

Chapter #14: Paper on Climate Change in Agriculture

CLIMATE CHANGE POLICY AND THE AGRICULTURAL SECTOR

Introduction

Climate change has become a major public policy issue and is the subject of a great deal of current economic research. While scientists continue to refine their estimates of the likelihood and dimensions of climate changes and their impacts, economists assess their implications on the economy and human well-being and design policies to slow climate change and reduce its adverse impacts.

This paper provides an overview of economic research on climate change, with an emphasis on policies affecting agriculture. It first presents general results of studies predicting the impacts of climate change on agriculture. Then, it presents suggested strategies to address the impacts of climate change. The last section of the paper concentrates on strategies and policies to delay the process of climate change through mechanisms that will lead to accelerated sequestration of carbon and other greenhouse gases.

Studies on the Economic Impacts of Climate Change on Agriculture

Economic predictions regarding the outcome of climate change depend on scientific knowledge. Since predictions of the physical dimensions of climate change are subject to vast uncertainty, the economic impacts are uncertain as well. The predicted impacts of change also depend on assumptions regarding other phenomena, such as population growth, the rate of technological change, and government policies. Furthermore, there are numerous models of climate change impacts. They vary in their assumptions about

risk and uncertainty, the degree of aggregation, and variability and spatial heterogeneity. The major modeling approaches to predict climate change impacts in agriculture are the following:

1. Hedonic Price Models (Mendelson et al.)

The two main premises underlying this approach are the following:

(a) Changing Asset Values. The economic impact of changes affecting agriculture is reflected by change in asset values due to the competitive nature of agriculture and its relatively small impact on the price of inputs besides land and agricultural fixed assets.

(b) Correlation with Temperature. Prices, in particular land prices, are the sum of the values of the assets' attributes. For example, the price of land can be decomposed to components that present the value of the attributes of the land, including soil quality, location, and weather characteristics. The contribution of one unit of temperature to the price of land is called the hedonic price of temperature. By using existing land price data, Mendelson et al. estimated how changes in temperature and other climatic variables affect land prices throughout the United States. They combined these estimates with prediction of changes in temperature and other indicators of climatic changes to obtain an estimate of the impact of climate change on asset values throughout the country.

Through aggregation, they obtained overall estimates on the impacts of climate change on the value of land and agricultural assets in the United States.

Mendelson et al.'s work predicts that, under most scenarios, the impact of climate change on U. S. agriculture will be modest and result in less than a 10 percent change in

the value of fixed agricultural assets. The impacts will vary significantly across regions, some regions will gain and others may lose.

The hedonic price approach is clever, but also relies on restrictive assumptions about competitive behavior of agricultural markets and it doesn't consider explicitly the impacts of consumers' well-being. The approach may be elegant and simple, but its simplicity does not provide as much information as decision-makers would like. These are advantages to alternative, more process-oriented prediction techniques.

2. Programming Models (Adams, McCarl et al.).

Programming models operate under the assumption that farmers are profit maximizers. These models require information on land allocation, input use, and, in particular, crop budgets for various locations in the country. They predict land allocations, commodity output and prices, and profits at various locations. The key parameters of the models are calibrated so they generate predictions that fit current land-use, resource allocation and price patterns. Then the calibrated models are run under various scenarios about the impacts of climate change on yields and costs.¹ The impacts of climate change on yield and crops are obtained from agronomical crop yield models that relate production to temperature, precipitation, and concentration of carbon dioxide in the atmosphere

Their main results of the programming model are consistent with those of the hedonic price models; namely, climate change will have a modest impact on U. S. agriculture overall. Both output levels and prices of most commodities will not change

¹Some of the models may also explicitly include demand equations that relate output price to quantity consumed. The models will compute supply of output for different prices and, using demand and supply relationships, find equilibrium prices the *source* for both prices and quantities of agricultural commodities.

by more than 10 percent. Field crop producers will actually gain from climate change, while livestock producers and consumers will lose. The big impact will be distributional. Some regions may gain while other regions; for example, the Plain states, may lose significantly.

3. Delphi Studies (Doering).

Doering reported on efforts conducted by extension specialists who interviewed numerous economists and natural scientists in the private and public sectors for their expert assessment on the impact of climate change under various scenarios. Their conclusions include:

(a) Geographic Shift. With climate change, there will be a northward shift of 75 to 150 miles of weather and land-use patterns in most regions of the United States. That may not affect the central areas in most regions but may drastically affect the peripheral locations. Some counties in Kansas and Oklahoma may lose their agricultural viability while some areas in the Dakotas may actually gain. The overall effect of climate change may not be as significant as its impact on specific regions, especially the outlying areas of major agricultural regions.

(b) Adjustment Costs. The major costs of adjustment to climate change will be results of increased variability and changes in the distribution of temperatures and sunlight over space and time. For example, in regions in California, climate change may lead to faster snowmelt and increased rainfalls, resulting in significant flooding and requiring adjustment in current water containment facilities. In general, ability to develop infrastructure to contain floods will be as important as the ability to deal with droughts. Segerson et al. found that in some cases the most severe impact of climate

change on yield might be related to increased variability in weather conditions during seasons and even 24-hour periods.

(c) Importance of Timing. The pace of climate change is an important determinant of the ability to contain its impacts. Climate change will require changes in production practices, design of new pest management strategies, reallocation of resources, and reorganization of the agricultural system. Agriculture is undergoing a natural process of change. Firms are established and then shut down. Old farmers retire, and new ones enter the system. Adjustments to climate change will require acceleration and expansion of these processes of change. The agricultural economy is designed to deal well with moderate rates of change. However, rapid changes in weather patterns may pose significant problems in the development of agronomical and technological responses to changing conditions as well as their introduction and implementation.

(d) Research Needs. There is need for expanded capacity of research and resource adjustments. The increased uncertainty that climate change brings to the agricultural system requires further research on alternative responses to drastic change in production and environmental conditions as well as improved physical infrastructure capable of adjusting to change. Governments may need to design institutional arrangements and partnerships between the public and private sectors to coordinate response to swift changes in climate.

Research on the impact of climate change on agriculture emphasizes domestic issues, but the most significant effects are likely to occur internationally. Furthermore, U. S. agriculture has been a major exporter, and one major effect of climate change on agriculture is through its impact on export demand. These types of links and the overall

impact of climate change on international agriculture have not been investigated as thoroughly as its impact on U. S. agriculture.

Furthermore, current studies look at the impact of changes in weather conditions based on current agricultural supply and demand relationships. However, the climate change events that we are concerned with will likely occur far into the future—20 to 50 years from now (1999).

Two other dynamic phenomena that will affect these future periods are population growth and technological change. The expected increase in both population and income in the next 50 years will result in increased food demand (see studies by IFPRI). Thus, it is important to evaluate the impact of climate change and its disruptive effect on supplies in the context of the growing demand for food and fiber. On the other hand, the impact of population growth may be countered or overcome by technological change in agricultural production systems. Over the last 100 years, we have seen the rate of technological change grow faster than the rate of population growth, which led to a relative decline in food prices. Technological changes may also improve the capacity to address the impacts of climate change. There is no assurance that the rates of innovations and technological changes that we have witnessed in the past will continue forever. Part of the growth in supply and agricultural production was due to overharvesting of natural resources such as fish. We have suffered from land degradation and overutilization of resources. Thus, we are uncertain whether our increased knowledge will enable us to develop the technology that will counter the major increase in population, the erosion of agricultural resource base, and the negative impact of the planet's productive capacity due to climate change.

For this reason, it is worthwhile to analyze global resource allocation and production patterns under alternative scenarios combining changes in climate population growth and technological change. More global analyses on the impact of climate change on agriculture will provide us with better predictions. Nevertheless, it is reasonable to assume that the overall impacts on climate change will be modest, relative to other major phenomena, in particular population growth and changes in technology. On the other hand, climate change may have a drastic effect on certain regions and lead to significant political impacts. In particular, climate change may be associated with rising sea levels that cause flooding and destruction of millions of acres of land and displace millions of human beings. Climate change may also result in significant desertification of various locations. Flooding and desertification may lead to destruction of life and severe levels of dislocation, which may result in violence and political ramifications. Isar argued that global warming or cooling triggered some of the most important events in history.² Future periods of climate change may have similar effects, and that is one reason why attempts to slow the process and restrict negative side effects should be taken.

Components of Climate Change Policy

Because of the high degree of uncertainty regarding the timing and magnitude of climate change, policy responses to address its impacts have to be flexible and adaptive. Some may be tempted to take the “wait and see” approach and not do much until more information is accumulated. However, as Fisher argues, such an approach is unwise

²He claimed, for example, that both the invasion of Rome by tribes from Northern Europe and the population movement during the period of the rise of Islam were associated with significant changes in weather.

because present decisions affect our capacity to alter the speed of climate change and to address some of its future implications. Decisions we make today, regarding the use of resources such as land and water, may be irreversible or costly to reverse. Thus, in making major irreversible resource use decisions, we have to consider, within a probabilistic framework, alternative climate change scenarios. That suggests that long-term investments and resource allocation plans that are likely to be unfavorably affected under alternative climate change scenarios will become less desirable. On the other hand, resource allocation choices and investments that may help to alleviate negative probable impacts of climate change are more valuable.

Because climate change increases the range of weather phenomena we may encounter, more resources should be allocated to research and development activities that improve our ability to handle extreme weather changes such as droughts. We should consider introducing water management schemes that will conserve water in areas where climate change will significantly reduce water availability in the future. Because of the uncertainty about climate change, “no regret” policies should be pursued. These are policies that are worthwhile regardless of climate change. Fortunately, policies that will slow climate change and mitigate some of its negative consequences and also enhance other environmental objectives. They may also have a positive effect on reducing air and water pollution, conserving natural resources such as land and water, preserving biodiversity, etc. Because of the positive correlation between climate change mitigation and other environmental objectives, to a large extent climate change policies have become an umbrella to numerous policies that aim to meet a wide range of environmental objectives.

There are two types of climate change policies—those that aim to delay climate changes and those that mitigate some of its implications once it occurs. Much of the emphasis is given to delay strategies, which will be emphasized in the rest of this paper. They include both activities to reduce human contribution to climate change by reducing carbon dioxide emissions and other climate change gases and sequestration activities that aim actually to sequester carbon from the atmosphere.

Policies that aim to change human behavior towards climate change-delaying activities include direct control and economic incentives. Key consideration for the use of these policies is discussed below.

Incentives and Resource Conservation

There is a wide body of theoretical literature and empirical evidence on the role of incentives as policy tools leading to resource conservation. The basic premise of these policies is that producers are profit seekers and, as prices change, they will change their production strategies to reduce cost or increase revenues. Farmers may choose environmentally unfriendly activities because they may not pay the full social cost of their action. For example, chemical residues applied by farmers may contaminate bodies of water and cause damage to the fish population. If farmers are not required to pay the cost of the damage to the fish, then they will not modify their behavior. Increasing the cost of the inputs (e.g., water and chemicals) will, however, lead to a change in behavior.

Khanna and Zilberman provide several examples that illustrate that, as price of the input increases, there is gradual change in behavior. A modest increase in price of input may lead to reduction with an existing technology. A larger increase in input price

may lead to a switch in technology. For example, farmers may switch to integrated pest management in the case of an increase in price of chemical input or, if the price of water increases significantly, farmers may switch from flood irrigation to drip irrigation. As the price of inputs increases drastically, some producers may stop their operation altogether.

Increases in input prices or regulations that limit their use do not only affect the behavior of farmers but also have a strong impact on the behavior of technology manufacturers. The design and introduction of agricultural technology is subject to economic consideration, and it was demonstrated empirically by Hayami and Ruttan who introduced the hypothesis of induced innovation. According to this hypothesis, societies will adopt technologies that save inputs that are scarce in those societies. The relative scarcity of labor in the United States, compared to the rest of the world, may explain the introduction of laborsaving technology in the United States. The introduction of both the cotton harvester and the tomato harvester has been explained by labor scarcity and in ability to obtain cheap domestic and migrant labor to harvest this crop (de Janvry).

The response to the energy crisis is especially relevant as we consider policies to address climate change. The increase in the price of oil and gasoline by 100 percent or more between 1973-1975 changed machinery, particularly the characteristics of automobiles that were introduced in the American market. In the 1970s, fuel-efficient cars became popular, and energy use predictions made before the energy crisis were significantly lowered.

Several studies documented how scarcity and the increase-effective prices led to changes in behavior and institutions during the recent drought in California (Zilberman et

al.). During the five-year drought of 1987-1991, precipitation was between 40 percent and 70 percent of normal. Water inventories provided the means to cope with these shortages in the first two years without water cutting supplies to agricultural producers. However, during the later years of the drought, supply was reduced significantly, especially to farmers with junior water rights. The impact on farm income and revenues was not significant. Farmers overcame surface water supply reduction their shortages through three means: (1) relying on ground water reservoirs, (2) adopting modern, water-saving irrigation technologies, and (3) fallowing land mainly used for low-value crop. Since 80 percent of agricultural production was grown with 20 percent of water, fallowing of low-value crops did not affect income very much. Furthermore, as the drought became more severe, California introduced a water bank, which enabled trading of water. Trading supplied water to producers of high-value crops in the cities. Actually, some of the growers who diverted the land did it to sell their water rights to cities. Actually, the drought left California's irrigated agriculture in better shape because of the institutional and technological changes and movement towards increased use of drip, sprinkler, and computerized irrigation. While the drought and energy crisis experience suggests that farmers should respond to incentives, it also implies that the derived response may take time and that incentives have to be quite significant for farmers to alter the way they operate.

The literature on the use of incentives for environmental protection and resource management (Tietenberg) states that producers will increase resource use efficiency and reduce activities that may cause negative environmental price effects if they receive the correct price signals. There are several mechanisms that may increase the price for

resource use or environmental damages. They include taxation, introduction of trading rights in resource use or pollution generation, and subsidies for resource conservation or pollution reduction. While these policies may have the same final outcome in terms of resource allocation, they have significantly different distributional effects. Farmers may oppose bitterly resource or pollution taxation because it may lead to reduction in production and transfer of income to the government. They would be less averse to setting upper limits to total resource use or pollution generated by the industry and introducing a market for emission rights. The industry would prefer this policy to pollution taxation because the tax revenues would remain within the industry rather than be transferred to the government. Actually, resource-using industries most favor subsidies for resource conservation. These subsidies generally make the industry better off relative to no intervention at all, but increased concern for government spending make this type of solution less achievable politically.

The recent success of tradable emission permits as tools to reduce air pollution (Cropper, Krupnick) makes this incentive mechanism more attractive. On the other hand, Dennis King argues convincingly that introduction of trading in wetland development rights has not worked as well. The basic idea was to have developers wanting to drain a wetland invest in an activity that would generate a wetland of the same quality elsewhere. The economic volume of these activities has been quite substantial. King argues that the replacement wetlands are not equivalent to the original ones. Success of the air pollution permit versus the problems of trading in wetlands development rights raises the importance of issues monitoring and commodification of environmental goods. Air polluting gases are well-defined substances, and their emissions through stacks can be

easily monitored. It is much more difficult to quantify and measure wetlands and, under the current arrangement, the performance approval mechanism requires much subjective evaluation and assessment from government officials. According to King, laxity in defining standards and in allocation of resources for their enforcement led to underperformance of the wetland development trading system.

Several issues impede the introduction and implementation of incentives for environmental performance. These issues include the following:

1. Difficulty in Evaluating Environmental Amenities and Natural Resources.

Because of this difficulty, Baumol and Oates suggested that governments determine target levels of environmental quality improvements and use trading as a mechanism to achieve these objectives. The determination of this target level will imply a value of these resources. Higher reduction levels suggest in most cases a higher evaluation of environmental amenities. While this type of approach may not yield the optimal resource allocation where the economic cost of environmental improvement is equal to the economic benefit at the margin, it is a practical approach that has been taken by policymakers in many arenas including climate change.

2. Monitoring of Environmental and Pollution Reduction Activities.

The key to having an effective incentive system is measurement of performance. However, it is very difficult to monitor pollution in many cases, for example, emission of carbon dioxide with various tillage activities or seepage of agricultural chemicals into ground water. That will make implementation of direct pollution reduction incentives difficult. An alternative approach is to provide incentives for proxies. For example, instead of taxing water pollution directly, a variable fee based on land use can be levied.

This fee can also be adjusted to water application technologies. For example, a farmer who grows oranges with drip irrigation may receive a subsidy or pay a lower fee than a farmer who grows alfalfa with flood irrigation.

3. Adjustment Time and Cost.

Improving environmental quality may take some time before producers adjust with both taxes and subsidies. There is significant heterogeneity among producers, and cost of adjustment for some are much higher than others, so they may pay the extra tax or forego a subsidy in order to continue with old technologies. Eventually, producers may adjust, but policymakers and the public may become impatient with the adjustment process. Stricter policies (direct control) have the advantage of meeting a higher level of compliance in less time. On the other hand, they may entail higher cost in terms of both production and other forms of adjustment.

One form of adjustment cost that has not received much attention in the literature (see Hochman et al.) is insolvency. An environmental regulation that increases the cost of production may reduce producers' profit margin and not avail to them the sufficient resources to pay their debt. The debt equity ratios vary among farmers. Financial viability of some producers is very vulnerable to a relatively small reduction in income, and environmental regulation may lead to their insolvency. In situations of insolvency, one may not observe significant change in resource allocation because the new owners will utilize the resources. But the social cost of the insolvency may be quite substantial, and may provide the main reason for objection to environmental regulation. Hanemann et al. showed that assessing the impact of drainage control in California revealed that

penalties on drainage that may reduce acreage in the Central Valley by 5 percent may lead to insolvency of farms with about 25 percent of the land.

Implementation of the Koyoto Agreement

The Koyoto Agreement provides a framework to slow and control the buildup of global warming gases in the atmosphere. Each country signing this agreement sets a target level of global warming gases not to exceed the year 2007. These target levels are based on global gas emissions of 1990. The United States aims to reduce its emissions by 6 percent of the 1990 benchmark. Both the European Union and Japan aim to reduce their emissions by 7 percent. The Soviet Union and other Eastern Block nations have a “black hole.” Their target levels are equal to the 1990 emission level but, since their economies and emission levels have declined since 1990, they actually have an added capacity to increase their emission levels.

Countries are allowed to form blocks that will meet the aggregate emission level of the countries forming the block. This type of arrangement can result in trading of emission rights. If, for example, the United States and Russia form a block, then the United States may pay Russia to use some of the unutilized reduction credit that are available to Russia because its emissions are below the 1990 benchmark level. Furthermore, in some cases it may be worthwhile for utilities in the United States not to invest in reduction of emissions but, rather, buy emission rights of a utility or a producer in the United States or in countries in the same block as the United States.

Each government may use a variety of tools to meet its target level. It may include taxation of carbon dioxide and fuels and direct controls that will require certain

technologies to be used at certain activities. For example, it may require that all new power stations use a certain type of energy, say, natural gas, while phasing out inefficient and polluting coal-burning facilities. The Conservation Development Methods (CDM) arrangements enables developed nations to earn emission credit by investing in emission reduction projects in developing nations.

The formal accounting of emission credits is conducted at the national level, so individual countries will have internal accounting. However, what matters at the end will be the national aggregations. For accounting purposes, an international cooperation with units in different countries is not considered one entity. Each plant will be part of the emission accounting of its own country.

The Koyoto Agreement will be binding once it is signed and verified by 126 nations. Thus far, mostly developed nations have signed the agreement. Developing countries that have signed include Costa Rica, Argentina, and some of the island nations. Some of the major developing countries such as India, China, and Brazil have not yet signed.

These countries have not signed the Agreement, not because they oppose setting a global limit on carbon emissions, but because they would like developed nations to pay the cost of reducing emissions. China and India are already among the largest emitters of carbon dioxide, but their per capita energy consumption is far below that of developed nations. They will continue to grow, and that implies increasing energy consumption. Under current prices, it may mean more than doubling their emissions of global warming gases. The perception in some developing countries is that they did not cause the current mess and should not have to pay for it. One perspective that is supported by some groups

in India is to assign nations emission rights based on their population. Of course, such an approach may increase incentives for population growth. It will also obviously benefit populated countries in Asia that can use it as a base for trade. Chakravorty views the current stance as part of a negotiation process where developing countries would like to make their participation in the carbon emission curtailment agreement subject to subsidization by the developed world of some of the modernization of their energy sector.

While the President of the United States has signed the Koyoto Agreement, the treaty has not been ratified by the U.S. Senate. It is not clear, under the current situation, if it enjoys sufficient support to be ratified. Senators of agricultural states control crucial votes, and many in agriculture object to the treaty because reduction in U. S. emissions will lead to increased energy taxes, which may increase the cost of agricultural production. Agriculture is likely to view this treaty more favorably if it provides farmers an opportunity to gain extra income through credit for sequestration of global warming gases.

Agricultural carbon sequestration may be one of the most cost effective way to slow processes of global warming, but it will be practiced only when such activities are considered part of the global warming gases accounting that are recognized by the Koyoto Agreement. The present implementation protocol of the Kyoto Agreement recognized forest sequestration as part of the emission reduction activities of the participating nations. The next section will discuss some of the elements needed to incorporate agricultural carbon sequestration in this process.

The Economics of Trading in Soil Carbon

According to Lal et al. there is twice as much carbon in the soil as in the atmosphere and, until the later stage of the industrial revolution, tillage activities were the major contributors to the accumulation of carbon in the atmosphere. By modification of soil management practices, for example, adoption of minimal tillage or planting of a wide variety of crops (e.g., legumes) on marginal land, significant levels of carbon can be sequestered. According to some estimates, about 20 percent of the U. S. annual carbon emissions can be sequestered every year for the next 50 years by changing crop management practices and rebuilding marginal soils (**cite**). The adoption of these soil management practices has another advantage: they are part of no-regret strategies since they help reduce soil erosion and improve water quality, and are consistent with a move to more sustainable and less chemically-dependent agriculture.

There is an even larger potential for carbon sequestration by improved soil management if it is done on a global basis (Lal et al.). This type of agricultural management activity can accompany forest expansion and management as part of a strategy to reduce buildup of carbon gases in the atmosphere or even reduce their stock. These activities are especially important during a transition period of 50 years or so when alternative energy sources are being developed.

Two sets of issues are raised when incorporating soil carbon as part of accounting of global warming gases conducted as part of the Koyoto Agreement. First, carbon sequestration has to be economical and compete with alternative means of reducing

global warming gas emissions. The second, and more difficult, issues are modification of soil carbon sequestration activities.

1. The Conditions for Economical Sequestration of Soil Carbons

The economic cost of soil carbon sequestration depends on alternative activities that reduce global warming gas stocks. These alternatives include the following:

(a) Improving efficiency of existing power plants and switching to clean energy sources. Khanna and Zilberman showed that improvement in management practices could reduce India's CO₂ emissions by about 10 percent and increase energy production from existing facilities by about 10 percent. A more drastic approach involves closing old, inefficient coal-burning facilities and switching to natural gas, wind, or nuclear power.

(b) Adopting more fuel-efficient appliances and improving energy management strategies to reduce energy demand. Increasing energy prices and taxing carbon or fossil fuel can induce these strategies. These taxes may be combined with subsidies for low-income individuals.

(c) Expanding forest areas and agroforestry activities. Managers of forests in Costa Rica have negotiated to sell their sequestration rights to a consortium of Canadian utilities. The potential of sequestration by trees has been significantly investigated, and sequestration by trees and use of biofuel is considered by some as an efficient strategy for slowing climate change (**cite**).

It is difficult to estimate an equilibrium price for sequestered carbon. There is a wide range of estimates of this price (Tweeten and Sungen). It may be between \$10 per ton to \$150 per ton. It is our personal assessment that carbon sequestration at below \$30

per ton is economically viable and that sequestration between \$30 and \$50 per ton may be economical under some circumstances. If the cost per ton is above \$60, then the likelihood of economic viability is negligible.

However, when carbon sequestration activities provide some added benefits that can be enumerated economically in terms of reduced soil erosion and water contamination, then benefits have to be taken into account in designing an optimal social resource management plan. When these benefits contribute to the profitability of farm operation, then rational growers will automatically take them into account. However, if these benefits contribute to the societal well-being, but not the well-being of individual producers, then individual decision-makers will take them into account only when appropriate incentives (subsidies) are established. It should be noted that other policies to control global warming (e.g., carbon taxes) also have beneficial side-effects such as reduction of traffic congestion and improvements in the balance of trade.

Future research will aim to provide information for a quantitative analysis of the economics of soil carbon sequestration. It should assess the cost of these activities at each location and provide some measure of their carbon sequestration potential and other benefits. Such research will be conducted consistently on a national or global basis. We have Geographical Information Systems that can identify the area where soil carbon sequestration provides the best economic opportunity, and policies will be designed to target these opportunities. These policies will include both payment for carbon sequestration and compensation for other socially beneficial side effects. Babcock et al. develop a methodology for targeting environmental conservation activities for the

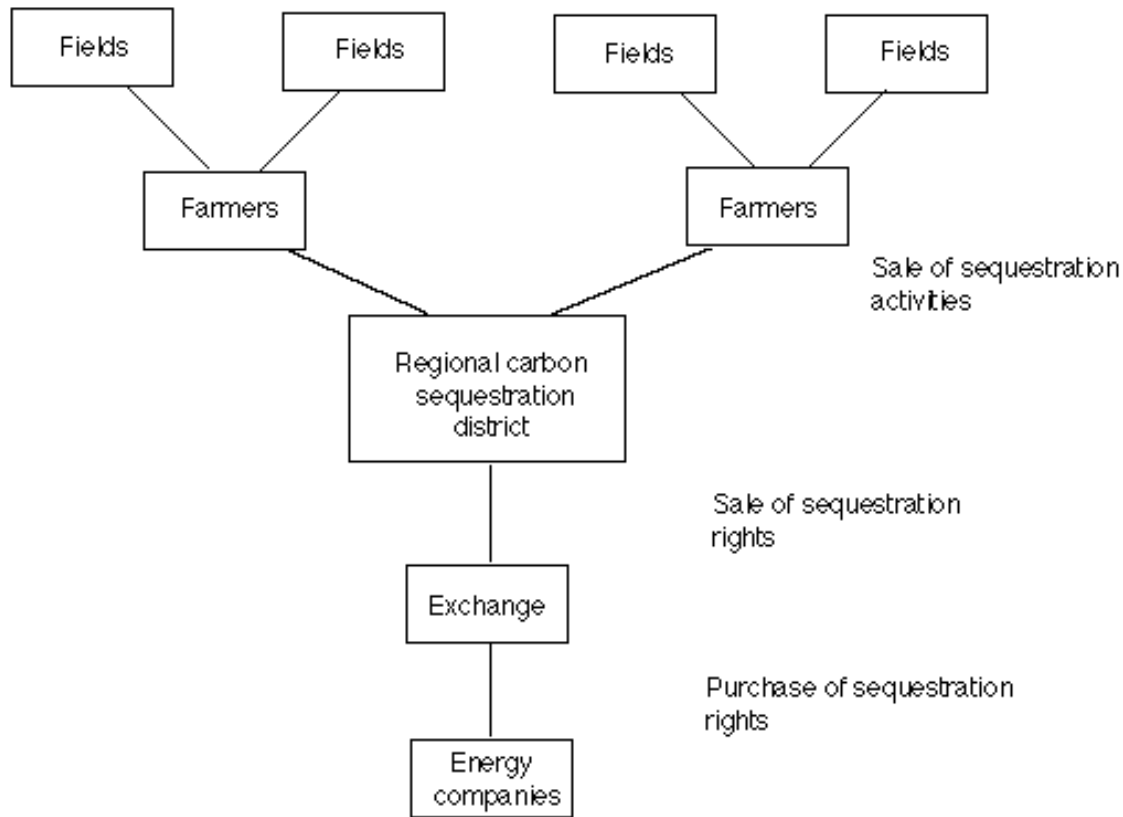
Conservation Reserve Program. Such methodologies should be developed for targeting and pricing carbon sequestration activities.

2. Implementation and Modification of Soil Carbon Sequestration Activities

The establishment of a workable implementation plan to incorporate soil carbon sequestration to a quantitative climate change control strategy requires addressing several challenging problems including:

(a) Organizational Structure

The remuneration and compensation of soil carbon sequestration activities may be conducted within a market system or as part of a government program. Figure 1 depicts the main organization needed to facilitate including soil carbon sequestration in a market for carbon emission rights. Buyers and sellers of emission rights will interact through an exchange (such as the Chicago Mercantile Exchange) which will manage documentation and transfer of rights and funds. The exchange will also likely be responsible for recording and incorporating various transactions within the appropriate national accounting systems for global gases since national accounts are officially recognized by the Kyoto Protocol. Because of the vast amounts of land and large number of farming



units involved in soil sequestration activities and the relative small monetary volume of soil sequestration activities of individual fields or farms, intermediate regional units will emerge. These units that will be referred to as carbon sequestration districts will sell (and sometimes buy) to the exchange carbon sequestration contracts. Utilities and other emitters of global warming gases will purchase these contracts. The sequestration districts will manage the accounting with individual farms and monitor activities at the field level. The exchange may monitor the performance of the sequestration districts.

This type of decomposition is not unusual and is consistent with organizations such as water districts or pest management districts. The decomposition reduces transition costs and enables establishing different types of contracts for units of different sizes.

Soil carbon sequestration activities may be remunerated through a government program. This may be an expansion of the Conservation Reserve Program (CRP) where the USDA (or other agency) will pay farmers for specified soil management activities through contracts. The government will obtain the rights to the carbon sequestered by these activities, and they will be credited to the national emission reduction effort or be traded.

Remuneration through a government program can rely on existing infrastructure for compensation and monitoring of soil management activities. Farmers' receipts from the program may add compensation for extra social benefits generated by carbon sequestering soil management practices. It may reduce transaction costs, since national governments are the entities engaged in the carbon accounting. On the other hand, credibility of carbon sequestration activities will be enhanced if they will be commodified and traded with a commercial market system.

(b) Measurement and Monitoring

The remuneration of carbon sequestration will not be based (in most cases) on actual sequestration levels but on estimated sequestration. Therefore, it is crucial to develop procedures, formulas, and software to translate farm management activities in the field to carbon sequestration units. The formulas rely on information on initial situations in the field, agro-economic activities, and climatic conditions to estimate sequestration levels. Obviously, accurate accounting requires accurate documentation of benchmark conditions and continuous monitoring of agro-economic activities, and that may result in high transaction costs.

The design of accounting and remuneration procedures is challenged in balancing the gains from increased accuracy with the cost of extra transaction costs. It is expected that software and accounting procedures will be modified and improved as new experience is accumulated and technologies progress. If carbon sequestration credits are traded within markets, the regional sequestration districts are likely to sell and sometimes buy)³ sequestration contracts (in units of, say, 100 tons of carbon) and buy from farmers long-term contracts (say, 5 to 10 years) that specify agronomic practices. Over time, we may expect that insurance, trading, and accounting arrangements will emerge, so that farmers will be able to buy the rights to discontinue contracted practices, and districts will be able to protect themselves if they fail to deliver a promised contract.

Agricultural practices that will be paid by sequestration contracts have to be easily observable. They may be specified in terms of crop selection, choice of irrigation and soil management practices, etc. Districts will monitor individual farmer behavior, and exchange may develop a mechanism (e.g., random checkup) to monitor districts' activities. When formulas require quantitative information on yields and actual input use, over time districts may obtain access to accounting data or monitor activities through remote sensing.

Establishing highly automated, electronic monitoring systems may be challenging but feasible in developed countries. The monitoring procedure may vary by location, and a bigger challenge is to develop effective monitoring procedures and remunerating formulas in developing countries. Research aimed at designing sequestration rights

³Sequestration districts may need to buy emission rights from time to time because some farmers may not fulfill their contracts or changes in conditions over time may make it uneconomical to conduct carbon sequestering activities (actually carbon emitting activities become profitable).

trading mechanisms have to emphasize the development of mechanisms that will facilitate implementing such markets in developing countries.

(c) Abuse Potential and Equity Considerations

Ideally, all soil emission and sequestration of carbon would be part of an aggregate national carbon accounting and treated like emissions from major industrial sources. Thus, the percentage (6 percent in the case of the United States) of reduction in carbon emissions will apply to all sources. The agricultural sector would have gained from such arrangement if emission reductions exceeded the national target and would have had extra costs if emission reductions did not meet the national target.

The across-the-board incorporation of soil carbon emissions and sequestration in the national carbon accounting is not likely to materialize partially because of monitoring and transaction cost consideration and mostly because of lack of political support. This arrangement is likely to eliminate much of the strategic behavior and abuse which may accompany the arrangements that are more likely to occur. These arrangements will apply only to part of the national land base, in particular, to locations with explicit engagement in sequestration activities. The voluntary (at least initially) participation in sequestration activities may motivate landowners to engage in carbon emitting activities prior to agreeing to a carbon sequestration contract. Such activities (intensive tillage) may increase immediate profits and generate larger potential for sequestration gains. Furthermore, with finite sequestration contracts, farmers may reverse the sequestration gains by changing land management activities when their contracts expire.

To reduce the potential for such abuses, the term of contracts may be very long, but farmers may exit from their contracts and reverse some of their sequestration

activities by purchasing emission rights. Furthermore, the benchmark determining the potential for carbon sequestration at a certain location will be decided by the state of the location at a moment in the recent past, say 1998, to eliminate incentives to carbon emission activities behavior before enrollment in sequestration programs.

The introduction of rewards for carbon soil sequestration may negatively affect individuals who have managed their soil soundly and thus have small potential for enhanced sequestration. This equity problem may reward unsound soil stewardship in the past and may divert most of the reward for restoration to regions with marginal and/or bad managed soils. These distributional side effects may have political economic implications where representatives of regions with high quality, well-preserved lands may not be major supporters of remuneration for soil carbon sequestration. Thus, the legislation to introduce rewards for soil carbon sequestration may be needed to accompany rewards to other environmental stewardship activities that are applicable to regions with lower potential for carbon sequestration.

The implementation difficulties associated with the introduction of rewards for soil carbon sequestration are even more daunting in developing countries. These difficulties may prevent obtaining much international support to inclusion of these activities in the Kyoto Protocol, especially in the long run. Since these soil carbon sequestration activities have the potential to be an important contributor to a global warming remediation strategy and, since the United States may benefit from remuneration of soil carbon sequestration, it may be useful if a soil carbon sequestration program is introduced unilaterally in the United States. First, so that the implementation issues will be ironed out and the feasibility of the strategy will be examined. The

successful implementation of this initial effort will domestically facilitate incorporating soil carbon sequestration in the Kyoto Protocol.

Some of the problems associated with wetlands development rights trading may also promote trading with carbon sequestration rights. It is important to develop mechanisms for measurement and verification and make sure problems of irreversibility are addressed.

The first problem is technical and may be the least difficult. Some basic formulas need to be established so one can translate soil management activities in the field to carbon sequestration levels. If one has the description of the initial situation of a field and certain activities occur, one can compute the levels of carbon sequestration over time. Secondly, activities over time may improve or worsen carbon situations in the atmosphere. Thus, accurate accounting requires some dynamic monitoring. Since changes in behavior affect carbon in the atmosphere, it would have been more accurate if credits and contracts were based on annual performance. However, that may result in high transaction costs, and one may have to consider longer term contracts to specify behavior for set periods, say, 10 years. There will be penalties for deviation from the prespecified agreements. The cost of implementation largely depends on the size of trading units. Ideally, it will be desirable to monitor behavior on a field-by-field basis, but it may be useful to establish larger units that will be responsible for sequestration activities. It may be a farm or a sequestration district. Land-use activities within this district will be monitored to provide accounting of emissions of sequestration, and that may be compared to some prespecified plan. The districts may maintain bookkeeping transactions with some carbon sequestration banks. Then we will handle bookkeeping

activities with each individual farmer. This type of approach of breaking national farming areas into districts that are responsible for all the transactions with the individual units is quite common in land resource management, water delivery and soil conservation, and can be pursued as a proven mechanism of trading soil carbon sequestration.

Conclusions

Climate change presents major uncertainties for the future of agriculture both domestically and globally. Future impacts have to take into account expected developments such as population growth, increase in demand of agricultural products, and changes in technologies that will likely increase productivity. Within this context, the overall impacts of climate change on agriculture are not likely to be drastic, and accommodation and adjustment for climate change have to be incorporated with policies that address these other phenomena.

The distributional effects of climate change are likely to be much more significant than its overall impacts. The economic viability of agriculture in some locations, especially on the periphery of major agricultural production regions, may be drastically altered. Some of these locations may benefit from improved climatic conditions, but production in others may no longer be economically feasible. Rising sea levels may present a major risk for farmers and other inhabitants in coastal zones. Adjusting to these locations and production systems will likely be a major challenge in coping with climate change.

Effective research, extension, and marketing capacities as well as an ability to raise funds for infrastructure and to design and finance appropriate adjustment schemes

will determine the capacity to accommodate and adjust to climate change events. The difficulty of adjustment will depend on the speed of these changes; obviously, fast changes in weather patterns will pose a much bigger challenge in terms of adjustment and accommodation. Uncertainty regarding the magnitude and locations of climate change phenomena should not hinder pursuit of economically viable policies that will expand our future options. No-regret policies that attain desirable objectives are especially valuable. Climate change policies should be integrated with other policies, especially those addressing environmental problems in agriculture.

Adjustment costs and the uncertainty of climate change are essential in slowing and reducing the magnitude of this process which is a major feature of the Kyoto Agreement. Agriculture maybe somewhat affected by increased energy prices as governments aim to reduce carbon emissions in energy production and transportation. The cost of adjustment to financial incentives and regulations that may result from the need to meet reduced emission targets are likely to be alleviated by the development and adoption of resource-conserving technologies that may be induced by these new policies.

Agriculture may become a major contributor to slowing global climate change if all carbon sequestration activities will be undertaken as part of the carbon emission reduction accounting initiated by the Kyoto Protocol and be compensated accordingly. Agricultural activities that sequester soil carbon are sources of numerous other environmental benefits and are important components of no-regret strategies. However, the implementation of schemes to incorporate soil carbon sequestration within the overall carbon accounting is quite challenging. They require establishment of organizational structure that will facilitate measurement, computation, and monitoring of soil carbon

sequestration. It demands development of accurate estimation schemes to accurately quantify the impact of agricultural practices on soil carbon. There are technological and institutional challenges in implementing effective monitoring and enforcement schemes to address possible problems of moral hazards. The implementation difficulties may hamper the enactment of soil carbon sequestration as part of the Kyoto Protocol in the short run. Because of the high potential benefits of these activities, the United States should unilaterally begin experimenting with policies and organizational arrangements to encourage carbon sequestration in agriculture, and should incorporate these arrangements as part of its national agricultural policies.

