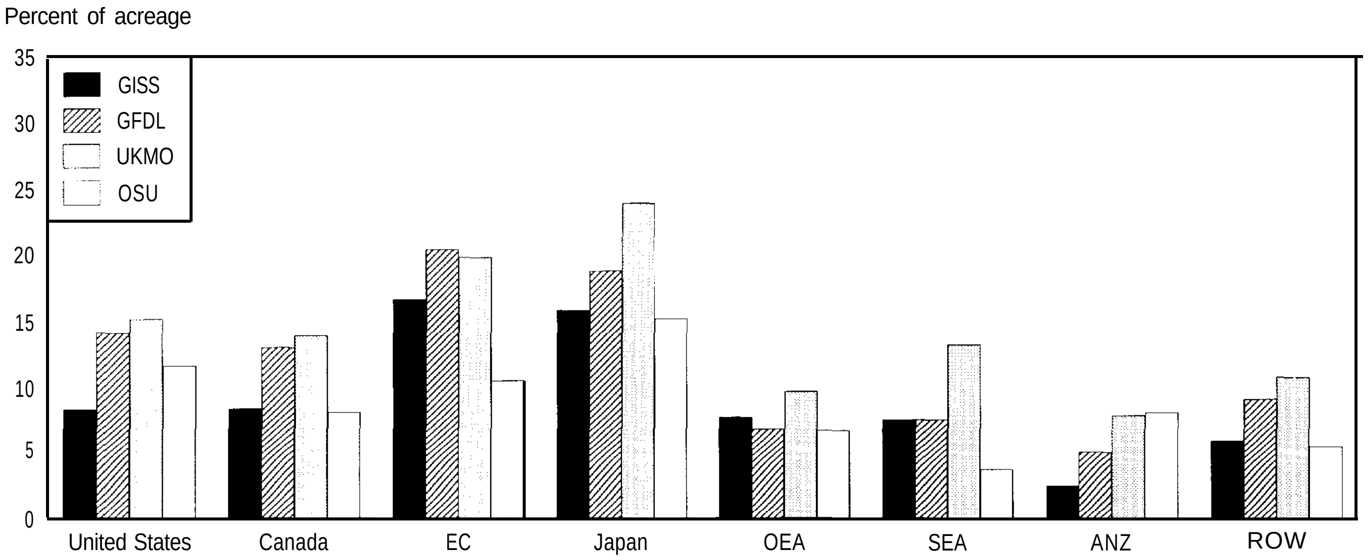
Table 25-Percentage of all land changing land use, by region and climate change scenario

	Region								
Scenario[1]	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
				Percent change					
GISS	8.3	8.4	16.6	15.8	7.7	7.5	2.4	5.9	6.4
GFDL	14.1	13.0	20.4	18.8	6.8	7.5	4.9	9.1	9.5
UKMO	15.1	13.9	19.8	23.9	9.7	13.2	7.9	10.8	11.3
OSU	11.6	8.1	10.5	15.2	6.7	3.5	8.1	5.4	6.4

[1] 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).
[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).
[4] Australia and New Zealand. [5] Rest of world.

Figure 8

Regional land use conversions



EC = European Community.
OEA = Other East Asia.
SEA = Southeast Asia.
ANZ = Australia and New Zealand.
ROW = Rest of world.
GISS = Goddard Institute for Space Studies
GFDL = Geophysical Fluid Dynamics Laboratory
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

In some areas, negative impacts of climate change would cause farmers to abandon existing cropland. For the world as a whole, 4.2 to 10.5 percent (60.2 million hectares to 150.7 million hectares) of existing cropland would be converted to other uses (table 26 and fig. 9). In percentage terms, cropland losses are greatest in the EC and the United States-from 7.2 to 15.6 percent (from 5.6 million hectares to 12.1 million hectares) and from 8.6 to 19.1 percent (16.2 million hectares to 36.4 million hectares), respectively. These results imply that some U.S. and EC farm communities could be severely disrupted by climate change.

Land newly converted to crop production is estimated to range from 14.4 to 25.2 percent (from 207.4 million hectares to 363.8 million hectares) of existing cropland (table 26). In percentage terms, the largest increases are in Canada, ranging from 54.5 to 115.4 percent (from 25.1 million hectares to 53.1 million hectares) of existing cropland (fig. 10). Such large increases may not be possible in Canada, however, because poor soil quality may limit cropland expansion regardless of how favorable temperature and precipitation conditions become (Ward, Hardt, and Kuhule, 1989). One advantage of our methodology is its ability to map the possibilities.

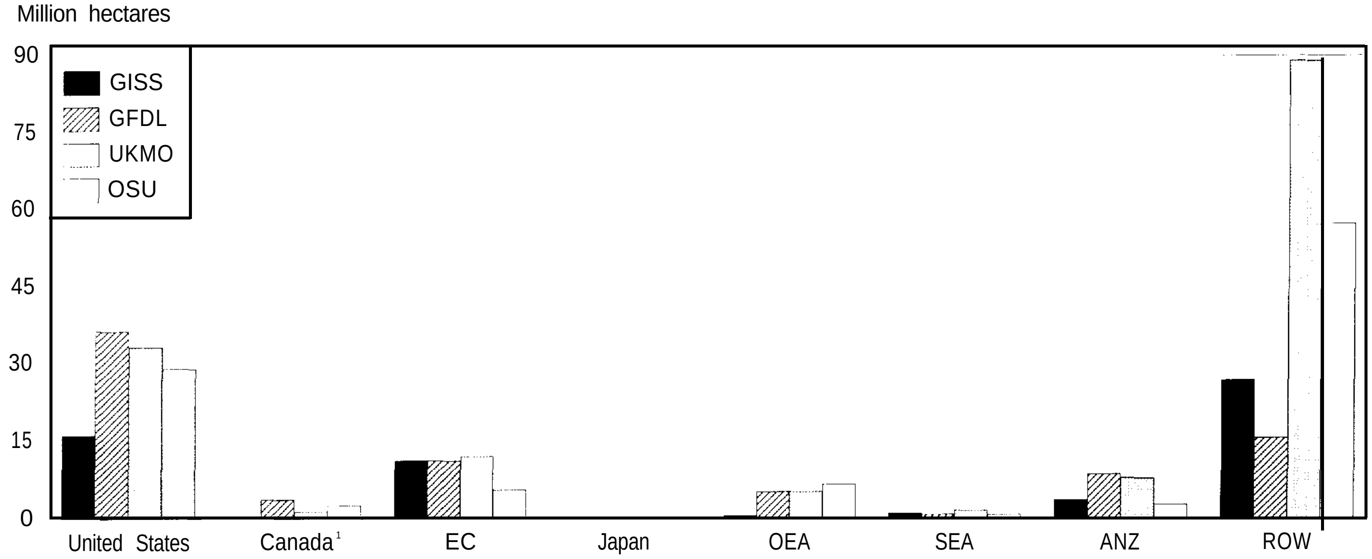
Table 26-New and abandoned cropland, by region and climate change scenario

	Region								
Scenario[1]	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
					Percent of current				
New cropland									
GISS	18.3	63.0	21.2	24.2	10.7	21.3	10.5	13.0	15.9
GFDL	23.1	87.1	23.1	31.9	12.2	23.2	19.0	8.4	14.9
UKMO	22.3	115.4	24.9	46.4	17.5	33.6	10.7	22.3	25.2
OSU	17.0	54.5	11.2	22.4	14.3	10.8	27.6	11.6	14.4
					Million ha				
New cropland									
GISS	34.8	28.9	16.5	1.1	10.5	12.1	5.2	119.9	229.0
GFDL	43.8	40.0	18.0	1.5	12.1	13.2	9.4	77.4	215.4
UKMO	42.4	53.1	19.4	2.2	17.2	19.1	5.3	205.2	363.8
OSU	32.2	25.1	8.7	1.0	14.1	6.1	13.6	106.4	207.4
					Percent of current				
Abandoned cropland									
GISS	8.6	0.0	14.4	6.3	0.6	1.9	7.8	2.9	4.2
GFDL	19.1	8.3	14.4	5.3	5.2	1.3	17.5	1.7	5.7
UKMO	17.5	3.1	15.6	5.7	5.3	2.9	16.1	9.7	10.5
OSU	15.3	5.4	7.2	4.7	6.8	1.4	5.6	6.2	7.3
					Million ha				
Abandoned cropland									
GISS	16.2	0.0	11.2	0.3	0.6	1.1	3.8	27.0	60.2
GFDL	36.4	3.8	11.2	0.2	5.2	0.8	8.6	15.8	82.0
UKMO	33.2	1.4	12.1	0.3	5.3	1.6	7.9	88.9	150.7
OSU	29.1	2.5	5.6	0.2	6.7	0.8	2.8	57.4	105.0

[1] Climate cnange 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).
[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).
[4] Australia and New Zealand. [5] Rest of world.

Figure 9

Cropland converted to other uses



[1] In Canada, no cropland was convened to other uses under the GISS scenario.

EC = European Community.

OEA = Other East Asia.

SEA = Southeast Asia.

ANZ = Australia and New Zealand.

ROW = Rest of world

GISS = Goddard Institute for Space Studies.

GFDL = Geophysical Fluid Dynamics Laboratory

UKMO = United Kingdom Meteorological Office.

OSU = Oregon State University.

Under the GISS scenario, for example, Canadian cropland is estimated to increase by 28.9 million hectares. Figure 11 maps primary locations of existing cropland as well as areas of potential cropland under the GISS climate scenario in Canada. Areas shown as high cropland potential are LC 2, LC 3, and LC 4 lands (not primarily cropland at present) that shift to or remain LC 4-approximately 144.6 million hectares. Areas with moderate cropland potential, about 36.9 million hectares. represent LC 3 land that remains LC 2. Areas of low cropland potential are LC 3 lands that remain LC 3.[32] Areas of very low cropland potential arc assumed to exist on land that had originally been LC I. Areas of low and very low cropland potential contain 190.8 million hectares and 588.2 million hectares, respectively.

Water Use

For the world as a whole, use of water for irrigation increases in all four scenarios (table 27). This is not surprising, since world supplies of water increase in all scenarios as well. Regions always using more irrigation water are Japan, other east Asia, and "rest of world." This is consistent with their greater reliance on irrigated agriculture. Not all regions use more water for irrigation, however. The EC and Australia/New Zealand use less water for irrigation despite genera1 increases in water supplies. Also, Southeast Asia uses less irrigation water in three scenarios despite supply increases. In the United States, consumption of irrigation water increases in the GFDL and OSU scenarios, but decreases in the GISS and UKMO scenarios.

Each climate change scenario affects water prices both when climate-induced water supply changes are simulated and when they are not (table 27). When water supply changes are simulated, price changes are presented for both the existing (fixed) and expanding cropland cases. The cases where water supply shocks are not simulated are expanding cropland cases. Water price increases indicate potential problems for water resource users.

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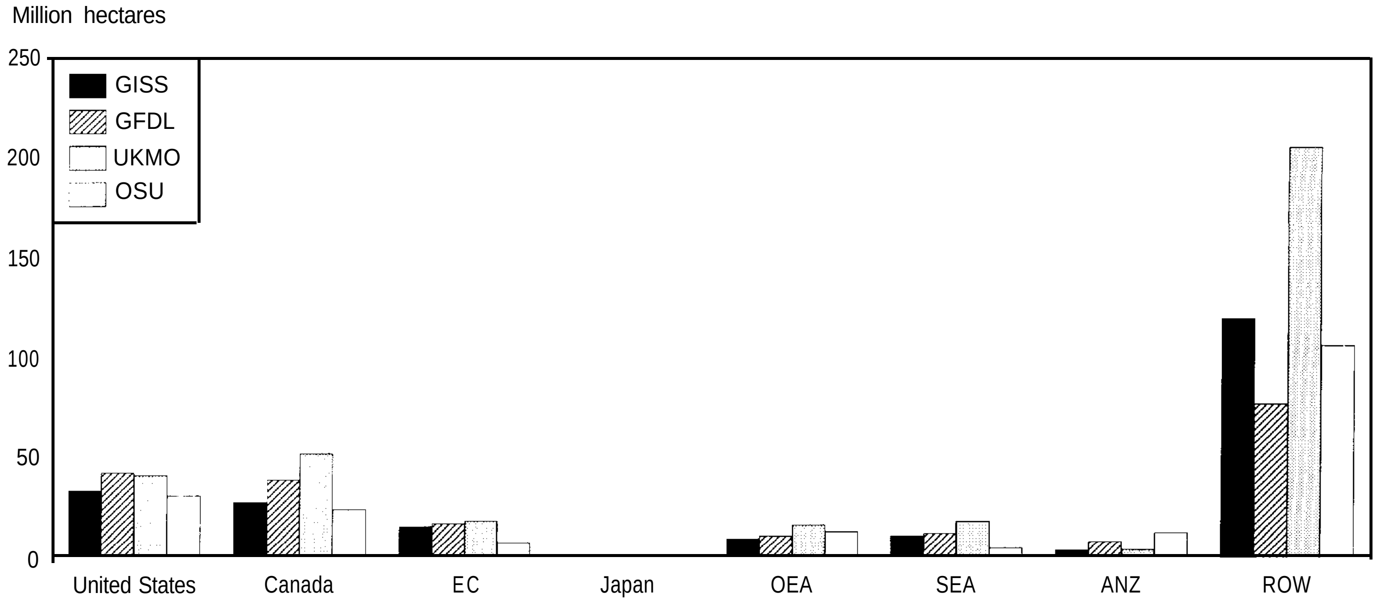
[32] Because it is located at lower latitudes, LC 2 that remains LC 2 in Canada is likely to have greater cropping potential than LC 3 that remains LC 3 under this scenario.

Figure 10

Increases in new cropland



EC = European Community.
OEA = Other East Asia.
SEA = Southeast Asia.
ANZ = Australia and New Zealand.
ROW = Rest of world.
GISS = Goddard Institute for Space Studies.
GFDL = Geophysical Fluid Dynamics Laboratory.
UKMO = United Kingdom Meteorological Office.
OSU = Oregon State University.

When cropland is allowed to expand and water supply shocks are simulated, world water prices increase, on average, for the OSU scenario and decrease for the GISS, GFDL, and UKMO scenarios. When cropland is held fixed, however, world water prices increase, on average, for the UKMO scenario and decrease for all other scenarios. These results demonstrate the potential sensitivity of water resource use to changes in the ability of farmers to take advantage of newly available cropland under alternative climates. When water supply shocks are not simulated, world water prices increase, on average, for the OSU and GFDL scenarios and decrease for the GISS and UKMO scenarios.

Regional water prices generally decline in the expanding cropland cases (table 27). The major exception is Japan, where water prices increase by more than 75 percent an all scenarios. These results indicate that, with a warmer climate, relatively severe conflicts over water resources are likely to occur in Japan. In the United States, water prices generally decline when there are no restrictions on cropland expansion (the exception is the OSU scenario). However, U.S. water prices increase in all scenarios when farmers are not allowed to adapt to climate change by expanding cropland.

Impacts on Gross Domestic Product

Real gross domestic product (GDP) is used as a measure of aggregate economic activity. Changes in GDP reflect changes in the prices of all goods and services consumed by households as well as changes in primary factor income and income from other sources.[33]

World GDP

Each climate change scenario affects GDP when cropland expansions are allowed, when land use changes

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[33] FARM uses utility functions to determine household demands for goods and services. Changes in real GDP are equivalent to changes in utility. The sensitivity of these results to 50-percent increases and decreases of selected model parameters in all regions is analyzed in appendix A. The analysis indicates that results presented here are not very sensitive to changes in model parameters.

Figure 11

Potential new cropland in Canada under the GISS 2xC0$_2$ climate change scenario

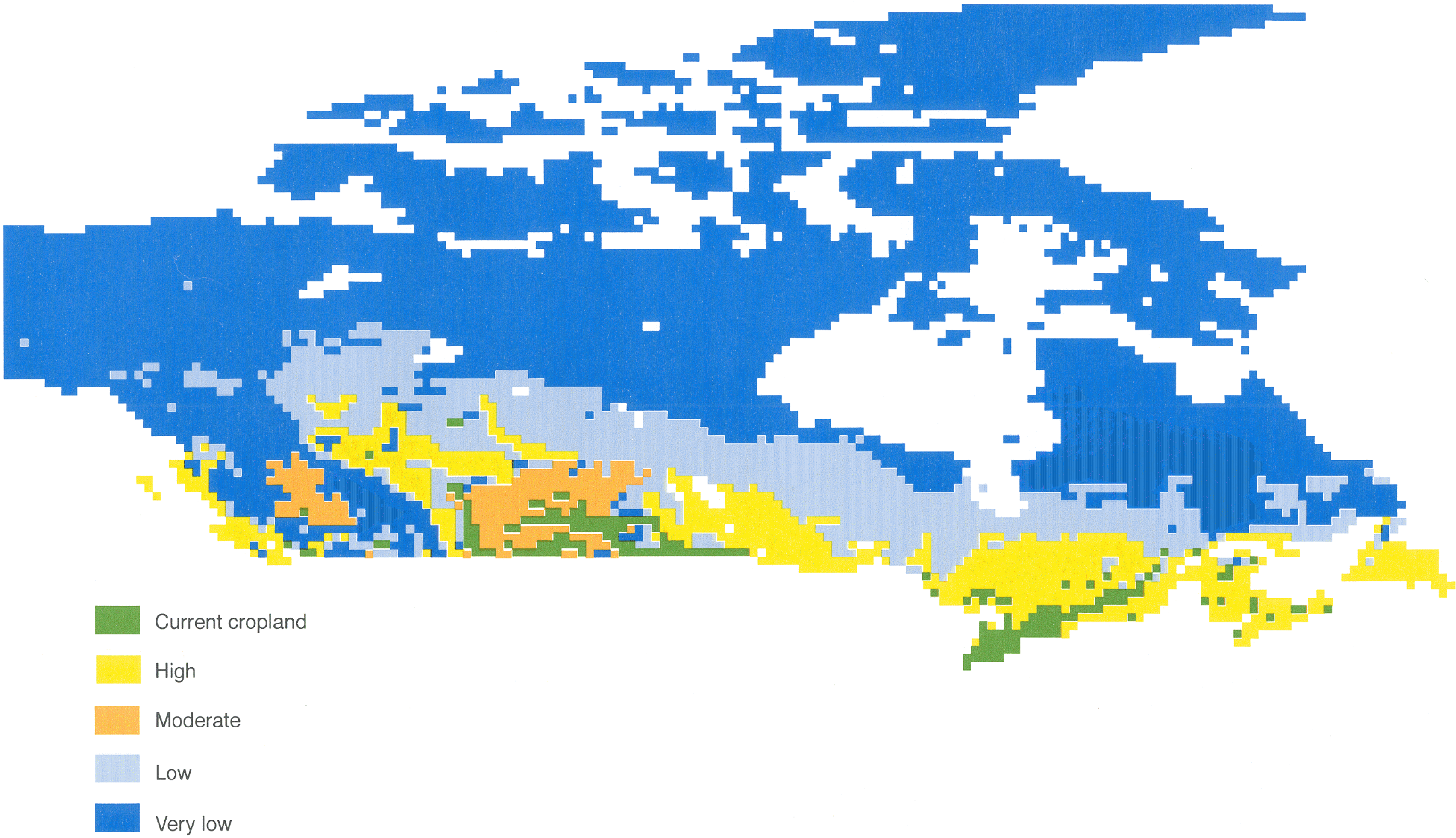

Table 27-Changes in the consumption and price of irrigation water, by region and climate change scenario

Simulation/ scenario[1]	Region								
	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
					Percent change				
Simulation: No land use restrictions, water shocks included									
Consumption effects									
GISS	-11.21	-40.06	-58.04	54.15	13.81	-11.82	-21.95	2.92	0.13
GFDL	5.57	55.68	-42.78	65.71	13.26	-1.51	-17.51	13.55	11.08
UKMO	-1.64	26.82	-63.37	57.82	5.31	-7.12	-3.40	4.19	1.73
OSU	16.18	64.65	-40.59	58.44	5.27	0.94	-51.41	6.52	7.23
Price effects									
GISS	-1.79	-5.75	-18.49	77.08	-28.21	-21.88	-23.91	-21.88	-16.88
GFDL	-1.52	0.82	-15.80	80.56	-15.47	-6.97	-22.50	-15.76	-10.48
UKMO	-3.22	-5.16	-21.81	111.51	-1.74	-17.51	-8.15	-15.54	-8.38
OSU	8.97	2.23	-14.08	83.70	-12.32	3.45	-27.23	0.30	1.10
Simulation: No land use movements, water shocks included									
Price effects									
GISS	6.41	-3.71	-6.34	70.37	-27.02	-17.95	-11.74	-13.62	-10.10
GFDL	4.05	-1.50	-5.18	76.57	-15.85	1.18	9.01	-8.77	-4.78
UKMO	9.29	-5.96	-6.50	109.46	26.37	0.73	30.67	0.78	8.42
OSU	11.73	-1.57	-10.53	71.85	-22.30	7.12	-7.81	-10.53	-6.07
Simulation: No land use restrictions, no water shocks									
Price effects									
GISS	-4.50	-1.90	-18.50	75.33	-10.48	-19.77	-10.62	-12.42	-8.60
GFDL	1.64	4.33	-14.63	91.10	0.82	-5.05	-9.61	0.01	2.11
UKMO	-1.51	2.26	-20.05	100.11	4.43	-14.72	-3.23	-7.13	-2.15
OSU	9.25	4.93	-13.79	84.27	-4.31	2.66	-16.54	-2.84	0.90

[1] 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).
[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).
[4] Australia and New Zealand. Rest of world.

are not allowed, and when water supply shocks are not simulated (table 28).[34] When cropland expansions are allowed, world GDP increases or decreases depending on the scenario. The impacts tend to be relatively small, in the range of + 0.1 percent of 1990 world GDP (losses of $24.5 billion to gains of $25.2 billion per year). World economic welfare appears to increase at relatively low levels of climate change and decrease at higher levels.

These results bound the 0.01-percent increase in world GDP reported for Kane, Reilly, and Tobey's (1990) "moderate impacts" scenario, which also did not include carbon dioxide fertilization. Our impacts on world GDP are less negative than results derived from Reilly, Hohmann, and Kane (1993) (table 29). These impacts, based on yield effects underlying Rosenzweig and others (1993) and Rosenzweig and Parry (1994), range from -0.6 to -1.3 percent. Reilly, Hohmann, and Kane (1993), however, did not consider Rosenzweig and Parry's (1994) level 2 adaptations. If they had, their results would have been less negative.

When land use changes are not allowed, world GDP declines by 0.004 to 0.352 percent (from $0.7 billion

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[34] We include the no-water-shocks cases to show that any bias associated with our water supply procedures does not have a major impact on estimates of overall economic activity (there is one small change in world product under the GFDL scenario).

Table 28-Changes in gross domestic product (GDP), by region and climate change scenario

	Region								
Scenario[1]	United States	Canada	EC	Japan	OEA[2]	SEA[3]	ANZ[4]	ROW[5]	Total
	Billion U.S. dollars								
Base GDP	5.497	598	5,923	3.041	743	292	362	4,603	21,059
	Percent change								
Unrestricted cases									
GISS	0.1	1.9	-0.9	0.8	0.4	-0.9	0.1	0.4	0.01
GFDL	-0.1	2.3	-0.7	0.6	0.4	-0.6	-0.2	0.3	-0.01
UKMO	0.0	2.8	-1.1	0.3	0.4	-1.3	-0.4	0.3	-0.12
OSU	-0.1	1.9	-0.3	0.7	0.2	-0.2	0.8	0.3	0.12
Land-use-restricted cases									
GISS	0.1	1.7	-1.1	0.6	0.2	-1.6	0.2	0.2	-0.13
GFDL	-0.2	2.0	-0.9	0.3	0.0	-1.3	-0.1	0.1	-0.25
UKMO	0.0	2.4	-1.3	0.0	-0.2	-2.6	-0.2	0.0	-0.35
OSU	-0.1	1.6	-0.5	0.5	0.0	-0.6	1.0	0.1	0.00
No-water-shocks cases									
GISS	0.1	1.9	-1.0	0.8	0.4	-0.9	0.1	0.4	0.01
GFDL	-0.1	2.3	-0.7	0.6	0.4	-0.6	-0.2	0.3	-0.02
UKMO	0.0	2.8	-1.1	0.3	0.4	-1.3	-0.4	0.3	-0.12
OSU	-0.1	1.9	-0.3	0.7	0.2	-0.2	0.8	0.3	0.12

[1] 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)
[2] Other East Asia (China, Hong Kong, Taiwan, and South Korea). [3] Southeast Asia (Thailand, Indonesia, Philippines, and Malaysia).
[4] Australia and New Zealand. [5] Rest of world.

Table 29-Changes in world gross domestic product, by climate change scenario

Scenario[1]	FARM	Alternative[2]
	Percent change	
GISS	0.01	-0.6
GFDL	-0.01	-0.8
UKMO	-0.12	-1.3

[1] Climate change scenarios generated by the general circulation models of the Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO). [2] Derived from results in Reilly, Hohmann, and Kane, 1993.

to $74.3 billion) per year across the four scenarios. One interpretation of these results is that, under global climate change, productivity losses on existing cropland, pasture, and forest land would generate losses in economic activity for the world as a whole.

Another interpretation is that these results serve as a correction for overly optimistic land use changes. Changes in land use implied by these scenarios may be overly optimistic because agricultural land expansion may be limited by agronomic, environmental, or other factors. Because of poor soil conditions, for example, some land may be unsuitable for some uses regardless of how favorable temperature and precipitation conditions become. Where production possibilities associated with land resources are limited by factors we have not considered, the cost of shifting land to some uses could be very high. Given the limitations of our modeling framework, results of the cases in which land use changes are not allowed represent lower bounds.

A third interpretation would be to consider the difference between the land-use-fixed and land-use-flexible scenarios as equivalent to the value of expanding cropland. Our analysis, however, considers only commercial use values associated with land and water resources. Not included here is the value of the environmental benefits provided by these resources (and their associated ecosystems).

Regional GDP

Changes in regional GDP are related to changes in regional production of primary commodities. Canada gains the most economically from climate change. Relative to 1990, real GDP increases in all scenarios (from 1.9 to 2.8 percent), Real GDP also increases in Japan (from 0.3 to 0.8 percent) and in other east Asia (from 0.2 to 0.4 percent). Real GDP drops by 0.2 to 1.3 percent in Southeast Asia and by 0.3 to 1.1 percent in the EC (table 28).

Impacts on U.S. GDP range from -0.1 to 0.1 percent (in 1990 dollars, from -US$4.8 billion to US$5.8 billion) per year. When land use changes are not allowed, changes in real GDP range from -0.2 to 0. I percent (in 1990 dollars, from -US$11.1 to US$5.9 billion) per year. These results indicate the impacts of climate change on U.S. GDP are characterized by a relatively high level of uncertainty.

Conclusions

As predicted by four major GCM's, global warming and associated changes in precipitation patterns during the next century are not likely to imperil food production for the world as a whole. Although world production of nongrain crops would probably decline, production of grain and livestock would likely increase. The net result is that world production of processed foods would be maintained slightly above current levels. These results are more positive than those suggested in previous research, even in research that included the beneficial effects of atmospheric carbon dioxide on plant growth.

The agricultural benefits of climate change are not equally distributed. In Canada, for example, output of agricultural and processed food commodities increases, while in Southeast Asia, output of these commodities generally decreases in all scenarios. Impacts on mid-latitude regions are mixed. These production changes are correlated with changes in the world's endowment of land resources. Warming in arctic and alpine areas is likely to increase the quantity of land suitable for agricultural production. Warming in some areas, however, particularly the tropics, is likely to reduce soil moisture, thereby shortening growing seasons and decreasing agricultural possibilities.

For world food production to maintain its level of output under climate change, farmers will have to respond to new climatic conditions. Even in areas where productivity is considerably reduced for existing agriculture, the initial impacts of climate change could be substantially alleviated by adopting appropriate crop and livestock mixes. Ways to encourage adopting appropriate crop and livestock mixes include reducing barriers to trade and implementing commodity support programs that allow farmers more flexibility in production decisions (Lewandrowski and Brazee, 1993). Also, though not explicitly modeled in this research, expanding technical possibilities by strengthening institutions currently involved in the identification, development, and transfer of agricultural technologies would increase crop and livestock possibilities available to farmers. Such technical advances would help farmers adjust to changes in soil or other nonclimatic characteristics not considered here.

Another key reason for maintaining world food production under global climate change will be the ability of farmers to increase the amount of land under cultivation. This could be especially important in high-latitude regions, where the amount of agriculturally suitable land is expected to increase with a warmer climate. Some farm communities could be disrupted in this process, however, particularly in areas where the only economically viable adaptation is to abandon agriculture. Some land use and cover changes we simulate, however, may be hindered by agronomic, political, environmental, or other constraints not accounted for in the FARM framework. Our framework's ability to link quantitative estimates of land use changes with specific geographic locations will help to flag and resolve some of these cases.

Another reason that world food production remains relatively stable under all climate change scenarios is that household consumption of food is likely to vary less than consumption of nonfood items during periods of economic change. This means that climate-induced impacts are likely to spill over into sectors only distantly related to food production. Thus, as indicated by our results. gross world product is likely to decline when climate change becomes relatively more severe because increases in food production will be more than offset by losses in other sectors.

In some regions, farmers will have a difficult time adapting to climate change. This may be because the initial effects on agricultural productivity are particularly severe, the amount of agriculturally suitable land remains the same or declines, or competition from foreign producers increases. In most regions, the direction of climate-induced impacts (both positive and negative) is the same for all four scenarios. In some regions, however, climate-induced impacts are characterized by uncertainty-their direction may vary from one scenario to another.

In the United States, for example, GDP increases in two scenarios and decreases in the other two. This uncertainty arises from differences in effects on land endowments. Productivity on existing agricultural land declines under three of the four climate change scenarios. In all scenarios, some gains obtained by increases in the amount of agriculturally suitable land are offset by negative impacts in the Corn Belt. Farmers adapt by increasing wheat production and reducing production of other grains, primarily maize. In two scenarios, negative impacts also occur in the Southeast, an important source of fruits and vegetables. Hence, output of nongrains also increases or decreases, depending on the scenario. The end result is that production of livestock, as well as fish, meat, and milk, decreases in all scenarios, while production of other processed foods decreases in three scenarios.

Finally, the potential for decreases in world production when climate change impacts are strong suggests that some mitigation of trace gas emissions is likely to be desirable. How aggressively to pursue mitigation, however, is a question that will be answered differently by people who live in regions that incur economic losses than by those who live in regions that benefit from climate change. More precise information about the costs and benefits of climate change can be obtained in future research by incorporating the effects of atmospheric carbon dioxide on plant growth, by improving the methods used to simulate water supply and use, and by further disaggregating the regions in the modeling framework. Adding these features, however, will probably have little qualitative effect on the responses to changing temperature and precipitation patterns captured by this research.

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Appendix A: FARM's CGE Model

FARM's economic structure is embodied in a multiregion, multisector, computable general equilibrium (CGE) model. CGE models explicitly account for all domestic and international value flows. Because households are assumed to own all primary factors of production, value flows are traced from households through domestic and international markets to producing sectors and then back to households. CGE models, therefore, provide comprehensive measures of economic activity. For surveys of computable general equilibrium studies, see Shoven and Whalley (1984) and Robinson (1989 and 1990).

Model Structure

FARM's CGE model is an aggregation and extension of the Global Trade Analysis Project (GTAP) model (Hertel, 1993). Appendix table Al shows the mapping between GTAP's regions, sectors, and commodities and FARM's regions, sectors, and commodities. FARM divides the world into 8 geographic regions. Each region has 11 economic sectors. which produce 13 tradable commodities. Except for the crops sector, there is a one-to-one correspondence between sectors and commodities. The crops sector is multioutput, producing wheat, other grains, and nongrains.

All regions produce, consume, and trade the 13 commodities. Moving goods across regions requires expenditures for international transportation services. All regional income ultimately accrues to households which, in turn, spend it on private consumption, government goods and services, and savings. Global savings finance the building of new capital goods (a 12th economic sector) in each region. Savings equals investment from a global perspective, but the equality need not hold in any given region.

FARM's major extensions to GTAP are (1) the inclusion of heterogeneous land endowments, (2) the introduction of water as a primary input in the crops, livestock, and service sectors, and (3) the modeling of crop production as a multioutput sector. These extensions allow us to account for climate-induced changes in the productivity and availability of land and water resources when analyzing how climate change might impact regional and world commodity markets (production, consumption, prices, and trade). These extensions also allow us to estimate climate-induced shifts in land use within and among the crops, livestock, and forestry sectors.

Primary Factor Endowments

There are four types of primary factors-land, water, labor, and capital. Primary factors are owned by households, which supply the services of these factors to producing sectors. Economic sectors compete for the services of each primary factor within each region. Primary factors are region-specific (one region's primary factors can not be used by another region's sectors).

To capture various productivity differences associated with land resources, FARM treats land as a heterogeneous factor. This is done two ways. First, each region may have up to six types of land resources or "land classes." Land classes are determined by the length of the growing season. Each land class supplies services to the 11 commodity producing sectors (app. fig. Al). Second, by basing land supplies on constant elasticity of transformation (CET) functions with Allen partial elasticities (σ_{TL}) less than zero, FARM simulates productivity differences within land classes. CET functions restrict land's mobility among sectors, so for a given region and land class, cropland owners may receive higher rents than pasture land owners. This structure allows land to shift among economic sectors (such as into new uses) in response to changing conditions without losing sight of land's inherent productivity differences.

Water in FARM is used by the crops, livestock, and service sectors. Appendix figure A2 depicts a regional water market. Within a region, the supply of water is perfectly inelastic. A region's water demand is downward sloping (sensitive to the price of water) and is the summation of water demands from the crops, livestock, and service sectors. The crops and livestock sectors use water for irrigation. The services sector uses water for all other uses. Water is a homogeneous input, which means that it is mobile among a region's crops, livestock, and services sectors and that there is one regionwide water price.

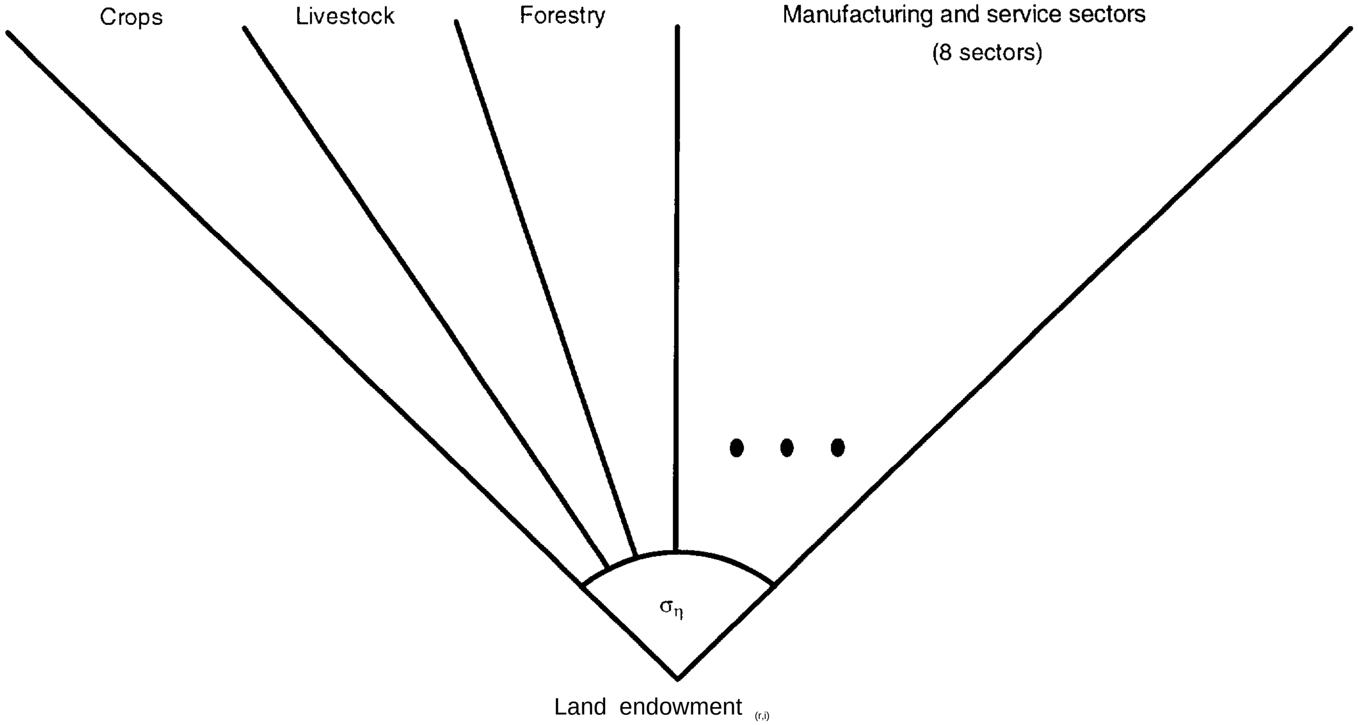
Regional markets for labor and existing capital are similar in structure to regional water markets. The supply of both factors are perfectly inelastic. Demands for both factors are downward sloping and are the summation of demands from all producing sectors. Labor and capital are also homogeneous within regions (mobile across all economic sectors and each with one regional price).

Production

Producer behavior in FARM is driven by profit maximization assuming competitive markets. Technology in each sector is assumed to be constant returns to scale. Three sectors (crops, livestock, and forestry) are composed of land-class-specific subsectors. Production in a crops subsector is depicted by the tree diagram in appendix figure A3. The branches of the

Appendix figure A1

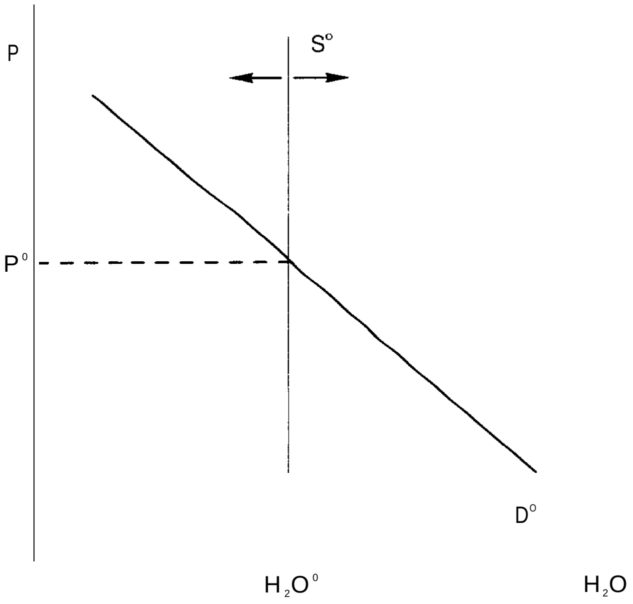
Supply of services from land in FARM



r=region=1,...,8.
i=land class=1, ..., 6.

Appendix figure A2

Regional water markets in FARM



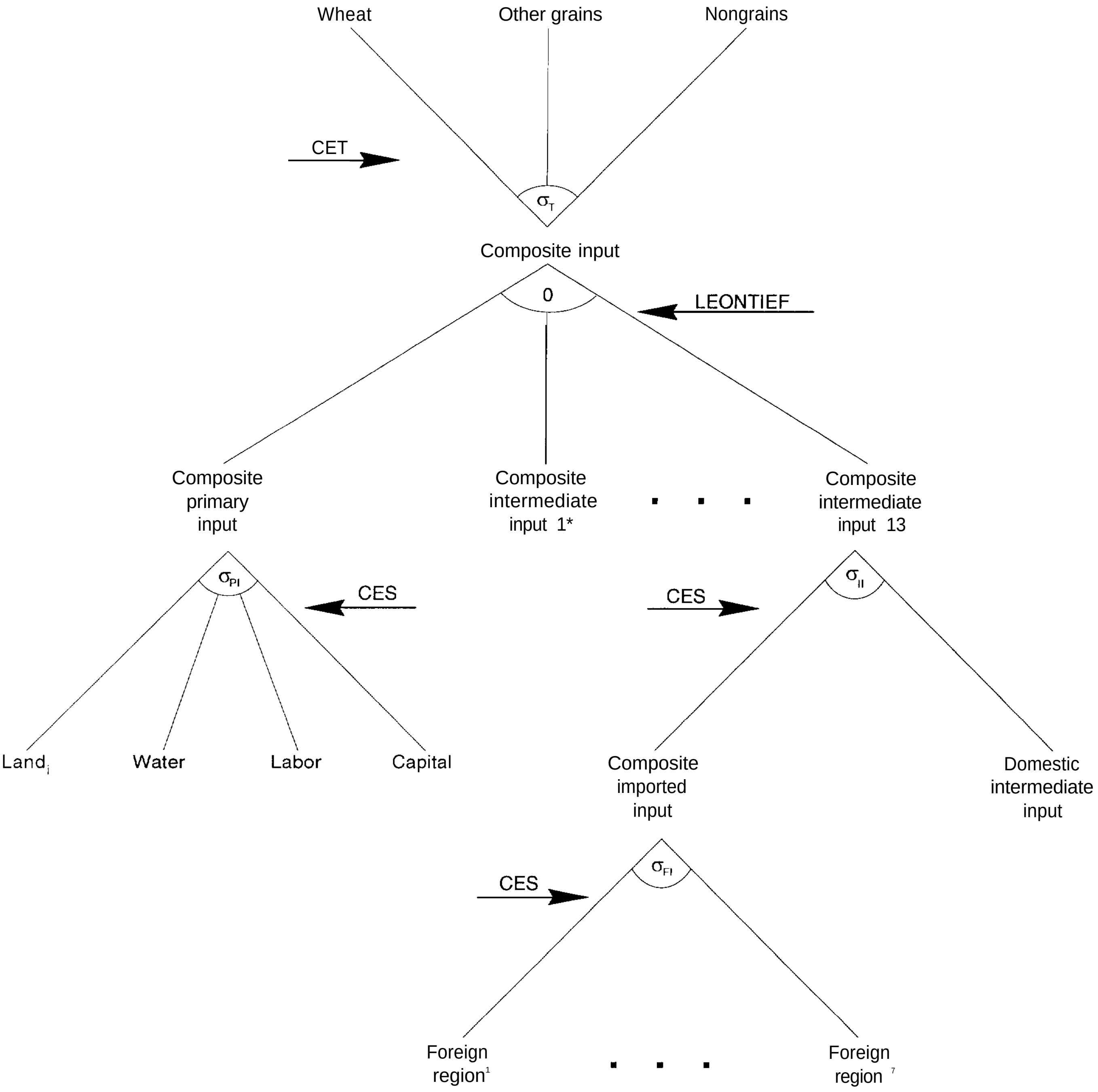
tree represent activities that connect different levels in the production process.

On the input side, crop producers start by undertaking two independent activities. One activity combines land (from a specific land class), labor, capital, and water into a composite primary input. The other activity combines domestically produced and imported intermediate inputs into composite intermediate inputs. The occurrence of these activities in different branches implies that the activities are separable (the optimal factor mix in a particular branch is unaffected by changes in the relative prices of factors in other branches).

Firms combine the composite primary factor with composite intermediate inputs in fixed proportions (using a Leontief technology) to produce a final composite input. In the crops sector, this final input is used to produce wheat, other grains, and nongrains. In single-output sectors, the final composite input is equal to output.

Appendix figure A3

Crop production in FARM



CES = Constant elasticity of substitution of inputs.
CET = Constant elasticity of transformation of outputs.
LEONTIEF = No substitution of inputs.
***Structure of composite same as for intermediate input 13.**

Primary inputs. As indicated by appendix figure A3, the composite primary input in the crops subsectors is a Constant Elasticity of Substitution (CES) function of land, water, labor, and capital. In CES functions, Allen partial elasticities (σ_{TL}) are greater than zero. CES functions mimic the difficulty in substituting one primary factor for another. Capital, for example, is not perfectly substitutable for land in agricultural production. This means that if the price of a particular factor increases, the sector will demand less of that factor. The relative strength of this effect is an increasing function of the Allen partial elasticity of substitution and a decreasing function of the factor's cost share.

The composite primary input in the livestock subsectors also contains land, water, labor, and capital. The composite input in the forestry subsectors only contains land, labor, and capital. Composite primary inputs in the manufacturing and service sectors are not land-class specific (there is not a unique production structure associated with each land class). Instead, each sector's composite primary input contains land from all six land classes together with labor, capital, and, in the services sector, water (app. fig. A4). The capital goods sector does not use primary factors; these have been incorporated in the cost structure of all other industries that provide intermediate inputs to the capital goods sector.

Intermediate inputs. As indicated by appendix figures A3 and A4, composite intermediate inputs are formed in two stages. For a given commodity, producers at one stage choose the optimal mix of imported and domestic goods. At another stage they source the amount to be imported by region. Both stages are modeled using CES specifications with Allen partial elasticities of substitution σ_{II} and σ_{FI}, respectively, greater than zero.

The σ_{II} elasticity measures the degree of substitution between domestic and imported commodities. It determines the change in imports demanded when the relative price of imported to domestic commodities changes. The σ_{FI} elasticity measures the degree of substitution among commodities from different regions. It determines the change in demand for imports from a region when the relative price of that region's goods changes. Prices of foreign intermediate inputs depend on prices in the region of origin plus transport costs and other import fees.

This structure means that trade in intermediate inputs follows an Armington structure. The Armington structure assumes that sectors differentiate among imported commodities according to the country of origin, and among domestic and imported varieties. The Armington structure has been criticized as being unnecessarily restrictive. It has, however, been popular in world trade models because it accommodates, in a straightforward manner, trade in similar goods (which is observed in trade statistics) and less-than-perfectly-elastic import demands (which are found in the literature). Also, as Hertel (1993) notes, more flexible functional forms of trade have not yet been operationalized in the context of disaggregated world trade models.

Composite primary inputs are then combined in fixed proportion with appropriate sets of composite intermediate inputs to produce composite inputs. This structure implies no substitution between primary and intermediate inputs or between intermediate inputs within a sector.

Product supply. Each crops subsector within a region produces its own mix of wheat, other grains, and nongrains. This mix is determined by CET functions with Allen partial elasticities σ_{T} less than zero. These elasticities determine how supplies of wheat, other grains, and nongrains change in response to changes in the relative prices of these commodities. Regional production of wheat, other grains, and nongrains is the sum of production across the six land classes. Regional livestock and forestry outputs are also obtained by summing production across the land classes in their respective sectors. In other sectors, the final composite input is equal to output.

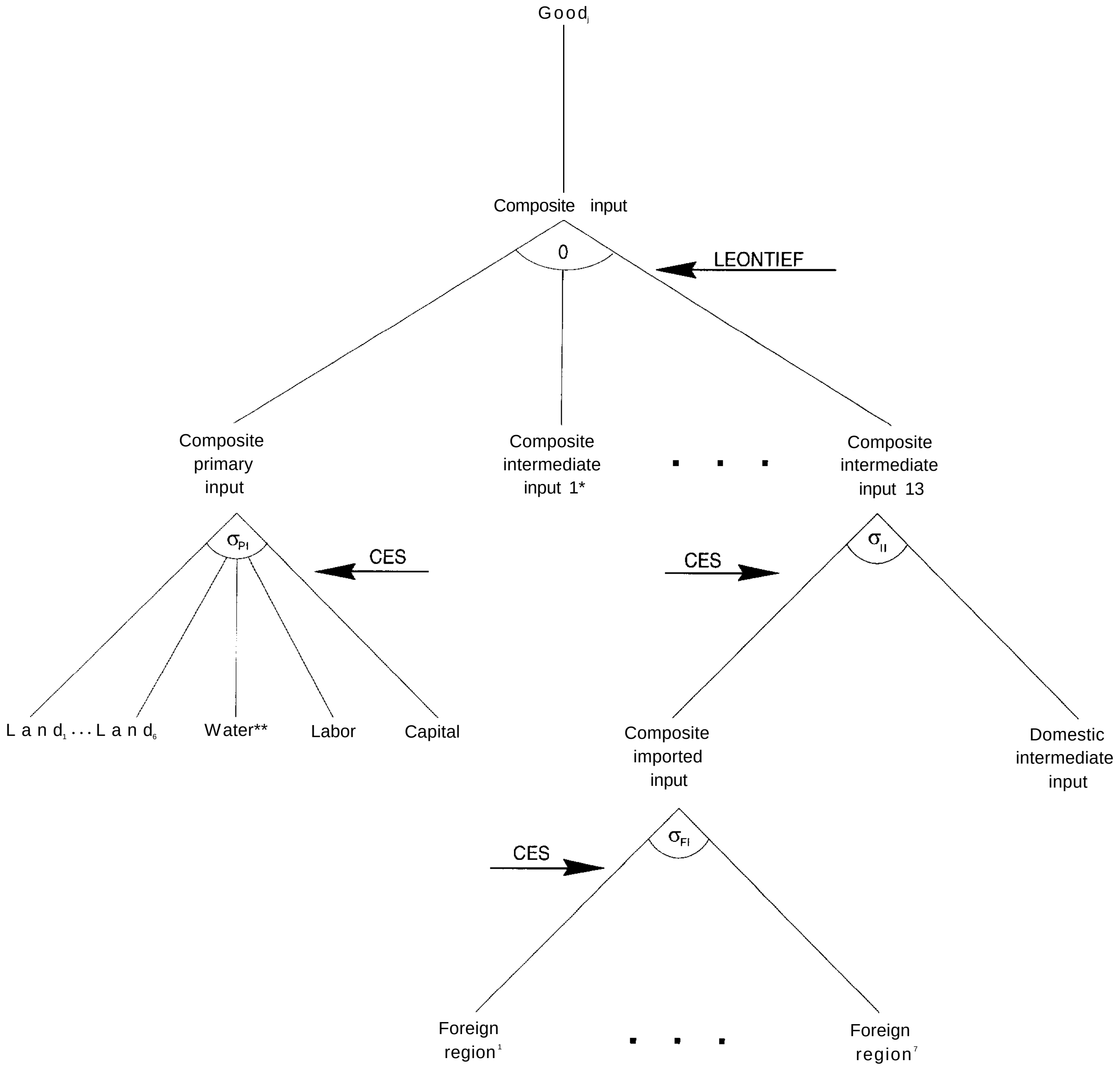
Consumption

Household behavior and consumption are depicted by the tree diagram in appendix figure A5. Consumption is modeled using the concept of a utility-maximizing "super household." The super household owns all primary factors of production and, through payments for the use of these factors, receives all regional income. The household maximizes utility derived from private consumption, government purchases, and savings (future consumption). Utility at this level is modeled using Cobb-Douglas utility functions (CES specifications with Allen partial elasticities of substitution equal to one). This means that the income shares of private consumption, government purchases, and savings within a region are constant (but not equal) across all income levels. Private households and governments consume domestic and imported commodities.

Private household demands are modeled with Constant Difference of Elasticities (CDE) specifications (Hanoch, 1975; and Hertel and others 1991). The CDE structure is less restrictive than the CES function in that (1) elasticities of substitution between pairs of commodities can differ (one elasticity does not capture all substitution possibilities between commodities), and (2) income elasticities are not restricted to equal one. Total gov-

Appendix figure A4

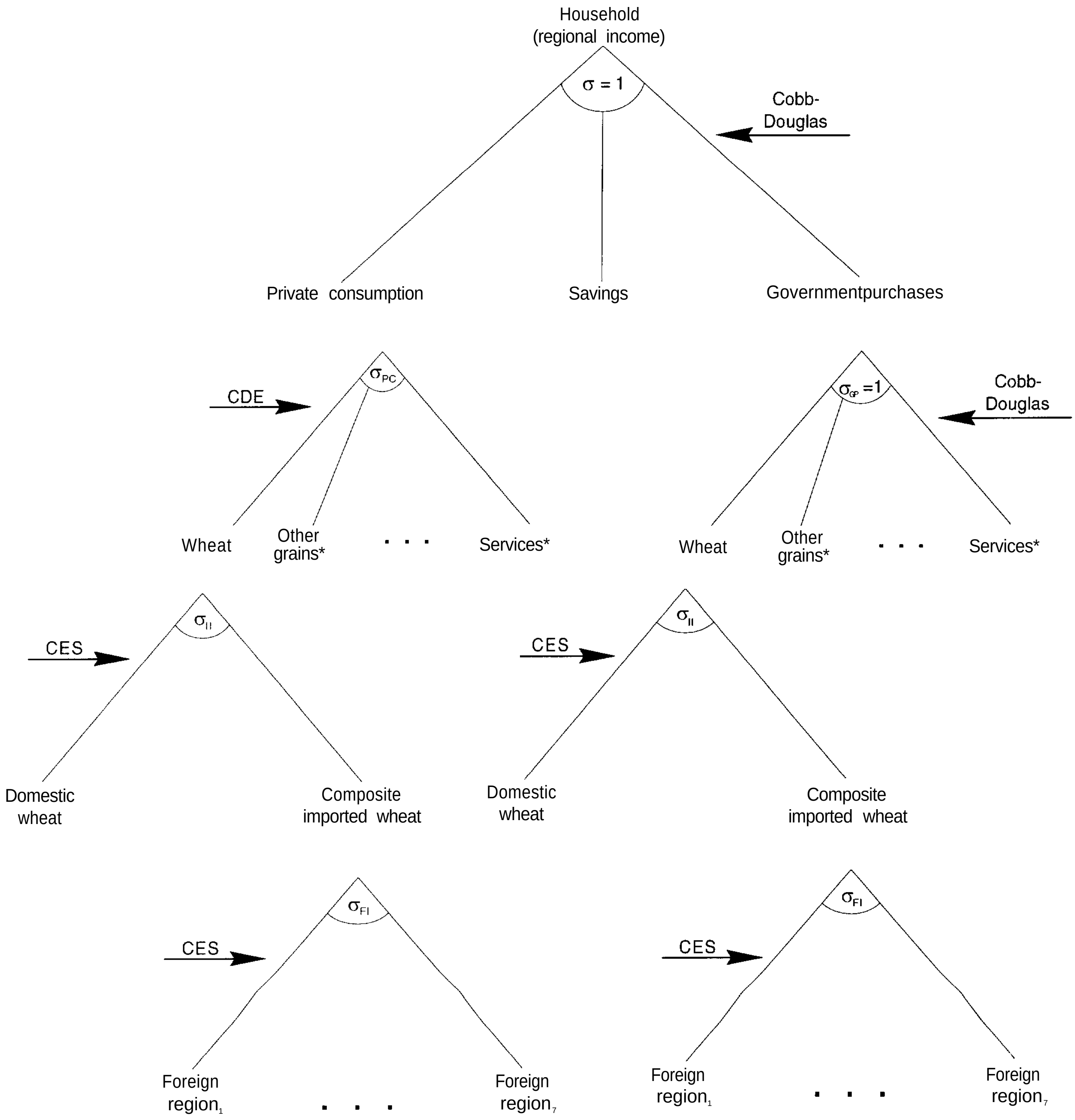
Production of manufacture and services in FARM



CES = Constant elasticity of substitution of inputs.
LEONTIEF = No substitution of inputs.
*Structure of composite same as for intermediate input 13.
**Services sector only.

Appendix figure A5

Household behavior and consumption in FARM



CDE = Constant difference of elasticities for input substitution.
CES = Constant elasticity of substitution of inputs.
Cobb-Douglas = Elasticity of substitution is equal to one.
*Stage 3 and 4 expenditure branches similar to wheat but omitted for clarity.

ernment purchases are allocated across commodities using Cobb-Douglas utility functions (commodity budget shares are constant but not equal).

Consumption of imported commodities by households and governments is subject to the Armington assumption in a manner analogous to the derivation of composite intermediate inputs in production. That is, for each commodity in the private consumption and government purchases nests, it is assumed that domestically produced and imported goods are imperfect substitutes. Commodity expenditures are allocated to domestically produced and imported goods using a CES functional form at one stage. Expenditures on imported commodities are allocated to foreign regions at another stage.

Regional savings are a constant share of income and savers across regions see the same price. The price of savings is also the numeraire. Savings is used to purchase the capital goods commodity. The sum of regional savings is allocated across regions based on their demand for new capital goods.

Global Transport Services

Commodities are traded both as intermediate inputs in production and as goods and services in private consumption and government purchases (app. fig. A3, A4, and A5). Trade across regions requires transportation services. Transportation requirements are route and commodity specific and are determined in fixed proportions to the quantities of goods shipped. The world price of transportation services is market determined and equates the global demand for such services with the global supply; each region supplies a fixed value share of global transportation services.

Parameter Calibration

To simulate with FARM, we need to specify values for all its production and consumption parameters. These parameters are usually calibrated (values are chosen such that the initial equilibrium data are reproduced exactly as an equilibrium solution) (Mansur and Whalley, 1984). For example, let output, Q, be a CES function of labor, L, and capital, K:

$$Q = \Phi \, [\delta \, L^{(\sigma-1)/\sigma} + (1-\delta) \, K^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)} \qquad \text{(A1)}$$

A standard approach is to obtain an estimate of the Allen partial elasticity of substitution, $\sigma > 0$, from the literature and then choose parameters Φ and δ such that in initial equilibrium: (1) the first order conditions for cost minimization with respect to capital and labor are satisfied, and (2) profits are zero.

FARM, however, uses linearized CES (or CET) functions.’ With a linearized CES function, we only need to obtain an estimate of σ. Estimates of Φ, and δ are not required because they are embedded in the initial equilibrium data which are in value terms. Thus, calibration is a simple task for FARM, because most of the functional forms are of the CES or CET type. The only exception is the private household commodity demand system which is based on the CDE expenditure function. Its calibration is discussed by Chyc (1993).

Most parameters in FARM come from GTAP (Hertel, 1993) and are based on a review of the literature. These include the Allen partial elasticities for primary factors, the Allen partial elasticities of import substitution of intermediate commodities, and the price and income elasticities for private consumption. These elasticities are presented in appendix tables A2-A5.

There are few estimates of Allen partial elasticities of substitution for land and crop supplies as modeled in FARM. At present, therefore, the default values for these elasticities (σ_{TL} and σ_{T} in appendix figures Al and A3, respectively) are set equal to -1.0. This reduces the CET frontiers to Cobb-Douglas form. This means that the revenue shares for crops services and livestock services, for example, received by land owners and the revenue shares received for wheat, other grains, and nongrains by crop producers within a region are constant (but not equal) across all levels of revenue.

Data Calibration

Because FARM calibrates crop, livestock, and forestry production by land class and water use by sector, the GTAP data on regional revenues and expenditures (in 1990 US dollars) for sectors and consumers needed to be disaggregated. Several global databases were used in conjunction with FARM's geographic information system to accomplish this task.

Resource Supply

All acreage in each region is allocated to one of four land-use types—cropland, permanent pasture, forest, and other-using 1990 estimates from United Nations, Food and Agriculture Organization (FAO) (1992). Regional land-use acreage is allocated to land classes by combining land use and cover data in Olson (1989-91) with the land class data set pertaining to current climatic conditions. These regional land class distributions of cropland, permanent pasture, and forest land are used in allocating the GTAP input and output values associated with the crop, livestock, and forestry sectors.

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[1] Hertel and Tsigas (1993) and Dixon and others (1982) show how these linearized functions are obtained from their nonlinear forms.

Regional water supply estimates are derived from water withdrawal data in World Resources Institute (WRI) (1992). WRI gives water withdrawals for agriculture and nonagriculture by country. In each region, irrigated acreage (FAO, 1992) is distributed to the land classes based on irrigated land data in Wilson and Henderson-Sellers (1985), crops and settlements data in Olson (1989-91), and length-of-growing-season data.

Output Values

GTAP's regional output values for wheat, other grains, nongrains, livestock, and forest products are distributed to the land classes based on various output quantity shares. Producers of a given commodity within a region are assumed to receive the same price for the commodity no matter what land class they use in production. Table 9 in the main text shows crop, livestock, and forest product quantities by region and land class.

Values of wheat, other grains, and nongrains are distributed to land classes based on 1990 crop production data compiled from FAO (1992). To keep the task manageable, the FAO data are aggregated into 32 crop groups. For paddy rice, regional production is allocated entirely to irrigated acreage. In making the rice allocations, differences in length of growing season, which governs plant maturing time and multicropping potential, were taken into account.

For all other crop groups, regression analysis was used to allocate regional production to the land classes. Specifically, regional output was regressed on cropland acreage in the six land classes with adjustments made to account for irrigation. Irrigation adjustments were necessary because irrigation lengthens the growing season and may move land into a new land class for purposes of crop production.

We were able to visually compare most of our crop distributions with crop distribution maps from other sources (U.S. Department of Agriculture, Foreign Agricultural Service, 199 I). These comparisons resulted in some adjustments to our distributions. The land class shares of total value of regional wheat, other grain, and nongrain production are obtained by appropriately aggregating the land-class distributions of the 32 crop outputs.

Production of cattle, sheep, pigs, goats, and other livestock in ! 990 is detailed in FAO (I 992). Regional production of these livestock is distributed among the land classes based on animal densities in Lerner, Matthews, and Fung (1989). Land class shares of total value of regional livestock production are obtained by aggregating the land-class distributions of the different livestock outputs.

Regional forestry outputs are based on 1990 production data for coniferous and nonconiferous industrial roundwood and fuelwood from FAO (1992). These are allocated to land classes based on distributions of coniferous, broadleaf, and mixed forests derived from Olson (1989-91). Adjustments are made to capture productivity differences due to length of growing season. Each land class's share of total value of regional forestry production is obtained by aggregating its shares of the various forest products.

Input Values

To maintain the integrity of the database, FARM uses GTAP's sectoral payments to each intermediate input as well as GTAP's sectoral payments to primary factors in each region. GTAP's primary factor payments, however, do not include separate values for water or for land in nonagricultural sectors. The first step in allocating input values, therefore, is to divide GTAP's primary factor payments into land, labor, and capital. From a review of the literature we obtained a more complete set of sectoral payments to land, labor, and capital in each region. For GTAP's nonagricultural sectors, the land payments are subtracted from GTAP's payments to capital; that is, we assume that, in the GTAP data, payments to capital include payments to land.

Next, we distribute the (revised) agricultural and silvicultural sectors' payments to land, labor, capital, and intermediate inputs to the land classes. These payments are distributed to the land classes based on their respective commodity output shares. Input payments for the crops subsectors are then obtained by summing across the appropriate land-class specific input values attributed to wheat, other grains, and nongrains. This results in a different input structure for each crop subsector.

We then distribute the remaining sectors' land payments to the land classes. Except for the services sector, land payments are allocated to land classes based on the land class distribution of crops and settlements in Olson (1989-91). For the services sector, 90 percent of the land payment is allocated based on the land class distribution of crops and settlements in Olson (1989-91) and 10 percent of the land payment is allocated based on length of growing season (as defined by the land class distribution of hectare day shares).

Once regional payments to land, labor, capital, and intermediate inputs are distributed to the land classes, three land-class-specific adjustments are made. First, payments to water are subtracted from payments to land. Second, payments to irrigation capital are subtracted from land and added to capital. Third, payments to livestock feed and pasture are adjusted to account for the relative importance of grazing on dryland pasture in areas where growing seasons are short.

Water. FARM requires values for water used in the crops, livestock, and services sectors. Global data on water prices are almost nonexistent so a price of $2.55 million (US) per cubic kilometer is used in all regions. This value is based on U.S. data (U.S. Department of Commerce, 1990). The same water price is applied to water used in the agricultural and services sectors. The latter is composed of both domestic and industrial water (WRI, 1992). Values of irrigation water on cropland and permanent pasture are derived by allocating 90 percent of agriculture's water payments to crops and 10 percent to livestock.

Once total water payments for the three sectors are derived, the amount to charge each land class is determined. This determination is based on estimates of each land class's requirement for irrigation water (each land class's share of regional water shortages on irrigated land). Water shortage is defined as the amount of water required to maintain potential evapotranspiration during the growing season minus precipitation. Each sector's land class specific water payments are then subtracted from the appropriate land payments.

In this approach, variability of water requirements is reflected in the variability of water payments by the land-class-specific crops and livestock subsectors. Variability in water requirements is also reflected in a region's service sector by varying payments to land. The service sector's payment to water, however, occurs as one lump sum. It is not differentiated by land class.

Irrigation capital. Regional payments to irrigation capital are calculated from payments to land using the shares of total hectare-days in a region's growing season attributed solely to irrigation (total hectare-days minus rainfed hectare-days divided by total hectare-days).[2] This assumes that value of a region's irrigation capital is equivalent to the additional length of growing season that such capital provides. Ninety percent of these payments are allocated to crops and 10 percent to pasture. Land-class-specific payments to irrigation capital are based on the distribution of a region's requirements for irrigation water. These payments are then added to the appropriate land class's capital payments.

Livestock feed and pasture. GTAP's regional values for livestock feed are allocated to the land classes based on weighted shares of feed consumed by the livestock associated with the land classes. The weights are 20, 15, 10, 3, and 2 percent, respectively, for dairy cattle, beef cattle and water buffalo, horses and camels, pigs, and sheep and goats. These weights are combined with the animal densities in Lemer, Matthews, and Fung (1989).

We also adjust for the relative importance of grazing on unirrigated pasture in areas where growing season is less than or equal to 100 days. We assume, for example, that sheep, goats, camels, and horses raised on these lands would receive little, if any, livestock feed other than hay. Therefore, payments to dryland pasture in areas where growing seasons are less than or equal to 100 days are increased, while the value of livestock feed allocated to these pastures is decreased. We make the adjustment using densities of camels, goats, and sheep in Lerner, Matthews, and Fung (1989). These changes are balanced by decreasing values of pasture and increasing values of livestock feed on other land classes. This approach simulates the substitution of land for feed in some livestock operations.

Modeling Climate Change

FARM models global climate change as (1) right or left shifts in regional water supplies and (2) changes in the distribution of land across land classes (app. fig. A2) These regional changes in land and water endowments are computed in FARM's geographic information system for each climate change scenario considered. We assume that climate change does not affect endowments of either labor or capital.

FARM is implemented using the GEMPACK suite of model development software (Codsi and Pearson, 1988; and Pearson, 1988). GEMPACK solves a system of nonlinear equations via a linearized representation and this has implications for data requirements and interpretation of results (Pearson, 1991). First, an initial equilibrium is fully described in terms of revenues and expenditures only (information on the associated quantity and price terms is not necessary). Second, results for variables are given in terms of percentage changes.

Most model results can be interpreted in a straightforward manner; the major exception is land services. The CET functions used to simulate supplies of land services in FARM are nonlinear. Quantities of land services, therefore, are not measured in hectares (or any other measure of area). Rather, they are measured in "productivity" units, which are consistent with a CET frontier. Because land is generally measured, and more easily comprehended, in area units, we convert productivity units to hectares. This conversion, however, is somewhat imprecise because conversion factors (hec-

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[2] The number of hectare-days in a region's growing season accounts for both growing season lengths and the amount of land under cultivation.

tares per unit productivity) and complete specifications of the CET functions are not known (app. equation Al).

We start by assuming that the relationship between percentage changes in land area and percentage changes in productivity quantities (as computed in FARM) is direct and monotonic. If, for example, a crops subsector uses more land services while the corresponding livestock subsector uses less, then we assume that the crops subsector uses more land area, while the corresponding livestock sector uses less.

We also impose three constraints. First, the sum of net changes in land use within each land class of any region must equal the climate-induced shock to that land class endowment. This ensures that the net change in total land within each region equals zero. This constraint is imposed by proportionally adjusting land quantities derived from the FARM simulations. Proportional adjustments also maintain our second constraint (all land quantities must be non-negative.

The third constraint is that land-use changes must be sign preserving relative to expected changes. Expected land use changes equal the climate-induced land-class changes. When this constraint fails, we compute sectoral differences between reported and expected land use quantities, group them by sign, and calculate the absolute value of each group's total differences. The first constraint is imposed by assigning the smallest absolute value of differences to each group. This also ensures that land quantities remain equal to or greater than zero. The adjusted differences are then proportionally reassigned to the sectors contributing to that group.

Sensitivity Analysis

Most parameters in FARM were obtained from a review of the literature. In some cases, however, parameters that were estimated for a limited number of countries have been applied broadly. In addition, empirical estimates of some model parameters were unavailable. We therefore conducted sensitivity analyses to assess the importance of model results to parameter specifications. All sensitivity analyses were done using the climate change scenario generated by the Goddard Institute of Space Studies' general circulation model.

The analysis consisted of simultaneously increasing or decreasing all substitution elasticities of a given type (such as land supply, crop supply, primary factor demand, and import demand) by 50 percent. This, therefore, is not an uncertainty analysis (an attempt to predict a range of results given information about the bounds or confidence limits of parameters). This also means that the focus of the analysis is on global, rather than regional, impacts. Sensitivity analysis results for impacts on gross world product as well as world production of agricultural and silvicultural products are presented in appendix tables A6 and A7.

Results pertaining to gross world product suggest that model results are relatively sensitive to changes in values assumed for the primary factor demand elasticities (app. table A6). Reducing these elasticities by 50 percent causes gross world product to decrease by $115.9 billion, while increasing them by 50 percent causes gross world product to increase by $45.2 billion. This is a range of $161.1 billion. Results are much less sensitive to changes in values of land supply, crop supply, and imported demand elasticities. The range of gross world product between high and low values of these elasticities is always less than $8.8 billion.

A similar pattern occurs with world production of selected commodities. In general, commodity production is more sensitive to changes in primary factor demand elasticities than to changes in land supply, crop supply, or import demand elasticities (app. table A7). The reason results are most sensitive to changes in primary factor demand elasticities is that they affect all commodities through all primary factors. Land supply elasticities, on the other hand, affect all commodities but only through one primary factor (land), while crop supply elasticities affect crop commodities only and import elasticities affect only the traded portion of commodities.

This analysis suggests that FARM simulation results are generally robust with respect to land supply, crop supply, and import demand elasticities. Adjusting any one set of these elasticities has a relatively small impact on the magnitude of climate change's impact on gross world product or on world production of agricultural and silvicultural products relative to the base simulation. Using different values of primary factor demand elasticities does affect model results more. FARM's primary factor demand elasticities are based on a review of the literature and so reflect empirical evidence to date. Our analysis suggests, however, that this is an area where good parameter estimates are important. More generally, this analysis suggests that FARM's "solution method" is robust (the results are stable within a very large neighborhood of solutions generated with the base parameter set).

Appendix table Al--Regional, sectoral. and commodity aggregation for FARM

A. Regional aggregation

1. ANZ-Australia and New Zealand

2. CAN-Canada

3. USA-United States of America

4. JPN-Japan

5. OEA-Other East Asia
    - Republic of Korea
    - People's Republic of China
    - Hong Kong
    - Taiwan

6. SEA-Southeast Asia
    - Indonesia
    - Malaysia
    - Philippines
    - Thailand

7. EC-European Commodity

8. ROW-Rest of the world

B. Sectoral Aggregation

1. CRP-Crops (six sectors)
2. LIV-Livestock (six sectors)
3. FOR-Forestry (six sectors)
4. COG-Coal, oil, and gas
5. MIN-Other minerals
6. FMM-Fish, meat, and milk
7. OPF-Other processed food
8. TCF-Textiles, clothing, and footwear
9. NMM-Other nonmetallic manufactures
10. OMN-Other manufactures
11. SRV-Services
12. FCF-Fixed capital formation

C. Endowments

l-6. Six land classes
7. Water
8. Labor
9. Capital

D. Commodity aggregation

1. WHT-Wheat
2. OGR-Other grains
    - Paddy rice
    - Other grains
3. NGR-Nongrains
4. Livestock
    - Wool
    - Other livestock products
5. Forestry
6. Coal, oil, and gas
7. Other minerals
8. Fish, **meat,** and milk
    - Fishing
    - Meat products
    - Milk products
9. Other processed foods
    - Processed rice
    - Other food products
    - Beverages and tobacco
10. Textiles, clothing, and footwear
    - Textiles
    - Wearing apparel
    - Leather, fur, and their products
11. Other nonmetallic manufactures
    - Lumber and wood products
    - Pulp, paper, and printed products
    - Petroleum and coal products
    - Chemicals, rubber, and plastic
    - Nonmetallic mineral products
12. Other manufactures
    - Primary iron and steel
    - Primary nonferrous metals
    - Fabricated metal products
    - Transport industries
    - Other machinery and equipment
    - Other manufacturing
13. Services
    - Electricity, gas, and water
    - Construction
    - Trade and transport
    - Other services (private)
    - Other services (government)
    - Other services (dwellings)
14. Fixed capital formation

Appendix table A2--Allen partial elasticities for primary factors (σ_{PI}) used in FARM[1]

Sector	σ_{PI}
Crops	0.56
Livestock	0.56
Forestry	0.56
Coal, oil, and gas	1.12
Other minerals	1.12
Fish, meat, and milk	0.85
Other processed food	1.12
All other manufacturing sectors	1.26
Services	1.39

[1] Elasticities are the same in all regions.

Source: Hertel, 1993.

Appendix table A3--Allen partial elasticities of substitution between domestic and imported commodities (σ_{II}) used in FARM[1]

Commodity	σ_{II}
Wheat	2.20
Other grains	2.20
Nongrains	2.20
Livestock	2.78
Forestry	2.80
Coal, oil, and gas	2.80
Other minerals	2.80
Fish, meat, and milk	2.34
Other processed food	2.44
Textiles, clothing, and footwear	3.17
Other nonmetallic manufactures	2.06
Other manufactures	3.28
Services	1.94

[1] Elasticities are the same in all regions. Allen partial elasticities of substitution between imported commodities (σ_{FI}) are twice as large as the elasticities listed above.

Source: Hertel, 1993.

Appendix table A4--Compensated own-price elasticities for private consumption in FARM at initial equilibrium

	Region							
Commodity	Australia and New Zealand	Canada	United States	Japan	Other East Asia	Southeast Asia	European Community	Rest of World
Wheat	-0.0705	-0.0638	-0.0657	-0.1380	-0.1505	-0.1063	-0.1490	-0.1201
Other grains	-0.0706	-0.0636	-0.0657	-0.1380	-0.1498	-0.1226	-0.1489	-0.1801
Nongrains	-0.0722	-0.0642	-0.0663	-0.1433	-0.1833	-0.1438	-0.1510	-0.2022
Livestock	-0.6347	-0.5694	-0.5880	-0.4545	-0.3547	-0.2451	-0.5521	-0.3023
Forest products	-0.6287	-0.5681	-0.5868	-0.4528	-0.3508	-0.2392	-0.5440	-0.4003
Coal, oil, and gas	-0.6298	-0.5703	-0.5867	-0.4528	-0.3496	-0.2346	-0.5456	-0.4007
Other minerals	-0.6285	-0.5672	-0.5867	-0.4528	-0.3496	-0.2348	-0.5436	-0.4000
Fish, meat, and milk	-0.1011	-0.0704	-0.0745	-0.2083	-0.2484	-0.1536	-0.1746	-0.2042
Other processed food	-0.3044	-0.2202	-0.2384	-0.2539	-0.2223	-0.1547	-0.2967	-0.2474
Textiles, clothing, and footwear	-0.3639	-0.3912	-0.4131	-0.3384	-0.2320	-0.1448	-0.2923	-0.1737
Other nonmetallic manufactures	-0.6840	-0.6098	-0.6375	-0.4787	-0.3649	-0.2533	-0.5955	-0.4108
Other manufactures	-0.6318	-0.5712	-0.6057	-0.4477	-0.3153	-0.2119	-0.5333	-0.3636
Services	-0.2092	-0.1713	-0.1559	-0.1527	-0.4292	-0.3393	-0.2288	-0.2690

Appendix table A5--Income elasticities for private consumption in FARM at initial equilibrium

	Region							
Commodity	Australia and New Zealand	Canada	United States	Japan	Other East Asia	Southeast Asia	European Community	Rest of World
Wheat	0.9996	0.9997	0.9976	0.9997	0.8701	0.9959	0.9710	0.9447
Other grains	0.9962	0.9991	0.9941	0.9994	0.6817	0.9206	0.9729	0.8167
Nongrains	0.7736	0.7470	0.8511	0.8133	0.6426	0.7227	0.8723	0.6520
Livestock	0.8966	0.9520	0.9689	0.9648	0.7957	0.9021	0.8356	0.8795
Forest products	1.0002	1.0031	1.0005	1.0000	1.0007	1.0302	1.0016	1.0076
Coal, oil, and gas	1.0015	1.0087	1.0002	1.0001	1.0397	1.0049	1.0066	1.0181
Other minerals	1.0001	1.0003	1.0003	1.0000	0.9899	1.0046	1.0003	1.0009
Fish, meat, and milk	0.4172	0.3477	0.5285	0.7239	0.8859	0.8921	0.4484	0.7889
Other processed food	0.4680	0.4478	0.4937	0.5265	0.7346	0.7246	0.5736	0.6417
Textiles, clothing, and footwear	0.9499	0.9431	0.9512	0.9539	0.9586	0.9610	0.9440	0.9489
Other nonmetallic manufactures	1.0828	1.0668	1.0362	1.0613	1.1780	1.1493	1.0812	1.1191
Other manufactures	1.0144	1.0045	1.0000	1.0058	1.0498	0.9697	1.0061	0.9385
Services	1.0972	1.0868	1.0503	1.0951	1.2342	1.1647	1.0971	1.1272

Appendix table A6--Effects of changing FARM's elasticity parameters on gross world product under a climate change scenario based on the Goddard Institute for Space Studies' general circulation model

Elasticity	Change from base elasticity		
	-50 percent	None	50 percent
Land supply			
		Percent	
Percentage	-0.013	0.011	0.029
		$U.S. million	
Value	-2,633	2,230	6,191
Crop supply			
		Percent	
Percentage	0.003	0.011	0.016
		$U.S. million	
Value	563	2,230	3,277
Primary factor demand			
		Percent	
Percentage	-0.549	0.011	0.215
		$U.S. million	
Value	-115,900	2,230	45,153
Import demand			
		Percent	
Percentage	0.004	0.011	0.014
		$U.S. million	
Value	797	2.230	3.026

Appendix table AT--Effects of changing FARM's elasticity parameters on selected commodities under a climate change scenario based on the Goddard Institute for Space Studies' general circulation model

	Change from base elasticity		
Elasticity	-50 percent	None	50 percent
		Percent	
Land supply			
Wheat	1.945	1.920	1.907
Other grains	0.516	0.409	0.340
Nongrains	-0.578	-0.505	-0.466
Livestock	0.974	0.858	0.787
Forest products	0.372	0.274	0.200
Fish, meat, and milk	0.338	0.371	0.392
Other processed food	0.343	0.382	0.404
Crop supply			
Wheat	2.466	1.920	1.621
Other grains	0.184	0.409	0.569
Nongrains	-0.599	-0.505	-0.440
Livestock	0.860	0.858	0.856
Forest products	0.244	0.274	0.291
Fish, meat, and milk	0.354	0.371	0.381
Other processed food	0.357	0.382	0.397
Primary factor demand			
Wheat	3.098	1.920	1.717
Other grains	1.983	0.409	0.427
Nongrains	-0.398	-0.505	-0.399
Livestock	1.852	0.858	0.808
Forest products	-0.609	0.274	0.463
Fish, meat, and milk	0.206	0.371	0.439
Other processed food	0.605	0.382	0.447
Import demand			
Wheat	1.701	1.920	2.099
Other grains	0.785	0.409	0.074
Nongrains	-0.196	-0.505	-0.825
Livestock	0.807	0.858	0.885
Forest products	0.330	0.274	0.399
Fish, meat, and milk	0.384	0.371	0.380
Other processed food	0.115	0.382	0.114

Appendix B: Detailed FARM Results

Appendix table Bl--Changes in land class areas due to simulated climates based on doubling of atmospheric carbon dioxide levels

Scenario[1]/ land class	United States	Canada	European Community	Japan	Other East Asia[2]	Southeast Asia[3]	Australia/ New Zealand	Rest of World	Total
	Region								
	Percent change								
GISS									
1	-51.77	-40.74	-64.14	-95 00	-26 02	0 00	-93.69	-40.39	-39.77
2	-9.97	4.89	-57.80	0 00	-2 45	0 00	-3.90	-0.09	-1.44
3	45.83	26.32	-56.69	-85 93	5 20	476 43	36.20	32.92	28.71
4	-14.84	411.26	-69.36	-0 40	32 45	963 06	-4.18	78.05	51.64
5	36.61	0.00	37.48	-11 38	-42 05	-43 15	11.51	6.54	4.68
6	38.96	0.00	536.96	610 97	46 63	-12 50	-13.52	-21.08	-10.06
GFDL									
1	-54.84	-45.26	-85.33	-95 00	-30 25	0 00	-93.69	-50.58	-47.72
2	1.89	186.91	-70.03	0 00	16 67	0 00	-2.70	17.91	17.22
3	105.41	-2.01	-3.18	-93 15	-32 79	426 49	43.61	37.06	28.74
4	-25.42	296.50	-62.73	-9 92	-0 69	875 58	-12.19	64.47	36.98
5	63.11	0.00	28.22	-8 59	-35 60	-0 78	29.31	19.30	18.21
6	-49.54	0.00	417.72	757 09	63 05	-17 46	-28.90	-42.25	-31.05
UKMO									
1	-67.28	-59.48	-92.85	-95.00	-55.36	0.00	-95.00	-64.08	-62.45
2	8.40	135.56	-71.95	0.00	24.58	0.00	3.67	15.56	16.39
3	42.85	3.71	-56.79	-93.24	5.44	331.43	8.96	59.73	38.81
4	-27.96	620.66	-68.34	-16.37	38.53	1533.83	-15.18	116.16	78.09
5	101.64	0.00	25.18	-28.30	-54.85	-24.09	6.14	1.42	4.37
6	-7.68	0.00	574.49	933.24	35.92	-24.74	-16.19	-54.29	-39.20
OSU									
1	-43.57	-33.96	-64.14	-95.00	-20.96	0.00	-93.69	-32.76	-32.57
2	9.42	155.41	-32.46	0.00	-4.78	0.00	-18.74	8.32	6.87
3	48.42	-0.42	-9.26	-72.08	27.28	50.38	80.21	12.93	16.68
4	-29.98	169.77	-54.93	-8.90	-6.71	378.13	18.48	43.34	21.87
5	16.81	0.00	89.57	-14.64	-40.49	15.99	50.56	18.06	17.76
6	14.25	0.00	189.38	643.39	48.25	-9.43	-9.24	-19.57	-11.69

[1] Climate change scenarios based on results generated by the general circulation models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meterological Office (UKMO), and Oregon State University (OSU).

[2] China (including Taiwan), Hong Kong, and North Korea. [3] Indonesia, Malaysia, Philippines, and Thailand.

Appendix table B2--Percentage land class changes on existing cropland, pasture land, and forest land due to simulated climates based on doubling of atmospheric carbon dioxide levels

Scenario[1]/	Region							
land use/ land class	United States	Canada	European Community	Japan	Other East Asia[2]	Southeast Asia[3]	Australia/ New Zealand	Rest of World
				Percent change				
GISS								
Cropland								
1	-95 00	0.00	-36.06	0.00	-84 66	0.00	0.00	-68.89
2	-5 73	-10.62	-40.81	0.00	-9 89	0.00	22.68	-4.88
3	14 19	-36.24	-51.73	-95.00	-18 86	804.50	5.01	-3.32
4	-41 09	91.57	-82.37	-45.26	12 43	998.61	10.75	54.38
5	79 21	0.00	13.26	-29.62	-42 62	-64.11	19.16	-7.17
6	75 36	0.00	742.30	415.49	49 07	-21.43	-20.85	-23.40
Pasture								
1	-61.68	-19.24	-47.15	0 00	-26.61	0.00	-95.00	-52.37
2	-7.38	-2.53	-57.33	0 00	-12.79	0.00	-2.59	-2.62
3	60.84	101.74	-76.58	-78 66	59.79	67.41	39.89	43.71
4	7.22	64.23	-44.95	-35 74	25.76	134.03	1.82	44.73
5	-31.37	0.00	48.11	-16 01	-43.96	-12.93	7.75	9.25
6	45.78	0.00	612.26	1531 04	20.74	-11.36	-6.61	-27.29
Forest								
1	-89.16	-81.71	-88.57	0.00	-60.93	0.00	-95.00	-52.39
2	-11.64	9.06	-94.95	0.00	47.43	0.00	-16.28	74.13
3	15.76	17.76	-38.91	-84.39	-38.42	1103.84	33.84	24.87
4	6.15	510.33	-76.81	30.67	21.95	3438.73	-10.62	176.29
5	30.26	0.00	83.32	0.62	-44.22	-45.86	10.59	3.79
6	25.55	0.00	304.09	799.72	69.67	-10.89	-16.58	-19.46

Continued--

See footnotes at end of table.

Appendix table B2--Percentage land class changes on existing cropland, pasture land, and forest land due to simulated climates based on doubling of atmospheric carbon dioxide levels--continued

Scenario[1]/ land use/ land class	Region							
	United States	Canada	European Community	Japan	Other East Asia[2]	Southeast Asia[3]	Australia/ New Zealand	Rest of World
				Percent change				
GFDL								
Cropland								
1	-95.00	0.00	-63.44	0.00	-88.08	0.00	0.00	-79.24
2	-34.95	24.90	-42.91	0.00	-1.12	0.00	106.21	8.58
3	253.95	-20.74	-0.02	-95.00	-44.31	673.90	-16.73	22.68
4	-53.49	3.44	-82.37	-55.59	-26.28	860.02	4.28	27.10
5	34.67	0.00	14.97	-36.84	-54.65	-5.42	68.72	17.85
6	-34.24	0.00	625.31	491.80	85.75	-30.64	-26.67	-44.45
Pasture								
1	-66.07	-88.52	-42.91	0.00	-29.78	0.00	-95.00	-53.27
2	-9.85	4.00	-84.69	0.00	12.76	0.00	-2.35	11.96
	165.41	112.54	-55.12	-95.00	-18.88	56.33	37.37	48.00
	-11.42	53.66	-29.71	-48.31	-21.47	90.96	14.67	33.69
	9.27	0.00	24.51	-5.11	-46.59	14.74	-17.48	7.94
6	-22.77	0.00	487.69	1861.55	41.96	-13.66	-11.48	-53.82
Forest								
1	-90.71	-89.86	-95.00	0.00	-58.78	0.00	-95.00	-63.55
2	54.95	446.79	-81.28	0.00	193.84	0.00	-15.69	285.72
3	27.44	-16.41	61.20	-92.45	-71.11	1100.37	55.21	23.30
	1.00	370.29	-69.85	23.70	15.64	2958.18	-28.32	163.21
5	119.33	0.00	72.20	6.67	-21.13	2.45	40.69	24.03
6	-62.15	0.00	169.12	1067.75	65.78	-13.97	-47.83	-37.58

See footnotes at end of table.

Continued--

Appendix table B2--Percentage land class changes on existing cropland, pasture land, and forest land due to simulated climates based on doubling of atmospheric carbon dioxide levels--continued

Scenario[1]/ land use/ land class	Region							
	United States	Canada	European Community	Japan	Other East Asia[2]	Southeast Asia[3]	Australia/ New Zealand	Rest of World
				Percent change				
UKMO								
Cropland								
1	-95.00	0.00	-68.03	0.00	-88.08	0.00	0 00	-94.84
2	-2.02	9.40	-40.81	0.00	32.21	0.00	134.68	20.21
3	97.13	-8.23	-48.17	-95.00	-32.45	478.50	-19.30	43.46
4	-76.75	2.13	-86.73	-65.83	3.90	1434.48	7.58	36.43
5	130.24	0.00	2.89	-43.82	-64.70	-7.45	-27.27	-50.07
6	66.61	0.00	804.92	567.05	19.90	-45.57	-14.02	-44.87
Pasture								
1	-73.03	-94.24	-73.58	0.00	-60.87	0.00	-95.00	-73.45
2	0.02	16.43	-92.56	0.00	17.92	0.00	-4.47	11.47
3	80.07	127.28	-77.26	-95.00	40.10	39.85	33.13	62.28
4	-20.19	1.84	-33.38	-65.31	25.81	226.51	41.84	75.53
5	10.68	0.00	23.06	6.41	-51.13	34.00	-15.28	-5.89
6	9.49	0.00	616.72	2180.82	5.08	-29.82	-7.54	-70.85
Forest								
1	-98.12	-96.13	-95.00	0.00	-87.44	0.00	-95.00	-78.43
2	52.87	308.77	-80.31	0.00	110.55	0.00	39.76	213.62
3	-16.78	-25.78	-57.29	-92.54	-46.14	964.79	2.57	49.28
4	20.58	739.84	-80.82	23.77	28.65	5766.71	-45.73	280.19
5	119.06	0.00	90.40	-28.64	-54.65	-56.40	21.65	20.56
6	-36.77	0.00	330.64	1461.28	74.77	-19.37	-26.74	-51.48

See footnotes at end of table.

Continued--

Appendix table B2--Percentage land class changes on existing cropland, pasture land, and forest land due to simulated climates based on doubling of atmospheric carbon dioxide levels--continued

Scenario[1]/ land use/ land class	Region							
	United States	Canada	European Community	Japan	Other East Asia[2]	Southeast Asia[3]	Australia/ New Zealand	Rest of World
				Percent change				
OSU								
Cropland								
1	-95.00	0.00	-36.06	0.00	-84.66	0.00	0.00	-57.26
2	-4.65	11.85	-57.03	0.00	-28.45	0.00	13.64	26.80
3	160.10	-22.44	13.43	-95.00	58.92	81.74	-15.65	-3.74
4	-58.09	27.57	-64.49	-45.26	-42.40	573.84	4.74	22.52
5	36.79	0.00	76.41	-40.20	-24.75	15.39	53.39	-14.82
6	32.40	0.00	263.06	438.44	49.82	-21.78	-5.70	-24.31
Pasture								
1	-51.30	-24.24	-47.15	0.00	-20.30	0.00	-95.00	-42.86
2	0.01	9.07	-52.05	0.00	-12.74	0.00	-19.05	3.22
3	64.18	26.23	-46.15	-78.66	62.64	5.60	134.13	10.21
4	-8.55	1.50	-42.84	-35.74	-15.46	58.12	96.01	32.57
5	-47.00	0.00	115.06	-18.13	-52.91	3.81	12.49	19.77
6	26.35	0.00	211.68	1547.63	34.58	-6.32	2.60	-22.80
Forest								
1	-75.72	-69.90	-63.13	0.00	-52.85	0.00	-95.00	-44.84
2	51.73	377.11	67.19	0.00	28.59	0.00	-36.45	147.23
3	-15.45	-9.63	-12.95	-70.34	-20.67	159.60	46.02	11.84
4	-1.14	207.27	-51.57	16.57	11.03	1036.42	-14.25	92.81
5	30.15	0.00	89.94	2.33	-49.75	27.66	62.38	23.58
6	4.98	0.00	108.05	881.13	60.93	-7.45	-20.64	-17.23

[1] Climate change scenarios based on results generated by the general circulation models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meterological Office (UKMO), and Oregon State University (OSU).

[2] China (including Taiwan), Hong Kong, and North Korea.

[3] Indonesia, Malaysia, Philippines, and Thailand.

Appendix table B3--Base values and changes in commodity production, by region and climate change scenario

Region/ commodity	Base (1990) value[2]	Scenario[1] GISS Rest[3]	 GISS Unrest	 GFDL Rest	 GFDL Unrest	 UKMO Rest	 UKMO Unrest	 OSU Rest	 OSU Unrest
	Number	---------------------------- Percent				change---------------------------			
United States									
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
Nongrains	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 manufactures	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
Canada									
Wheat	32,098	-2.149	2.402	5.138	9.548	13.175	7.440	-1.568	14.045
Other grains	24,981	3.456	12.441	5.084	16.751	3.951	17.828	4.807	15.529
Nongrains	13,015	19.253	35.579	6.815	36.054	4.908	46.809	8.014	23.247
Livestock	23,820	5.455	8.620	3.866	8.390	4.117	10.530	2.655	7.124
Forest products	155,475	2.631	3.470	2.851	3.854	3.467	5.321	1.766	2.616
Coal/oil/gas	27,388	1.937	1.781	3.067	2.638	3.535	3.090	2.430	2.018
Other minerals	10,210	1.557	1.184	3.259	2.173	3.533	2.372	2.579	1.692
Fish/meat/milk	24,438	3.396	4.852	2.673	4.883	2.984	6.049	1.879	4.087
Other processed foods	32,418	2.513	3.141	2.109	3.333	2.582	4.099	1.726	2.654
Text./cloth./footwear	18,635	1.914	1.768	2.867	2.596	3.419	3.093	2.124	1.910
Other nonmetal. manuf.	130,143	2.219	2.548	2.512	3.059	3.126	3.871	1.979	2.314
Other manufactures	119,236	1.477	1.003	3.091	2 001	3.642	2.320	2.418	1.508
Services	719,538	1.800	1,944	2.206	2.453	2.630	2.937	1.797	1.961

See footnotes at end of table.

Continued--

Appendix table B3--Base values and changes in commodity production, by region and climate change scenario--continued

		Scenario[1]							
Region/	Base (1990)	GISS		GFDL		UKMO		OSU	
commodity	value[2]	Rest[3]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	--Percent change--							
European Community									
Wheat	80,319	-18.590	-13.170	17.111	-11.978	-21.123	-14.713	-8.002	-6.616
Other grains	24,994	28.408	29.207	27.128	21.912	33.109	29.565	16.627	17.270
Nongrains	279,884	-17.892	-10.609	13.033	-6.525	-17.407	-9.294	-6.992	-5.176
Livestock	295,049	-2.864	-1.672	-1.982	-1.572	-2.761	-1.888	-1.706	-1.041
Forest products	171,394	0.693	3.546	0.408	3.412	0.942	3.937	0.181	1.770
Coal/oil/gas	82,886	-1.885	-1.851	-1.310	-1.271	-1.937	-1.860	-0.828	-0.775
Other minerals	270,580	-1.374	-1.477	-1.002	-1.002	-1.410	-1.450	-0.633	-0.602
Fish/meat/milk	157,710	-2.250	-1.279	-1.664	-1.088	-2.383	-1.439	-1.036	-0.609
Other processed foods	485,433	-2.265	-1.411	-1.702	-1.167	-2.397	-1.618	-0.891	-0.626
Text./cloth./footwear	284,159	-1.840	-1.725	-1.050	-1.081	-1.596	-1.562	-0.743	-0.742
Other nonmetal. manuf	1,472,520	-1.451	-1.227	-1.057	-0.860	-1.516	-1.263	-0.613	-0.489
Other manufactures	1,292,320	-1.130	-1.278	-0.832	-0.842	-1.128	-1.214	-0.515	-0.492
Services	5,815,930	-1.165	-1.068	-0.864	-0.771	-1.280	-1.154	-0.467	-0.400
Japan									
Wheat	952	-31.428	-49.832	-43.388	-60.279	-47.984	-64.489	38.036	-55.747
Other grains	13,499	6.890	11.270	11.859	12.522	10.365	12.445	11.628	13.217
Nongrains	32,151	9.369	13.388	13.458	17.175	14.142	17.854	10.263	14.893
Livestock	16,665	1.254	1.644	1.076	1.582	0.885	1.424	1.023	1.603
Forest products	29,593	5.181	6.224	.854	9.136	8.478	10.425	5.667	6.737
Coal/oil/gas	8,662	0.844	0.801	0.167	0.057	-0.759	-0.730	0.678	0.590
Other minerals	16,568	0.868	0.937	0.450	0.559	0.040	0.160	0.720	0.804
Fish/meat/milk	68,056	1.100	1.410	0.776	1.262	0.607	1.066	0.879	1.353
Other processed foods	312,381	0.820	1.395	.478	1.392	0.384	1.306	0.600	1.313
Text./cloth./footwear	121,234	1.014	1.188	0.467	0.811	0.158	0.505	0.778	0.979
Other nonmetal. manuf.	719,010	0.928	1.083	0.616	0.835	0.312	0.532	0.820	1.005
Other manufactures	1,146,530	0.708	0.649	0.165	0.157	-0.217	-0.254	0.506	0.468
Services	3,327,640	0.695	0.794	0.386	0.554	0.086	0.258	0.597	0.724

See footnotes at end of table.

Continued--

Appendix table B3--Base values and changes in commodity production, by region and climate change scenario--continued

Region/ commodity	Base (1990) value[2]	Scenario[1] GISS Rest[3]	GISS Unrest	GFDL Rest	GFDL Unrest	UKMO Rest	UKMO Unrest	OSU Rest	OSU Unrest
	Number	----------------------------	-Percent	change-	-----------------				
Other East Asia[4]									
Wheat	98,233	-0.500	-0.260	-14 003	-12.128	0.730	-0.654	-5.477	-5.159
Other grains	314,527	1.184	0.612	2 962	0.905	1.058	-0.158	1.330	0.358
Nongrains	428,755	5.113	3.755	11 288	6.563	1.903	3.054	6.676	4.703
Livestock	691,279	0.427	0.663	-0 088	0.729	-0.506	0.479	-0.450	0.157
Forest products	283,530	0.049	0.553	1 332	1.284	-0.040	0.797	0.507	0.689
Coal/oil/gas	21,468	-0.329	0.004	-0 737	-0.174	-0.461	0.057	-0.453	-0.189
Other minerals	15,752	-0.250	0.008	-0 842	-0.282	-0.159	0.091	-0.480	-0.253
Fish/meat/milk	35,760	0.459	0.601	-0 073	0.565	-0.202	0.514	-0.427	0.064
Other processed foods	102,987	0.778	0.982	-0 083	0.812	-0.458	0.750	-0.547	0.197
Text./cloth./footwear	149,392	0.851	1.458	-0 062	1.241	-0.066	1.512	0.323	1.006
Other nonmetal. manuf.	223,391	0.149	0.376	-0 230	0.226	-0.121	0.390	-0.123	0.131
Other manufactures	323,723	-0.306	0.019	-0 986	-0.255	-0.085	0.234	-0.514	-0.191
Services	650,319	0.054	0.220	-0 223	0.123	-0.102	0.251	-0.125	0.064
Southeast Asia[5]									
Wheat	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other grains	89,191	-6.104	-3.744	-5.720	-3.079	-9.823	-5.487	-2.949	-1.008
Nongrains	200,148	-6.186	0.340	-5.778	1.319	-11.138	2.252	-4.836	-1.158
Livestock	74,225	-2.611	-0.900	-2.377	-0.797	-4.380	-1.593	-1.200	-0.135
Forest products	260,901	-2.518	-4.633	-1.423	-4.399	-2.746	-6.594	-1.278	-2.481
Coal/oil/gas	23,597	0.379	-0.603	0.624	-0.315	0.925	-1.116	1.084	0.448
Other minerals	6,084	0.477	-0.476	0.255	-0.526	0.775	-1.264	0.981	0.421
Fish/meat/milk	20,591	-2.249	-1.161	-1.995	-1.031	-3.731	-1.948	-0.851	-0.181
Other processed foods	51,512	-6.000	-3.427	-5.788	-2.838	-9.835	-5.069	-3.021	-0.914
Text./cloth./footwear	30,416	-0.173	-0.066	-0.986	-0.480	-0.839	-0.916	0.431	0.666
Other nonmetal. manuf.	68,154	-1.299	-0.985	-1.472	-0.896	-2.318	-1.661	-0.397	-0.055
Other manufactures	50,624	0.463	-0.165	0.113	-0.216	0.821	-0.571	0.747	0.475
Services	247.521	-0.793	-0.621	-0.744	-0.479	-1.373	-1.048	-0.147	0.023

See footnotes at end of table.

Continued--

Appendix table B3--Base values and changes in commodity production, by region and climate change scenario--continued

Region/ commodity	Base (1990) value'	Scenario[1]							
		GISS		GFDL		UKMO		OSU	
		Rest[3]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	--Percent change--							
Australia and New Zealand									
Wheat	15,254	26.170	17.509	12.064	3.278	11.432	2.818	7.646	17.659
Other grains	8,584	4.850	4.301	7.202	1.708	9.292	-3.333	3.614	11.714
Nongrains	33,360	-2.776	-3.849	-0.424	-3.874	1.638	-2.505	0.757	-1.992
Livestock	264,475	1.019	-0.923	0.990	-1.229	2.224	-3.293	10.337	3.539
Forest products	32,132	-1.835	-0.547	-2.409	-0.333	-4.080	-1.671	-0.228	2.193
Coal/oil/gas	12,659	-1.082	-0.024	-1.371	0.007	-2.381	-0.173	-0.552	0.624
Other minerals	8,372	-1.105	0.155	-1.441	0.195	-2.429	0.148	-0.726	0.680
Fish/meat/milk	17,714	0.813	-0.176	0.792	-0.494	1.502	-1.375	4.992	2.005
Other processed foods	20,731	0.413	0.303	0.388	0.028	0.655	-0.346	1.521	1.491
Text./cloth./footwear	18,175	-0.997	-0.141	-1.054	-0.103	-1.126	-0.172	1.592	1.350
Other nonmetal. manuf.	66.743	-0.094	0.138	-0.408	-0.113	-0.649	-0.302	0.805	1.017
Other manufactures	62,302	-0.646	0.221	-0.953	0.225	-1.456	0.263	-0.163	0.811
Services	413,544	-0.016	0.086	-0.296	-0.165	-0.495	-0.340	0.746	0.812
Rest of world									
Wheat	291,182	4.334	5.637	3 869	5.103	4.491	8.669	1.845	2.888
Other grains	644,130	0.977	1.606	1.192	1.448	1.444	2.434	1.207	0.945
Nongrains	1,948,909	-0.582	-0.662	-0.589	-1.249	-1.911	-2.040	-0.918	-0.702
Livestock	2,605,951	1.102	1.463	0.817	1.267	1.026	1.853	0.686	0.887
Forest products	1,883,532	0.077	0.183	-0.140	-0.090	-0.252	0.019	-0.015	0.052
Coal/oil/gas	518,792	0.276	0.535	-0.100	0.278	-0.081	0.390	0.083	0.301
Other minerals	198,475	0.517	0.744	0.090	0.446	0.235	0.639	0.228	0.413
Fish/meat/milk	251,547	0.882	1.098	0.542	0.758	0.691	1.152	0.496	0.595
Other processed foods	642,189	0.962	1.454	0.472	0,809	0.600	1.468	0.521	0.633
Text./cloth./footwear	378,729	0.131	0.596	-0.370	0.148	-0.542	0.205	-0.150	0.267
Other nonmetal. manuf.	1,608,410	0.385	0.677	0.056	0.401	0.066	0.580	0.165	0.377
Other manufactures	1,720,940	0.517	0.734	0.139	0.486	0.320	0.697	0.260	0.434
Services	4,277,060	0.353	0.497	0.135	0.315	0.127	0.383	0.203	0.317

See footnotes at end of table.

Continued--

Appendix table B3--Base values and changes in commodity production, by region and climate change scenario--continued

Region/ commodity	Base (1990) value[2]	Scenario[1]							
		GISS		GFDL		UKMO		OSU	
		Rest[3]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	--Percent change--							
World									
Wheat	592,515	0.625	1.920	-0.971	0.471	1.171	3.293	-0.395	0.781
Other grains	1,358,258	0.006	0.409	-0.434	0.287	-0.811	0.320	-0.532	-0.125
Nongrains	3,130,611	-1.250	-0.505	-0.596	-0.432	-2.633	-1.252	-0.417	-0.170
Livestock	4,142,111	0.589	0.858	0.340	0.744	0.383	0.899	0.786	0.723
Forest products	3,314,557	0.117	0.274	-0.190	0.007	-0.342	-0.014	0.027	0.144
Coal/oil/gas	910,525	0.001	0.182	-0.155	0.097	-0.223	0.101	-0.004	0.145
Other minerals	550,827	-0.467	-0.409	-0.432	-0.280	-0.596	-0.439	-0.186	-0.089
Fish/meat/milk	697,179	-0.013	0.371	-0.207	0.273	-0.349	0.310	-0.002	0.294
Other processed foods	1,940,501	-0.140	0.382	-0.406	0.161	-0.580	0.225	-0.070	0.260
Text./cloth./footwear	1,156,739	-0.171	0.120	-0.332	0.049	-0.509	-0.022	-0.049	0.190
Other nonmetal. manuf.	5,356,261	-0.107	0.098	-0.208	0.062	-0.346	-0.006	-0.002	0.162
Other manufactures	5,982,195	0.011	0.114	-0.095	0.060	-0.179	0.001	0.066	0.156
Services	21,555,422	-0.068	0.023	-0.147	-0.003	-0.271	-0.107	0.032	0.122

[1] Climate scenarios based on results generated by the general circulation models of the Goddard Institute for Spaces Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meterological Office (UKMO), and Oregon State University (OSU).

[2] For wheat, other grains, and nongrains, values are in 1,000 metric tons. For livestock, values are in 1,000 head. For forest products, values are in 1,000 cubic meters. For all other commdities, values are in million U.S. dollars.

[3] Rest = cropland, pasture, forest, and land in other uses restricted to 1990 locations and quantities. Unrest = all land can move among cropland, pasture, and other uses.

[4] China (including Taiwan), Hong Kong, and North Korea.

[5] Indonesia, Malaysia, Philippines, and Thailand.

Appendix table B4--Changes in 1990 prices paid to commodity producers, by region and climate change scenario

Region/	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
commodity	Rest[2]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Percent change							
United States								
Wheat	10.621	2.995	-5.633	-10.367	3.916	-3.470	-1.639	-2.401
Other grains	3.839	1.111	18.751	2.184	13.673	-0.042	16.703	6.250
Nongrains	-4.990	-4.308	8.130	3.861	-2.133	-0.644	-0.378	-1.390
Livestock	0.759	0.050	2.917	-0.614	3.146	-0.717	3.252	1.188
Forest products	-3.479	-3.047	2.242	-0.076	-0.467	-1.659	-1.383	-1.167
Coal/oil/gas	0.180	0.042	-0.095	-0.058	0.101	-0.054	0.074	0.042
Other minerals	0.148	0.037	-0.093	-0.042	0.069	-0.046	0.060	0.044
Fish/meat/milk	0.488	-0.019	1.726	-0.433	1.911	-0.519	1.965	0.683
Other processed foods	-0.068	-0.376	1.370	0.285	0.537	-0.135	0.564	0.026
Text./cloth./footwear	0.024	-0.072	0.092	0.028	0.038	-0.067	0.043	-0.001
Other nonmetal. manuf.	0.058	-0.037	-0.053	-0.054	0.033	-0.095	0.021	0.009
Other manufactures	0.132	0.038	-0.106	-0.041	0.047	-0.041	0.042	0.038
Services	0.143	0.018	-0.053	-0.031	0.094	-0.053	0.097	0.063
Canada								
Wheat	18.664	7.375	3.865	-4.112	9.266	1.810	1 190	-3.826
Other grains	-1.801	-11.727	1.966	- 14.623	0.127	-16.866	5 275	-11.285
Nongrains	-11.357	-19.820	1.898	- 16.872	0.981	-21.482	1 289	-13.948
Livestock	-5.023	-9.188	-2.193	-8.990	-2.163	-11.020	-4 555	-7.271
Forest products	-4.585	-6.198	-1.462	-4.416	-3.433	-8.017	-0 038	-2.714
Coal/oil/gas	-0.318	-0.151	-0.828	-0.428	-0.922	-0.477	0 329	-0.300
Other minerals	-0.275	-0.114	-0.759	-0.372	-0.842	-0.414	0 321	-0.255
Fish/meat/milk	-2.675	-4.747	-1.433	-4.770	-1.447	-5.817	-1 972	-3.840
Other processed foods	-0.920	-1.791	-0.175	-1.820	-0.493	-2.287	0 576	-1.504
Text./cloth./footwear	-0.193	-0.082	-0.496	-0.253	-0.604	-0.309	-0 246	-0.173
Other nonmetal. manuf.	-0.498	-0.443	-0.730	-0.560	-0.934	-0.811	0 276	-0.365
Other manufactures	-0.160	-0.026	-0.585	-0.239	-0.630	-0.263	0 298	-0.143
Services	-0.737	-0.617	-1.291	-0.979	-1.504	-1.169	0.296	-0.726

See footnotes at end of table,

Continued--

Appendix table B4--Changes in 1990 prices paid to commodity producers, by region and climate change scenario--continued

Region/ commodity	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
	Rest[2]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Percent change							
European Community								
Wheat	62.740	30.948	45 237	19 277	73 875	31.930	15.506	8.659
Other grains	26.799	- 29.742	-22 489	-25 135	-27 459	-31.393	-15.009	- 19.478
Nongrains	15.757	6.597	15 694	6 051	19 750	7.784	6.564	3.002
Livestock	3.339	1.113	2 119	1 396	2 477	0.943	2.835	1.303
Forest products	-5.586	- 10.726	-2 665	-8 837	-5 826	-11.163	-1.873	-4.900
Coal/oil/gas	0.337	0.474	0 212	0 314	0 252	0.404	0.196	0.242
Other minerals	0.349	0.487	0 214	0 319	0 258	0.414	0.194	0.244
Fish/meat/milk	3.757	1.497	2 848	1 266	3 978	1.514	1.842	0.760
Other processed foods	1.811	0.683	1 763	0 672	2 367	0.882	0.836	0.233
Text./cloth./footwear	0.415	0.394	0 375	0 314	0 446	0.391	0.237	0.194
Other nonmetal. manuf.	0.265	0.331	0 185	0 211	0 195	0.263	0.164	0.175
Other manufactures	0.282	0.434	0 163	0 284	0 189	0.362	0.168	0.226
Services	0.473	0.607	0 301	0 402	0 388	0.535	0.240	0.286
Japan								
Wheat	40.081	56.056	37.154	59.088	55.055	79 917	33 718	55.918
Other grains	-5.806	-13.089	-4.045	- 14.295	-5.302	-16 136	-4 063	-12.186
Nongrains	12.534	-18.375	-13.645	- 20.119	-15.013	-21 768	-12 827	-19.059
Livestock	-1.552	-2.475	-1.263	-2.938	-1.429	-3 224	-1 103	-2.247
Forest products	-5.479	-5.280	-5.573	-6.698	-7.878	-8 774	-4 897	-5.112
Coal/oil/gas	-0.174	-0.053	0.017	0.176	0.144	0 326	-0 083	0.034
Other minerals	-0.196	-0.082	-0.010	0.141	0.123	0 295	-0 099	0.013
Fish/meat/milk	-0.584	-0.987	-0.240	-0.979	-0.196	-0 978	-0 379	-0.872
Other processed foods	-0.808	-2.409	-0.108	-2.688	-0.193	-2 860	-0 263	-2.183
Text./cloth./footwear	-0.258	-0.287	0.130	-0.006	0.188	0 051	-0 123	-0.137
Other nonmetal. manuf.	-0.319	-0.218	-0.131	-0.042	-0.094	0 029	-0 194	-0.109
Other manufactures	-0.215	-0.111	-0.071	0.071	0.039	0 199	-0 116	-0.014
Services	-0.390	-0.298	-0.259	-0.138	-0.136	0.003	-0.264	-0.177

See footnotes at end of table.

Continued--

Appendix table B4--Changes in 1990 prices paid to commodity producers, by region and climate change scenario--continued

Region/ commodity	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
	Rest[2]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Percent change							
Other East Asia[3]								
Wheat	13.231	5.466	17.300	9.228	5.776	0.861	7.935	4.104
Other grains	0.462	0.011	0.819	-0.919	2.635	-0.115	4.308	2.374
Nongrains	-5.398	-5.884	-7.396	-6.301	0.168	-3.884	-6.627	-6.327
Livestock	-0.041	-0.826	0.931	-1.060	0.914	-0.974	0.807	-0.224
Forest products	-0.347	-0.230	0.038	-0.093	-0.552	-0.169	-0.224	-0.159
Coal/oil/gas	0.129	0.129	0.221	0.189	-0.079	0.035	0.156	0.176
Other minerals	0.137	0.127	0.236	0.181	-0.061	0.033	0.173	0.170
Fish/meat/milk	0.098	-0.298	0.606	-0.364	0.430	-0.432	0.542	0.023
Other processed foods	0.349	-0.526	1.272	-0.660	1.777	-0.661	1.779	0.338
Text./cloth./footwear	-0.159	-0.364	0.241	-0.179	0.200	-0.271	-0.020	-0.235
Other nonmetal. manuf.	-0.008	-0.037	0.157	0.059	-0.033	-0.053	0.061	0.031
Other manufactures	0.086	0.081	0.187	0.143	-0.041	0.034	0.127	0.127
Services	0.094	0.065	0.252	0.152	-0.069	-0.016	0.171	0.144
Southeast Asia[4]								
Wheat	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other grains	16.521	10.046	15.415	7.771	27.414	14.441	8.509	2.802
Nongrains	4.534	-2.794	8.328	-0.918	12.082	-2.643	4.062	-0.685
Livestock	1.855	-1.111	1.939	-1.012	3.160	-1.305	0.963	-0.618
Forest products	-1.334	1.645	-0.264	2.425	-1.619	3.057	-0.790	0.843
Coal/oil/gas	-0.329	0.088	-0.390	0.031	-0.784	0.070	-0.347	-0.061
Other minerals	-0.304	0.102	-0.285	0.092	-0.678	0.166	-0.337	-0.087
Fish/meat/milk	0.573	-0.085	0.582	-0.119	0.833	-0.045	0.128	-0.214
Other processed foods	5.621	2.651	5.824	2.202	9.896	4.062	3.011	0.606
Text./cloth./footwear	-0.161	-0.183	0.239	0.061	0.033	0.044	-0.128	-0.210
Other nonmetal. manuf.	0.058	0.196	0.252	0.275	0.168	0.386	-0.031	0.003
Other manufactures	-0.200	0.039	-0.161	0.063	-0.393	0.100	-0.190	-0.041
Services	-0.209	0.090	-0.122	0.122	-0.430	0.206	-0.246	-0.079

See footnotes at end of table.

Continued--

Appendix table B4--Changes in 1990 prices paid to commodity producers, by region and climate change scenario--continued

Region/	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
commodity	Rest[2]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Percent change							
Australia and New Zealand								
Wheat	8.019	1.615	-0.035	-3.698	7.655	1.958	1.190	-5.955
Other grains	-4.508	-7.194	-0.512	-5.151	-3.849	-3.928	5.275	-6.886
Nongrains	3.575	1.227	5.646	3.601	4.150	1.608	1.289	0.836
Livestock	-0.428	-0.464	-0.003	-0.459	-0.846	0.241	-4.555	-2.173
Forest products	0.466	-0.418	2.551	-0.228	3.346	0.595	-0.038	-2.564
Coal/oil/gas	0.319	-0.003	0.348	-0.075	0.528	-0.160	0.329	-0.058
Other minerals	0.321	-0.003	0.350	-0.071	0.533	-0.150	0.321	-0.065
Fish/meat/milk	-0.005	-0.234	0.234	-0.250	-0.063	0.042	-1.972	-1.098
Other processed foods	0.695	-0.181	0.831	-0.109	0.965	-0.070	0.576	-0.578
Text./cloth./footwear	0.353	-0.026	0.537	0.029	0.520	-0.025	-0.246	-0.293
Other nonmetal. manuf.	0.284	-0.019	0.350	-0.073	0.512	-0.129	0.276	-0.101
Other manufactures	0.288	-0.000	0.307	-0.065	0.483	-0.124	0.298	-0.046
Services	0.345	-0.013	0.390	-0.075	0.604	-0.141	0.296	-0.125
Rest of world								
Wheat	-7.493	-14.882	12.653	-18.936	-11.441	-24.641	-5.556	-11.284
Other grains	-3.462	-6.700	-4.438	-8.188	-6.714	-12.368	-3.286	-4.175
Nongrains	.043	2.505	.307	5.556	10.309	7.897	4.222	2.026
Livestock	-1.705	-2.666	-1.277	-2.711	-2.063	-3.985	-1.111	-1.695
Forest products	-1.015	-0.661	0.905	0.869	-0.402	0.144	-0.008	0.301
Coal/oil/gas	-0.262	-0.243	-0.100	-0.136	-0.291	-0.263	-0.071	-0.081
Other minerals	-0.239	-0.227	-0.086	-0.134	-0.270	-0.257	-0.069	-0.080
Fish/meat/milk	-0.709	-1.187	-0.431	-1.116	-0.742	-1.655	-0.394	-0.714
Other processed foods	-0.487	-1.669	-0.214	-1.574	-0.359	-2.392	-0.273	-0.984
Text./cloth./footwear	0.055	-0.154	0.461	0.151	0.503	0.145	0.222	-0.017
Other monmetal. manuf.	-0.178	-0.299	0.078	-0.121	-0.068	-0.277	0.007	-0.102
Other manufactures	-0.173	-0 165	-0.049	-0 093	-0.205	-0.199	-0.039	-0.050
Services	-0.267	-0.292	-0.086	-0.178	-0.278	-0.327	-0.081	-0.116

See footnotes at end of table.

Continued--

Appendix table B4--Changes in 1990 prices paid to commodity producers, by region and climate change scenario--continued

Region/ commodity	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
	Rest[2]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Percent change							
World								
Wheat	7.554	-2.481	0.584	-7.771	3.751	-9.704	0.512	-4,586
Other grains	-0.593	-3.468	1.528	-4.309	0.480	-6.426	2.399	-1.022
Nongrains	2.871	0.540	5.711	2.949	8.565	4.407	2.316	0.217
Livestock	-0.851	-1.855	-0.369	-1.928	-0.871	-2.735	-0.529	-1.169
Forest products	-1.794	-1.658	0.594	-0.093	-0.986	-1.022	-0.474	-0.413
Coal/oil/gas	-0.090	-0.087	-0.086	-0.071	-0.162	-0.138	-0.026	-0.022
Other minerals	0.085	0.157	0.064	0.108	0.018	0.109	0.066	0.091
Fish/meat/milk	0.537	-0.387	0.763	-0.489	0.927	-0.677	0.524	-0.224
Other processed foods	0.299	-0.824	0.780	-0.758	0.863	-1.032	0.330	-0.616
Text./cloth./footwear	0.073	-0.049	0.306	0.104	0.324	0.100	0.107	-0.016
Other nonmetal. manuf.	-0.021	-0.047	0.042	-0.004	0.011	-0.046	0.018	-0.005
Other manufactures	-0.000	0.036	-0.015	0.042	-0.014	0.046	0.012	0.043
Services	0.035	0.044	-0.022	0.013	0.007	0.022	0.010	0.020

[1] Climate scenarios based on results 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).

[2] Rest = cropland, pasture, forest, and land in other uses restricted to 1990 locations and quantities. Unrest = all land can move among cropland, pasture, and other uses.

[3] China (including Taiwan), Hong Kong, and North Korea.

[4] Indonesia, Malaysia, Philippines, and Thailand.

Appendix table B5--Base revenues from primary factors and changes in factor prices, by region and climate change scenario

Region/ commodity	Base (1990) value[2]	Scenario[1]							
		GISS		GFDL		UKMO		OSU	
		Rest[3]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Mil. $U.S.	Percent change							
United States									
Water	1,191	6.407	-1.792	4.052	-1.524	9.288	-3.217	11.731	8.972
Labor	3,273,810	0.191	0.100	-0.205	-0.075	0.036	-0.022	-0.023	-0.004
Capital	1,666,670	0.253	0.085	-0.147	-0.109	0.145	-0.053	0.040	-0.006
Land	114,317	0.753	-0.438	3.535	-1.150	2.558	-0.838	1.133	-1.062
Canada									
Water	107	-3.711	-5.751	-1.496	0.819	-5.964	-5.159	-1.571	2.227
Labor	322,388	0.758	1.034	0.471	1.054	0.608	1.290	0.458	0.887
Capital	211,063	0.864	1.114	0.651	1.197	0.823	1.455	0.589	0.998
Land	22,691	10.640	7.105	16.568	11.075	19.811	12.638	12.548	8.943
European Community									
Water	648	-6.338	18.489	-5.178	-15.797	-6.498	-21.809	10.526	14.081
Labor	3,601,650	-0.525	-0.279	-0.428	-0.226	-0.678	-0.397	-0.158	-0.053
Capital	1,836,530	-0.579	-0.313	-0.464	-0.254	-0.734	-0.438	-0.177	-0.071
Land	186,894	-4.304	-8.280	-1.850	-5.409	-3.727	-8.517	-1.206	-3.234
Japan									
Water	274	70.368	77.082	76.575	80.562	109.459	111.505	71.853	83.704
Labor	1,635,900	0.222	0.409	0.140	0.403	0.042	0.323	0.278	0.475
Capital	989,909	0.233	0.425	0.143	0.417	0.045	0.337	0.282	0.486
Land	175,307	0.801	-0.439	-0.234	-1.962	-2.151	-3.929	0.786	-0.679
Other East Asia[4]									
Water	1,200	27.021	28.206	15.850	-15.474	26.373	-1.735	22.299	12.321
Labor	354,219	0.487	0.440	0.678	0.489	0.125	0.300	0.500	0.432
Capital	252,881	0.319	0.379	0.312	0.418	0.108	0.318	0.183	0.335
Land	40,724	-2.023	-3.123	-1.363	-3.341	0.391	-2.132	-0.348	-2.805

See footnotes at end of table,

Continued--

Appendix table B5--Base revenues from primary factors and changes in factor prices, by region and climate change scenario--continued

Region/ commodity	Base (1990) value[2]	Scenario[1]							
		GISS		GFDL		UKMO		OSU	
		Rest[3]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Mil. $U.S.	--Percent change--							
Southeast Asia[5]									
Water	223	-17.946	-21.879	1.178	-6.974	0.726	-17.514	7.122	3.447
Labor	93,692	-1.322	-0.601	-0.975	-0.293	-2.248	-0.672	-0.699	-0.290
Capital	144,175	-1.246	-0.620	-1.151	-0.459	-2.236	-0.967	-0.567	-0.119
Land	25,112	3.713	-0.806	6.132	0.391	8.217	-0.312	3.228	-0.095
Australia and New Zealand									
Water	48	-11.744	-23.906	9.010	-22.504	30.671	-8.145	-7.808	-27.225
Labor	193,618	0.429	0.049	0.243	-0.252	0.365	-0.461	1.066	0.571
Capital	106,900	0.395	0.083	0.199	-0.212	0.265	-0.443	0.992	0.601
Land	18,382	1.912	0.428	0.329	-1.170	-0.543	-1.679	3.164	2.783
Rest of world									
Water	4,568	-13.622	-21.875	-8.771	-15.759	0.781	-15.536	-10.526	0.302
Labor	2,222,300	-0.028	-0.010	-0.005	-0.072	-0.241	-0.207	-0.158	0.040
Capital	2,115,540	-0.016	0.072	-0.008	0.045	-0.215	-0.056	-0.177	0.092
Land	260.384	0.930	-0.786	1.915	-0.054	1.816	-1.218	0.480	-0.028

[1] Climate scenarios based on results 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).

[2] Base values reflect total value of regional factor endowments (price times quantity). For (all) land, labor, and capital, regional endowments are constant across the base period and all GCM scenarios. For water, we use a price of $2.55 million per cubic kilometer globally; all percentage changes in water prices apply to this figure. Since climate change affects regional water endowments, percentage changes in water prices do not reflect percentage changes in total values of regional water endowments.

[3] Rest = cropland, pasture, forest, and land in other uses restricted to 1990 locations and quantities. Unrest = all land can move among cropland, pasture, and other uses.

[4] China (including Taiwan), Hong Kong, and North Korea.

[5] Indonesia, Malaysia, Philippines, and Thailand.

Appendix table B6--Changes in the household price index, household income, and real gross domestic product (GDP), by region and climate change scenario

Item/ region	Scenario[1] GISS Rest[2]	Unrest	GFDL Rest	Unrest	UKMO Rest	Unrest	OSU Rest	Unrest
	Percent change							
Household Price Index								
United States	0.102	-0.034	0.111	-0.010	0.147	-0.076	0.151	0.056
Canada	-0.776	-0.881	-0.990	-1.110	-1.202	-1.373	-0.802	-0.857
European Community	0.814	0.599	0.635	0.444	0.842	0.574	0.402	0.277
Japan	-0.536	-0.733	-0.325	-0.646	-0.255	-0.578	-0.363	-0.610
Other East Asia[3]	-0.089	-0.473	0.158	-0.502	0.569	-0.446	0.273	-0.196
Southeast Asia[4]	1.396	0.418	1.732	0.468	2.660	0.805	0.762	0.018
Australia/New Zealand	0.365	-0.027	0.453	-0.044	0.601	-0.094	0.197	-0.192
Rest of world	-0.264	-0.613	0.012	-0.444	-0.111	-0.722	-0.057	-0.314
Household Income								
United States	0.201	0.083	-0.132	-0.100	0.094	-0.042	0.001	-0.022
Canada	1.172	1.293	1.172	1.501	1.437	1.792	0.991	1.245
European Community	-0.590	-0.500	-0.460	-0.382	-0.747	-0.639	-0.180	-0.136
Japan	0.265	0.325	0.083	0.193	-0.109	0.008	0.286	0.355
Other East Asia	0.166	0.144	0.146	0.143	0.129	0.162	0.140	0.118
Southeast Asia	-0.811	-0.668	-0.403	-0.353	-1.226	-0.865	-0.227	-0.161
Australia/New Zealand	0.477	0.076	0.223	-0.283	0.262	-0.519	1.151	0.702
Rest of world	0.028	-0.029	0.108	-0.019	-0.103	-0.202	0.099	0.066

Continued--

See footnotes at end of table.

Appendix table B6--Changes in the household price index, household income, and real gross domestic product (GDP), by region and climate change scenario--continued

Item/ region	Scenario[1]							
	GISS		GFDL		UKMO		OSU	
	Rest[2]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Million $U.S.							
Real GDP[5]								
United States	5919.8	5784.2	-11142.6	-4818.5	-1246.8	1135.0	-6584.7	-3892.4
Canada	10350.1	11306.3	11638.8	13673.7	14147.5	16491.8	9594.4	11036.8
European Community	-67975.3	-56518.6	-52313.7	-42061.5	-77444.1	-63210.0	-27015.3	-20535.2
Japan	18124.0	23066.5	8675.9	17159.0	1341.9	10026.8	15507.1	21559.6
Other East Asia	1519.8	3019.6	186.1	3062.3	-1418.8	3103.2	-286.6	1579.1
Southeast Asia	-4596.0	-2652.6	-3950.2	-1812.8	-7812.3	-3877.8	-1851.5	-485.3
Australia/New Zealand	733.0	344.7	-403.9	-884.9	-710.6	-1597.7	3543.1	3027.8
Rest of world	9578.3	17879.9	4662.5	13063.8	-1160.3	13446.7	6343.8	12874.1
World	-26346.4	2230.2	-42647.2	-2618.9	-74303.5	-24481.9	-749.7	25164.3

[1] Climate scenarios based on results 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).

[2] Rest = cropland, pasture, forest, and land in other uses restricted to 1990 locations and quantities. Unrest = all land can move among cropland, pasture, and other uses.

[3] China (including Taiwan), Hong Kong, and North Korea.

[4] Indonesia, Malaysia, Philippines, and Thailand.

[5] Base (1990) values for GNP (in million $US) are: United States = 5,496,575; Canada = 597,823; European Community = 5,923,307; Japan = 3,041,381; Other East Asia = 743,368; Southeast Asia = 292,032; Australia/New Zealand = 361,917; Rest of world = 4,602,790; and world = 21,059,193.

Appendix table B7--Base values and chances in commodity supply, by region and climate change scenario[1]

Region/ commodity	Base (1990) value[3]	Scenario[2]							
		GISS		GFDL		UKMO		OSU	
		Rest[4]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	Percent change							
United States									
Wheat	74,475	-5.529	7.299	9.988	29.061	-1 020	22.275	0.622	-0.485
Other grains	238,352	-9.633	-1.361	-32.432	-12.039	-25 153	-2.264	-27.609	-18.794
Nongrains	194,389	14.005	16.109	-19.252	-10.195	7 196	6.308	-3.730	-3.351
Livestock	170,647	9.622	6.068	7.000	6.174	0 436	6.826	0.698	-2.727
Forest products	498,000	15.015	35.148	-9.009	-0.135	0 374	16.659	4.866	14.562
Coal/oil/gas	215,073	-4.007	-4.273	4.506	3.819	-0 283	-0.439	3.841	3.795
Other minerals	24,786	-3.130	-2.833	1.545	2.230	-0 750	-0.120	2.329	2.546
Fish/meat/milk	121,363	-2.860	-2.728	-2.277	-1.669	-2 238	-2.045	-0.240	-0.254
Other processed foods	292,850	-3.356	-3.205	2.298	2.636	-0 630	-0.202	2.716	2.866
Text./cloth./footwear	155,999	-2.716	-1.932	1.278	2.979	-0 437	0.974	2.530	3.047
Other nonmetal. manuf.	1,067,890	-3.082	-2.538	2.501	3.646	-0 243	0.839	3.162	3.572
Other manufactures	1,266,520	-2.755	-1.997	1.409	3.050	-0 417	0.960	2.597	3.103
Services	6,103,870	0.950	0.665	-0.508	-1.082	0 171	-0.348	-0.947	-1.127
Canada									
Wheat	32,098	-19.678	66.971	-3.583	164.539	-2.922	163.651	-7 596	126.480
Other grains	24,981	11.458	244.284	-1.694	259.211	-1.961	421.658	2 203	169.418
Nongrains	13,015	51.286	473.314	0.186	376.649	-0.934	751.158	14 416	221.047
Livestock	23,820	46.816	230.915	45.644	244.332	34.565	384.238	5 953	162.915
Forest products	155,475	18.647	50.192	3.657	20.500	11.056	51.191	1 400	10.676
Coal/oil/gas	27,388	6.146	-18.800	7.875	-18.855	7.499	-35.965	9 572	-9.487
Other minerals	10,210	-22.627	-28.256	-27.876	-32.807	-34.001	-43,662	-20 951	-24.595
Fish/meat/milk	24,438	-38.781	-32.613	-48.250	-41.112	-58.882	-50.176	-36 569	-31.657
Other processed foods	32,418	-24.942	-29.110	-30.606	-34.020	-37.008	-44.355	-23 392	-25.912
Text./cloth./footwear	18,635	-37.549	-35.071	-44.435	-41.361	-50.247	-47.997	-37 411	-34.714
Other nonmetal manuf.	130,143	-33.044	-33.234	-39.439	-38.880	-44.897	-46.530	-32 770	-31.998
Other manufactures	119,236	-30.566	-32.259	-36.652	-37.548	-41.873	-45.751	-30 214	-30.540
Services	719,538	12.152	5.763	15.770	8.961	18.571	7.237	12.965	8.393

See footnotes at end of table.

Continued--

Appendix table B7--Base values and changes in commodity supply, by region and climate change scenario[1]--continued

Region/ commodity	Base (1990) value[3]	Scenario[2] GISS		GFDL		UKMO		OSU	
		Rest[4]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	Percent change							
European Community									
Wheat	80,319	-58.023	-51.772	-51.542	-42.977	-62 726	-55.597	-25.701	-16.852
Other grains	24,994	70.306	152.121	56.176	109.012	73.737	157.921	34.835	75.581
Nongrains	279,884	-36.127	-17.035	-33.032	-16.739	-38.989	-18.360	-17.404	-5.046
Livestock	295,049	-13.293	-19.009	-7.942	-20.799	-8.226	-18.085	-13.697	-19.382
Forest products	171,394	19.057	159.057	9.233	117.281	20.769	171.292	5.700	49.988
Coal/oil/gas	82,886	-1.633	-0.467	-1.173	-0.254	-1.613	-0.392	-1.496	-1.268
Other minerals	270,580	-1.711	-0.220	-1.316	-0.203	-1.640	-0.108	-2.217	-1.392
Fish/meat/milk	157,710	-26.314	-24.746	-19.307	-17.965	-27.103	-25.451	-13.461	-12.453
Other processed foods	485,433	-1.623	-0.499	-1.155	-0.260	-1.609	-0.428	-1.912	-1.253
Text./cloth./footwear	284,159	14.678	16.035	9.349	10.285	15.538	16.873	3.793	4.519
Other nonmetal. manuf	1,472,520	15.087	14.734	10.054	10.037	15.683	15.372	5.050	5.094
Other manufactures	1,292,320	14.625	16.206	9.258	10.318	15.518	17.071	3.630	4.445
Services	5,815,930	-5.131	-5.931	-3.224	-3.687	-5.500	-6.252	-1.142	-1.567
Japan									
Wheat	952	-45.787	-16.270	-54.007	-23.529	-62.173	-36.919	-48.885	-24.826
Other grains	13,499	28.401	204.352	32.630	250.127	36.563	305.230	30.860	206.724
Nongrains	32,151	42.877	233.827	50.949	294.872	58.665	358.822	43.755	241.890
Livestock	16,665	21.875	11.259	28.089	8.955	31.392	-2.612	22.201	4.544
Forest products	29,593	17.300	15.164	20.855	20.413	28.941	28,266	16.565	12.431
Coal/oil/gas	8,662	-10.195	-10.079	-14.277	-14.020	-15.810	-15.352	-8.756	-8.535
Other minerals	16,568	-10.712	-10.970	-14.900	-15.109	-16.450	-16.572	-9.226	-9.397
Fish/meat/milk	68,056	-20.399	-19.331	-30.152	-28.783	-33.391	-31.571	-16.148	-14.907
Other processed foods	312,381	-11.386	-12.127	-15.713	-16.520	-17.285	-18.149	-9.841	-10.519
Text./cloth./footwear	121,234	-9.497	-12.679	-11.807	-15.772	-12.016	-16.960	-8.607	-11.847
Other nonmetal. manuf.	719,010	-6.652	-7.879	-8.265	-9.764	-8.287	-10.135	-6.032	-7.236
Other manufactures	1,146,530	-7.054	-8.564	-8.767	-10.628	-8.817	-11.121	-6.395	-7.894
Services	3,327,640	2.987	-0.998	3.265	-1.707	2.710	-3.306	2.521	-1.515

See footnotes at end of table.

Continued--

Appendix table B7--Base values and changes in commodity supply, by region and climate change scenario[1]--continued

Region/ commodity	Base (1990) value	Scenario[2]							
		GISS		GFDL		UKMO		OSU	
		Rest[4]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	-----------------------	-Percent	change	------------------	------------------	------------------	------------------	------------------
Other East Asia									
Wheat	98,233	-12.310	-16.270	-27.013	-10.960	-10.582	6.666	-13.662	-5.194
Other grains	314,527	4.015	204.352	7.811	16.268	-5.929	8.053	-1.242	4.805
Nongrains	428,755	16.	.827	29.500	31.292	-1.564	16.184	18.155	22.269
Livestock	691,279	4.336	11.259	-2.129	7.027	0.562	10.001	2.156	6.479
Forest products	283,530	10.634	15.164	6.050	0.849	10.684	1.683	9.509	10.068
Coal/oil/gas	21,468	3.841	-10.079	5.797	8.617	-2.038	5.020	3.484	5.632
Other minerals	15,752	-2.288	-10.970	-1.325	-1.475	-1.445	-1.869	-1.666	-1.650
Fish/meat/milk	35,760	-8.052	-19.331	-8.235	-11.342	-0.560	-8.636	-7.089	-8.871
Other processed foods	102,987	2.903	-12.127	4.703	7.047	-1.950	3.962	2.699	4.512
Text./cloth./footwear	149,392	-6.037	-12.679	-5.484	-6.998	-1.419	-5.939	-4.580	-5.774
Other nonmetal. manuf	223.391	1.440	-7.879	3.192	5.179	-2.161	2.434	1.777	3.125
Other manufactures	323,723	-3.087	-8.564	-2.074	-2.270	-1.720	-2.646	-2.062	-2.280
Services	650,319	-0.	.998	-2.956	-5.001	2.371	-2.016	-0.975	-2.666
Southeast Asia									
Wheat	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other grains	89,191	-25.713	-19.349	-25.456	-17.465	-37.880	-28.335	-15.688	-6.708
Nongrains	200,148	-17.076	-3.255	-20.585	-5.366	-30.304	-5.956	-13.748	-3.351
Livestock	74,225	-0.708	91.272	-0.376	81.673	-1.290	144.921	-0.813	28.787
Forest products	260,901	-0.691	-10.542	-1.080	-12.581	-0.947	-17.416	-0.350	-6.130
Coal/oil/gas	23,597	-12.601	-4.953	-13.295	-5.326	-19.622	-7.311	-8.388	-2.591
Other minerals	6,084	1.070	-2.673	3.061	-0.779	3.290	-2.792	2.901	0.387
Fish/meat/milk	20,591	-9.090	-8.153	-6.443	-5.456	-11.492	-9.878	-2.066	-1.585
Other processed foods	51,512	-1.865	-3.139	-0.490	-1.716	-1.842	-3.724	0.507	-0.222
Text./cloth./footwear	30,416	6.663	0.263	8.171	1.678	11.937	1.175	5.338	1.340
Other nonmetal. manuf.	68,154	-2.302	-1.157	-2.498	-1.139	-3.907	-1.697	-1.706	-0.459
Other manufactures	50,624	2.127	-0.441	2.749	0.276	3.777	-0.255	1.792	0.447
Services	247,521	5.459	-0.132	6.063	0.437	8.575	-0.572	4.137	0.620

See footnotes at end of table.

Continued--

Appendix table B7--Base values and changes in commodity supply, by region and climate change scenario[1]--continued

Region/ commodity	Base (1990) value[3]	Scenario[2]							
		GISS		GFDL		UKMO		OSU	
		Rest[4]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	--Percent change--							
Australia and New Zealand									
Wheat	15,254	10.426	18.182	10.120	21.438	-1.286	-4.254	3.815	66.372
Other grains	8,584	5.292	21.123	5.015	21.645	9.776	-1.343	-5.437	59.491
Nongrains	33,360	14.070	12.604	16.405	26.818	-10.942	17.838	-3.888	-0.818
Livestock	264,475	3.348	1.917	2.191	0.696	6.650	-5.654	30.122	19.527
Forest products	32,132	-2.316	3.963	-9.323	0.832	-12.457	-8.385	1.144	32.444
Coal/oil/gas	12,659	-1.264	-1.237	-1.264	-2.126	-0.418	-0.755	-2.219	-2.260
Other minerals	8,372	-1.046	-1.038	-1.001	-1.698	-0.187	-0.409	-2.368	-2.439
Fish/meat/milk	17,714	-0.022	-0.048	-2.095	-1.632	-1.203	-0.606	-1.259	-1.298
Other processed foods	20,731	-0.342	-0.396	-0.154	-0.314	0.556	0.707	-2.843	-3.008
Text./cloth./footwear	18,175	0.305	0.167	1.796	2.004	2.400	2.787	-4.308	-4.629
Other nonmetal. manuf.	66,743	-0.026	-0.134	1.391	1.338	2.044	2.249	-4.096	-4.375
Other manufactures	62,302	0.381	0.237	1.891	2.159	2.483	2.912	-4.359	-4.689
Services	413,544	0.251	0.155	-0.261	-0.156	-0.882	-0.302	1.159	0.704
Rest of world									
Wheat	291,182	13.035	47.596	18.012	50 905	15.783	78.260	8.020	29.559
Other grains	644,130	4.021	27.425	4.245	26.795	5.347	43.070	4.095	16.106
Nongrains	1,948,909	-6.311	7.204	10.410	0.515	-15.693	3.070	-6.688	2.990
Livestock	2,605,951	8.142	21.281	6.163	23.190	10.057	35.053	5.294	14.041
Forest products	1,883,532	2.194	-2.948	-3.227	14.163	-0.147	14.417	-0.355	-6.829
Coal/oil/gas	518,792	0.573	5.178	-0.729	3.275	-1.300	5.838	-0.296	2.612
Other minerals	198,475	-0.867	-0.075	-0.753	0.037	-1.604	-0.105	-0.422	0.091
Fish/meat/milk	251,547	-0.006	0.552	-1.838	-1.079	-5.562	-3.530	0.421	0.630
Other processed foods	642,189	-1.327	-1.708	-0.761	-0.984	-1.702	-1.945	-0.462	-0.707
Text./cloth./footwear	378,729	-2.989	-6.010	-0.463	-3.108	-0.397	-5.065	-1.054	-2.980
Other nonmetal. manuf.	1,608,410	-1.571	-1.040	-0.438	0.068	-0.086	0.647	-0.927	-0.507
Other manufactures	1,720,940	-2.535	-4.442	-0.455	-2.099	-0.297	-3.268	-1.013	-2.192
Services	4,277,060	1.803	-1.285	1.285	-1.513	1.774	-2.952	1.099	-0.739

See footnotes at end of table.

Continued--

Appendix table B7--Base values and changes in commodity supply, by region and climate change scenario[1]--continued

		Scenario[2]							
Region/ commodity	Base (1990) value[3]	GISS		GFDL		UKMO		OSU	
		Rest[4]	Unrest	Rest	Unrest	Rest	Unrest	Rest	Unrest
	Number	--Percent change--							
World									
Wheat	592,515	-9.216	14.860	-5.616	21.673	-8.157	29.780	-2.987	16.152
Other grains	1,358,258	0.513	19.342	-3.916	17.721	-5.642	25.048	-4.261	8.683
Nongrains	3,130,611	-5.814	8.502	-9.023	3.166	-15.456	4.452	-4.428	5.584
Livestock	4,142,111	5.647	15.265	3.604	15.835	6.393	23.958	4.458	10.331
Forest products	3,314,557	6.151	10.051	-2.143	-4.518	2.359	-0.656	1.776	1.303
Coal/oil/gas	910,525	-0.987	1.191	0.349	2.082	-1.519	1.763	0.555	1.950
Other minerals	550,827	-2.145	-1.292	-1.898	-1.213	-2.642	-1.659	-1.887	-1.400
Fish/meat/milk	697,179	-11.298	-10.399	-11.576	-10.438	-15.581	-13.968	-6.664	-6.051
Other processed foods	1,940,501	-3.631	-3.594	-3.288	-3.249	-4.929	-4.809	-2.195	-2.203
Text./cloth./footwear	1,156,739	-0.312	-1.662	-0.437	-1.621	1.210	-1.254	-1.271	-2.233
Other nonmetal. manuf.	5,356,261	0.958	1.039	0.784	1.025	1.298	1.475	-0.085	0.041
Other manufactures	5,982,195	-0.603	-1.095	-0.613	-0.970	0.132	-0.823	-1.080	-1.481
Services	21.555.422	0.096	-1.751	0.196	-1.731	0.020	-2.742	0.475	-0.913

[1] Changes in supply represent the additional quantities (positive or negative) that firms would be willing to sell at 1990 prices under the alternative climate.

[2] Climate scenarios based on results 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).

[3] For wheat, other grains, and nongrains, values are in 1,000 metric tons. For livestock, values are in 1,000 head. For forest products, values are in 1,000 cubic meters. For all other commodities, values are in million U.S. dollars.

[4] Rest = cropland, pasture, forest, and land in other uses restricted to 1990 locations and quantities. Unrest = all land can move among cropland, pasture, and other uses.

[5] China (including Taiwan), Hong Kong, and North Korea.

[6] Indonesia, Malaysia, Philippines, and Thailand.

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