Chapter 4: Empirical Framework

The empirical framework for this study, the U.S. Agricultural Sector Model (USMP), is a spatial and market equilibrium model built to assess a wide range of economic, environmental, and policy issues of interest to U.S. agriculture. USMP simulates farm-sector impacts resulting from changes in commodity market conditions, agricultural technologies, and Government policies related to commodity production, resource use, environmental quality, and trade. Because adjustment paths are not modeled, USMP simulation results are properly interpreted as a comparison between an initial baseline and a new medium-run equilibrium state.[1]

USMP can be used to carry out analysis relative to any base year between 1988 and 2010 inclusive. Simulations begin by calibrating the model's acreage, tillage practice shares, domestic production, domestic consumption, imports and exports, input and output prices, and corresponding spatial information to the desired historical year or to approximate conditions in a USDA baseline year.[2] In response to changes in farm policy or market conditions, the model endogenously determines new equilibrium levels of its variables after all output and input markets have fully adjusted. Agriculture's response to price changes involves all producers adjusting their input use, output choices, and production levels such that the marginal value of product produced per unit of input equals the marginal input cost for all inputs and the net returns to the last units of production are equal across all commodities.

Reported farm-sector impacts include changes in regional commodity production, national commodity prices, national commodity consumption, use of production inputs, farm income, agricultural producer and consumer surplus, participation in Government commodity programs, Government program expenditures, and environmental indicators.[3] The model is linked with regularly updated USDA production practices surveys (USDA, ERS, 1992; and USDA, NASS, 1996), the USDA multiyear baseline, and geographic information system databases, such as the National Resources Inventory (NRI) (USDA, NRCS, 1994).

USMP depicts the U.S. farm sector in considerable geographic, commodity market, and production-enterprise detail (fig. 4.1, table 4.1). The model disaggregates the 48 contiguous States into 45 regions defined by the intersection of the 10 USDA farm-production regions and 26 land-resource regions. Crops include corn, sorghum, oats, barley, wheat, rice, cotton, soybeans, hay, and silage. Collectively, these 10 crops account for about 75 percent of the value of U.S. agricultural production (USDA, OCE, 1999).[4] USMP also includes 16 primary livestock commodities (the most important being dairy, swine, beef cattle, and poultry) and over two dozen processed and retail products (including dairy, pork, fed beef, nonfed beef, poultry, soy meal, soy oil, and livestock feed). With respect to enterprise management, USMP has nearly 1,000 production activities reflecting alternative choices of input mixes, output choices, production technologies (e.g., choice of tillage system), and crop rotations. The model also includes 70 production activities that process primary farm commodities into intermediate and final demand products.

USMP's objective function is to maximize the sum of consumer and producer surplus across all commodity markets. The input markets for cropland, pasture land, family labor, hired labor, and irrigation water are modeled at the regional level with upward-sloping supply curves—that is, input supplies increase (decrease) when their prices increase (decrease). Twenty-three other farm-input markets—including fuels, fertilizers, pesticide, seed, machinery, and custom operations—are modeled at the national level. In national input markets, supply functions are perfectly elastic—implying input supplies can change without affecting input prices.[5]

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[1] The elasticities that determine supply and input use changes in USMP are medium-run elasticities.

[2] The USDA Long-Term Agricultural Baseline provides annual projections for various market variables related to U.S. agriculture through the 2010. Detailed information about the baseline can be obtained at USDA, OCE (2001), and at *http://usda.mannlib.cornell.edu/data-sets/baseline*

[3] USMP is modeled in the General Algebraic Modeling System (GAMS) as a nonlinear programming problem with solutions obtained using the MINOS nonlinear optimizer solver. The model consists of some 2,000 equations and 5,400 variables.

[4] Due to limited production data, fruits, vegetables, and sugar are not included in USMP. These crops are the only major commodity groups not included in the model.

[5] Conceptually it would be straightforward to model these input markets with upward-sloping supply curves, but there is generally limited empirical work on which to base the choice of supply elasticity.

Figure 4.1

USMP model regions

Farm Production Regions

NT - Northeast
LA - Lake States
CB - Corn Belt
NP - Northern Plains
AP - Appalachia
SE - Southeast
DL - Delta States
SP - Southern Plains
MN - Mountain
PA - Pacific

Land Resource Regions

A - NW Forest, Forage, and Spec. Crops
B - NW Wheat and Range
C - Cal. Subtrop. Fruit, Truck, and Spec. Crops
D - Western Range and Irrigated
E - Rocky Mountain Range and Forest
F - N. Great Plains Spring Wheat
G - W. Great Plains Range and Irrigated
H - W. Great Plains Winter Wheat and Range
I - SW. Plateaus and Plains Range and Cotton
J - SW. Prairies Cotton and Forage

K - N. Lake States Forest and Range
L - Lake States Fruit, Truck, and Dairy
M - Central Feed Grains and Livestock
N - East and Central Farming and Forest
O - Mississippi Delta Cotton and Feed Grains
P - S. Atl. & Gulf Slope Cash Crops, Forest, Lvst.
R - Northeast Forage and Forest
S - North Atlantic Slope Diversified Farming
T - Atlantic & Gulf Coast Lowland Forest and Crop
U - Fla. Subtropical Fruit, Truck Crop, Range

The model disaggregates the 48 contiguous States into 45 regions defined by the intersection of the 10 USDA farm-production regions and 26 land-resource regions. USMP model region nomenclature is the concatenation of abbreviations for farm production and land resource region, e.g., CBM is Corn Belt M, LAM is Lake States M.

USMP production units reflect representative farm enterprises for the relevant geographic areas (e.g., a State or region). Hence, production activities in each USMP region are composites of the different production techniques that are actually practiced in the particular geographic area. Production activities are generally represented by fixed-coefficient production functions. In the case of crop enterprises, fertilizer inputs per acre (and their corresponding yields) are variable coefficients. For livestock operations, the mixes of feed input and the feed rations vary with changes in feed grain and livestock prices (subject to various physical requirements of the different livestock). For crop commodities, production activities are differentiated by tillage practice, multiyear crop rotation, dryland or irrigated system, participation in Government farm programs, and other characteristics.

Final product markets are modeled at the national level. On the demand side, USMP distinguishes between the demands for domestic consumption, export, commercial stocks, and Government stocks. Government farm programs in USMP include production flexibility contract payments, target prices, acreage reduction, acreage flexibility, acreage diversion, conservation reserve, and Commodity Credit Corporation (CCC) loan programs.[6] Participation in

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[6] Historically, not all of these programs are in effect in any given year.

Table 4.1—USMP commodity coverage

Farm-produced crops	Farm-produced livestock	Processed products
Barley	Whole farm milk	Eggs
Corn	Cull dairy cows for slaughter	Broilers
Cotton	Cull dairy cows for veal	Turkeys
Hay	Feeder pigs	Evaporated milk
Oats	Cull sows for slaughter	Fluid milk
Rice	Slaughter hogs	Manufactured milk
Silage	Beef feeder calves	Nonfat dry milk
Sorghum	Beef feeder yearlings	Butter
Soybeans	Cull beef calves for slaughter	American cheese
Wheat	Cull beef cows for slaughter	Other cheese
	Cull bulls for slaughter	Ice cream
	Fed beef for slaughter	Ethanol
	Fed beef for commercial feedlots	Soybean meal
	Nonfed beef for slaughter	Soybean oil
	Other livestock	Other oilseed meal
	Items not otherwise specified	Animal protein
		High-protein beanmeal feed
		Fed beef
		Nonfed beef
		Veal
		Pork
		Corn oil
		Gluten meal
		Gluten feed
		Distillers dried grains
		Livestock feed mixes

Source: Economic Research Service, USDA.

farm programs is voluntary and is determined endogenously in response to market forces affecting the costs and returns associated with commodity production, participation costs, and program benefits.

Carbon Sequestration Rates

Changes in soil-carbon levels that result from changes in land uses or production practices are determined by a variety of relatively local factors—including climatic conditions, soil characteristics, historical land-use patterns, and current management practices (Lal et al., 1998). Data derived from field experiments are not available in sufficient detail to account for all of these factors across the full range of U.S. agricultural soils. Therefore, this study uses a less precise but more broadly applicable approach based on the IPCC methodology for estimating the effects of changes in land uses and/or production practices on the quantity of carbon stored in agricultural soils (IPCC, 1997).

Cropland Management and Land-Use Change to Grassland

The IPCC methodology was developed for use in national assessments as a first-order approach to estimating changes in soil-carbon levels. It uses simple assumptions about the effects of land use and management changes on soil-carbon stocks. The framework is based on a 20-year inventory period and the top 30 cm of the soil profile. The IPCC methodology also provides guidelines and default values for estimating initial soil-carbon stocks for land in different uses as well as changes in soil carbon levels related to changes in land uses or production practices that occur over the inventory period. Because experimentally derived parameters are not available for much of the United States, we applied the default-factor values provided in the IPCC documentation, which take into account differences in climate, soil, disturbance history, tillage intensity, productivity, and residue management. Estimates of average annual sequestration rates are obtained by subtracting soil carbon stocks at the start of the inventory period from soil carbon stocks at the end of the inventory period and dividing the results by 20.

Climate regions in the IPCC inventory are delineated based on average annual temperature, precipitation, and potential evapotranspiration. Of the eight IPCC climatic regions, six are represented in the contiguous United States (i.e., cold temperate moist, cold temperate dry, warm temperate moist, warm temperate dry, subtropical moist, and subtropical dry) (Eve et al., 2001). Soil categories in the IPCC inventory are groups of taxonomic soil orders based on a soil's ability to store and stabilize organic carbon. The default IPCC guidelines contain five categories of mineral soils and one category of organic soils (IPCC, 1997).

To establish a set of initial soil-carbon levels for lands in different uses, we first derive a composite native soil for each of the 10 farm production regions. Each of these soils is a weighted average of all of the agricultural soils represented in the 1997 National Resources Inventory (NRI) data points within that region (USDA, NRCS, 2000).[7] Next, based on the six representative IPCC soil groupings, IPCC assigns each composite native soil a native soil (i.e., undisturbed) carbon stock. The IPCC

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[7] The NRI data describe soil conditions and track land-use changes at over 800,000 locations across the United States. While aggregating these sites to the Farm Production Region level obscures significant variations among soils in each region, it does at least capture more aggregate differences in productivity and climatic conditions.

base factors (i.e., default parameters that account for the effect of the historical land use on soil-carbon stocks) are then used to determine initial carbon levels for soils that have been under long-term cultivation and in long-term grasslands.

The IPCC methodology assigns native soils a base factor of 1.0 and soils under long-term cultivation a base factor of 0.7 (0.6 for wetland soils). That is, the methodology assumes that long-term cultivation decreases native soil-carbon levels by about 30 percent. Continuous hay or pasture is not explicitly reflected in the IPCC framework. We assume that lands in hay or pasture will accumulate soil carbon but will not return to their native soil-carbon levels without improved management. Hence, the methodology assigns a base factor of 0.9 (i.e., 10 percent less carbon than in native soils)—which is the average of the base factor values for soils under long-term cultivation and improved pasture. Improved pasture—that is, pasture being managed for increased biomass production through fertilizer use, irrigation, or species selection—is included in the IPCC with a default base factor of 1.1 (i.e., 10 percent more carbon than soils under native conditions).

In addition to assigning base factors, the IPCC methodology assigns tillage factors and input factors. tillage factors are used to estimate the longrun impacts of tillage management on soil carbon. The default tillage factor for conventional tillage is 1.0 (i.e., no longrun change in soil carbon over the inventory period). Changing from conventional tillage to no-till is assumed to increase soil carbon by 10 percent over the 20-year inventory period (a tillage factor of 1.1). Reduced tillage (more than 30 percent residue remaining at planting, but less than no-till) also increases soil carbon but to a lesser degree than no-till. For temperate climate zones, the IPCC tillage factor for reduced till is 1.05. In subtropical climates, the tillage factor values are somewhat lower.

Input factors are used to measure longrun effects of residue management on soil carbon. Input factor values reflect the level of biomass input to the soil. A crop/fallow rotation is considered low input because residue is only being produced every second year (input factor of 0.9). Continuous annual cropping is considered medium input, with an input factor of 1.0. Increasing soil residue by adding a winter cover crop or putting hay into a crop rotation is considered high input (input factor of 1.1). To estimate changes in soil carbon on lands that shift from crop production to grasses, we use the base factor for continuous pasture (i.e., we assume these lands will return to 90 percent of their native soil-carbon levels over a 20-year period).

Given the set of initial soil-carbon conditions for lands in different uses in each farm production region, we apply the IPCC's default tillage and input factors to develop a "from-to" table showing changes in annual soil-carbon levels associated with shifting "from" any possible rotation-tillage system in USMP "to" another possible rotation-tillage system (table 4.2). The "from" management systems are assumed to have been in place long enough for soil-carbon levels to be in a steady state and the "to" management systems are assumed to have been adopted for long-term use. If land use or production practice does not change during the inventory period, the IPCC framework assumes no change in soil carbon. If land use or production practice does change, change in the opposite direction results in an equal and opposite impact on soil-carbon stocks. Because of the relatively large quantities of potentially affected land, the values most relevant to this analysis are the values for shifting cropland into permanent grasses and changing from continuous cropping with conventional tillage to continuous cropping with no-till.

Land-Use Change to Forest

For each USMP region, we develop estimates of carbon sequestered by afforesting agricultural lands from data in Birdsey (1996). Birdsey disaggregates the 48 contiguous States into eight forest regions and reports per acre carbon accumulation in forests for selected tree species in each region.[8] Carbon accumulation values are reported in 5-year intervals from year 0 (conversion from pasture or cropland to forest) to year 120 and reflect fully stocked timberland under average management conditions. Carbon values are presented for trees, soils, understory, litter, and total ecosystem.

For this analysis, we assigned to each USMP region the tree species associated with the most geographically similar region in the Birdsey study. For regions

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[8] Birdsey focuses on commercially valuable species. Specifically, southern pine in the Southeast and South Central regions, white/red pine and fir/spruce in the Northeast and Lake State regions, white/red pine and oak/hickory in the Central States, ponderosa pine in the northern and southern Rocky Mountain regions, and douglas fir and ponderosa pine in the Pacific Coast.

with multiple tree species, we selected the species with the highest value for accumulated ecosystem carbon over the first 15 years of forest growth (i.e., the duration of our commitment period). We then took this accumulated carbon value and divided it by 15 to obtain an average annual rate of carbon sequestration (table 4.2, fig. 4.2). Hence, our values for carbon sequestered on lands shifted from cropland or pasture to forest reflect average per acre annual sequestration in trees, soils, understory, and litter over the first 15 years of growth.

Economic Incentives for Carbon Sequestration: Basic Features for Each Activity

In calculating the net returns to the activities covered by our carbon sequestration incentives (see box on structure of incentives) we employ a 15-year contract period for adoption of carbon-sequestrating land uses and production practices. This timeframe follows previous studies and is consistent with the historical tendency to limit farmer commitment periods in USDA conservation programs.[9] We assume farmers will participate when the net economic returns to shifting land into the carbon-sequestering land uses or production practices for 15 years exceed the net economic returns of allocating land to the next most profitable use for 15 years.[10] Reflecting the medium-run nature of USMP simulations, this calculation reflects any price increases (or decreases) induced by farm-sector adjustments to the incentives.

Land-Use Change to Forest

The net value of the afforestation option will be the sum of the sequestration payments plus the present discounted value of the standing timber at the end of 15 years minus the costs of establishing trees. To simplify the modeling exercise, we annualize these benefits and costs, which allows us to capture their collective net effect on producer decisions with a single number.

Our analysis does not offer the afforestation incentive in the Southern Plains, Northern Plains, or the Mountain regions because natural conditions do not favor forest growth throughout much of these regions. Establishing forests in these regions would require relatively costly human interventions (e.g., fire-suppression activities), compared with regions in which we offer the afforestation incentive. Nor does our analysis offer incentives to convert lands currently enrolled in CRP. CRP objectives include reducing soil erosion, improving water quality, and enhancing wildlife habitat—not all of which are necessarily compatible with increasing carbon sequestration. Including CRP lands in our analysis would conflate the costs and benefits associated with carbon sequestration with those associated with the other environmental goods and services provided by CRP (particularly in cases where there are tradeoffs). Consequently, we focus our carbon sequestration incentives on land currently in crop or livestock production.

We derived expected per acre timber quantities, prices per 1,000 cubic feet, and per acre values of timber at the end of the contract period by region and prior land use from various sources (table 4.3, figs. 4.3a-b). The timber quantities on converted pasture and converted cropland are from Birdsey (1996). Expected timber prices in each region reflect average prices for timber harvested from Federal forests between fiscal years 1996-1997 and 1999-2000 (inclusive).[11] The per acre timber values are the products of the timber quantities and their associated prices.

Current estimates of forest-establishment costs are not generally available for most regions of the country but

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[9] Conservation programs in the Farm Security and Rural Investment Act of 2002 (i.e., the 2002 Farm Act) that contain longrun land retirements include the Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP). The CRP is by far the larger program with over 33.6 million acres enrolled as of August 2001 (USDA, FSA, 2001). CRP contracts run for 10 years. WRP enrollment is presently about 1 million acres. WRP easements run for 30 years or perpetuity. Additionally, except in the Pacific region, all of the forest types used in this analysis reach their maximum annual carbon accumulation rate between 15 and 20 years. Differences in the 15- and 20-year rates, however, are typically less than 0.25 mt per acre per year. Given these marginal differences and the demonstrated preference for shorter land-retirement programs, we selected 15 years as the length of our contract period.

[10] To be more precise, USMP does not operate strictly on the basis of profit maximization. It also includes a set of parameters that reflect the "stickiness" of decisionmaking regarding choices of rotations and tillage systems, in response to changes in costs and returns. That is, these parameters dampen what otherwise might be large-scale shifts in input use and/or commodity production in the model when costs or returns change by very small amounts but certain economic thresholds are crossed.

[11] These prices are available on the U.S. Forest Service website: *http://www.fs.fed.us/land/fm/s_h/s_hindex.htm*

Table 4.2—Selected carbon-sequestration rates by USMP region, for changes in land use or production practice

Region	From cropland to forest	From pasture to forest	From CAC* to grassland	From conventional till to conservation till	Forest species planted (for afforestation)
	Metric tons per acre per year				
Appalachia/ N	1.724	1.028	0.383	0.134	Southern pine
Appalachia/ P, S, and T	1.573	0.938	0.383	0.134	Southern pine
Corn Belt/ L, M, N, O	0.938	0.847	0.491	0.170	White/red pine
Corn Belt/ R	1.210	1.119	0.491	0.170	White/red pine
Delta States	1.724	1.028	0.506	0.178	Southern pine
Lake States	1.331	1.240	0.425	0.150	White/red pine
Mountain States**			0.249	0.085	--
Northeast	1.210	1.119	0.384	0.134	White/red pine
Northern Plains**			0.378	0.134	--
Pacific States/A and D	0.817	0.877	0.312	0.109	Douglas fir
Pacific States/B, C, and E	0.786	0.726	0.312	0.109	Ponderosa pine
Southeast	1.573	0.938	0.329	0.113	Southern pine
Southern Plains**			0.394	0.138	--

Note: See figure 4.1 for USMP regions.

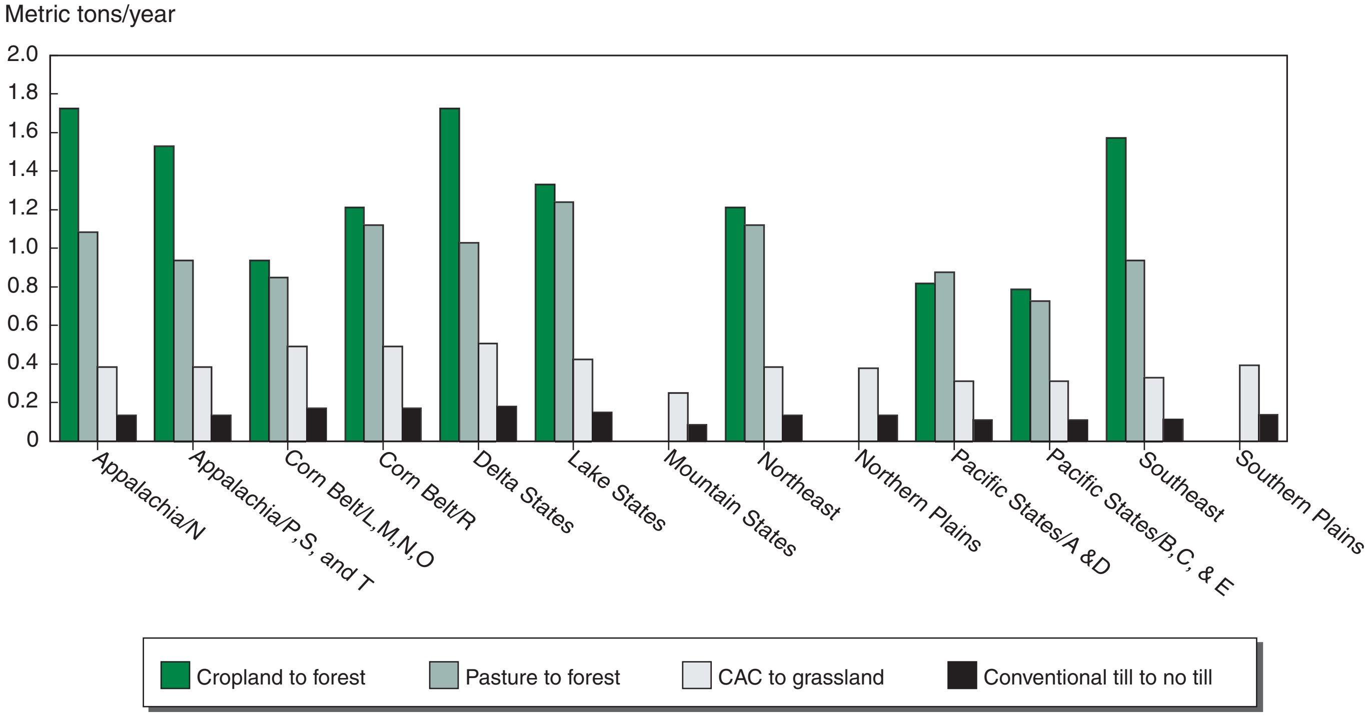
* Continuous annual cropping (CAC) reflects use of conventional tillage and moldboard plow. Depending on the region, CAC includes some combination of soybeans, corn, sorghum, silage, oats, wheat, barley, peas, barley, and rice. Sequestration values are generally lower for rotations with cotton or fallow periods and higher for rotations with hay.

** Our analysis does not offer afforestation incentives in these regions.

Sources: IPCC inventory method for cropland and grassland carbon levels (IPCC, 1997); Birdsey (1996) for forest carbon levels. See text for detailed explanation.

Figure 4.2

Selected carbon sequestration rates by USMP region, for changes in land use or production practice



Note: See figure 4.1 for USMP regions.

CAC = continuous annual cropping.

Sources: IPCC inventory method for cropland and grassland carbon levels (IPCC, 1997); Birdsey (1996) for forest carbon levels.

See text for detailed explanation.

Table 4.3—Estimated quantities and values of timber per acre at end of 15-year carbon sequestration program, by farm-production region

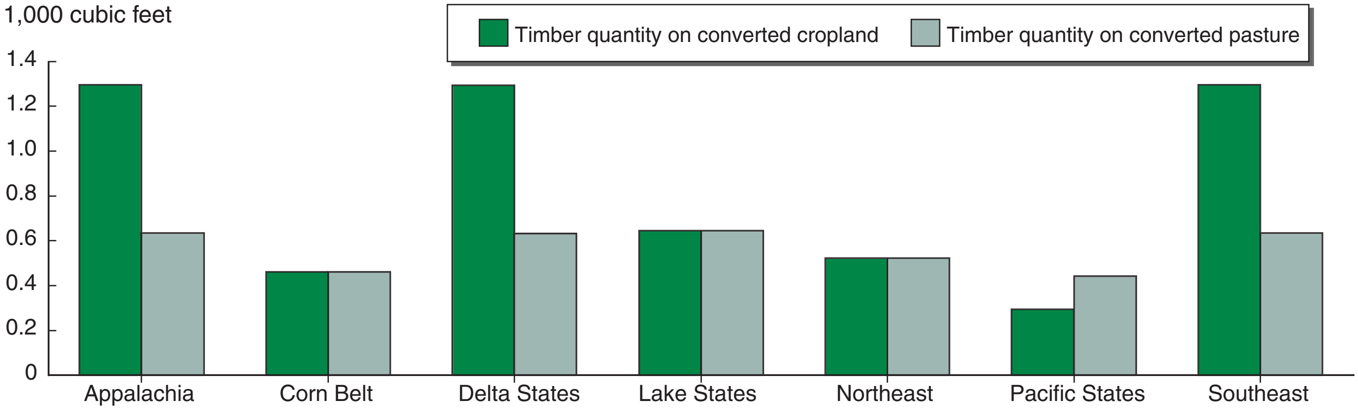
		From cropland		From pastureland	
Region	Price	Timber quantity	Timber value	Timber quantity	Timber value
	$/1,000 cu. ft.	1,000 cubic feet	Dollars	1,000 cubic feet	Dollars
Appalachia	790.18	1.295	1,023.28	0.634	500.97
Corn Belt	485.24	.461	223.70	.461	223.70
Delta	790.18	1.293	1021.70	.632	499.39
Lake States	485.24	.644	312.99	.644	312.49
Northeast	485.24	.522	253.30	.522	253.30
Pacific	696.92	.295	205.59	.443	308.74
Southeast	790.18	1.295	1023.28	.634	500.97

Note: Quantities and dollar values are per acre.

Sources: Timber quantity source is Birdsey (1996). Timber prices source is *http://www/fs.fed.us/land/fm/s_h/s_hindex.htm*.
Prices reflect average prices for timber harvested from Federal forests between fiscal years 1996-1997 and 1999-2000 (inclusive).

Figure 4.3a

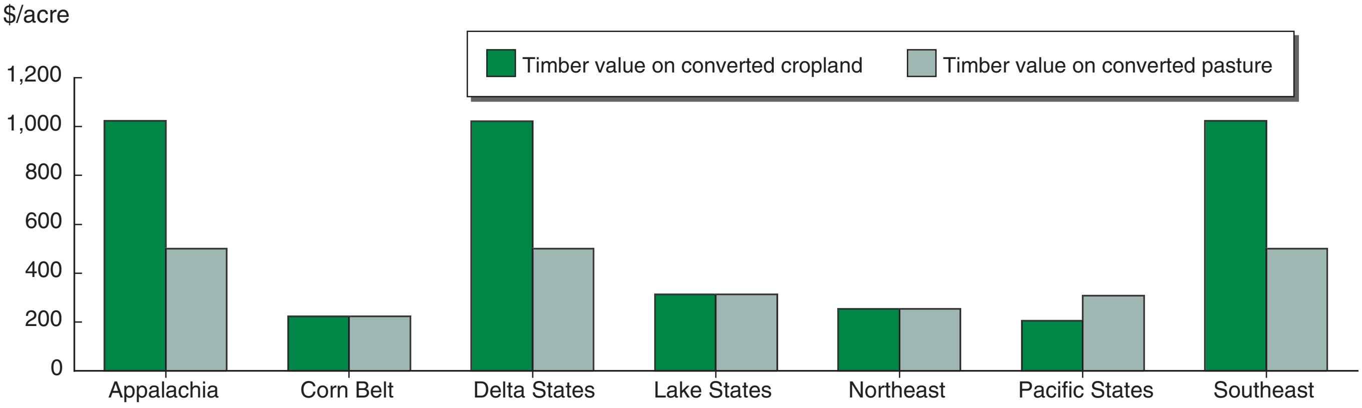
Estimated quantities of timber per acre at end of 15-year carbon sequestration program, by farm-production region



Source: Birdsey (1996).

Figure 4.3b

Estimated values of timber per acre at end of 15-year carbon sequestration program, by farm-production region



Prices reflect average prices for timber harvested from Federal forests between fiscal years 1996-1997 and 1999-2000 (inclusive).
Source: *http://www/fs.fed.us/land/fm/s_h/s_hindex.htm*

Structure of Carbon Sequestration Incentives in USMP Simulations

Generic features

- Farmers commit to adopt carbon-sequestering land uses and production practices for 15 years. Commitment period begins in 2010.
- Sequestration payments are only offered for bringing new lands into forests, grasses, or carbon-sequestering production practices. Hence, forest land that stays in forest, grassland that stays in grass, and cropland that is in, and remains in, no-till count for zero additional sequestration.

Afforestation

- Establishment costs—annualized over 15 years.
- Value of standing timber at the end of 15 years.
- Payment for carbon sequestered.
- Ineligible lands: Southern Plains, Northern Plains, or Mountain regions (throughout much of these regions, natural conditions do not favor forest growth).
- No double enrollment in CRP.

Land-use change to grassland

- Establishment costs—annualized over 15 years (estimates based on CRP data).
- No value from sale of co-products (not used by livestock for forage).
- Payment for carbon sequestered.
- Eligible land: all cropland in all regions.
- No double enrollment in CRP.

Changing production practices (i.e., adopting conservation tillage on carbon-sequestering rotations)

- Costs of production by rotation and by tillage system.
- Revenue from sale of crops (reflecting potential yield/acre effects).
- Payment for carbon sequestered.
- Eligible land: all land in all regions where conservation tillage or carbon-sequestering rotations are currently practiced.

are published biannually for the South. The total cost of seedlings, prescribed burning, and hand planting in the Southeast in 1998 averaged about $93.29 per acre (DuBois et al., 1999). To estimate regional forest-establishment costs, we used State-level data on the value and quantity of timber harvested from National Forests in 1998 (USDA, FS, 1999) to derive a share of harvest-weighted timber price for each farm production region and then also for the Southeast as defined by the Forest Service. To generate estimates of forest establishment cost differentials for each region, we divided the farm production region prices by the Forest Service Southeast region price; these ratios were multiplied by the Southeast cost estimate of $93.29 to obtain an estimated forest-establishment cost in each farm production region.

Land-Use Change to Grasslands

The net value of the grassland-conversion option will be the sum of the annualized sequestration payments net of the sum of annualized grassland establishment costs. In our simulation scenarios, we assume no revenue from the sale of co-products, such as forage or hunting opportunities, for lands converted to permanent grass.[12] All cropland is considered eligible for conversion to grasses. Pasture land, which has the same carbon-sequestration rates as grassland in our carbon-sequestration methodology, is not eligible for conversion. Again, our analysis does not allow incentives to convert grasslands enrolled in the CRP. Estimates of grassland-establishment costs are based on CRP data. Estimates of the carbon-sequestration rates that provide the basis for the incentive payments are based on the IPCC inventory methodology.

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[12] This assumption is consistent with the CRP, which limits (and until 2002 generally prohibited) grazing or haying on enrolled lands. Allowing lands covered by this incentive to be grazed or hayed would make this incentive more attractive to landowners. It would also, however, require that we specify how these lands are managed—since management practices would affect the net sequestration achieved. Given the example of the CRP, and the finding in Antle et al. (2001) and McCarl and Schneider (2001) (see chapter 3 in this report) that this land-use change would not be competitive with other carbon-sequestration activities, we simplify our analysis and omit co-products on croplands converted to grasses.

Cropland Management

For each cropland-management activity that receives a sequestration payment, the net value of the option to the farmer will be the expected net revenue from the sale of crops (reflecting any changes in yields or acreage) plus the annualized payment for net carbon sequestration minus the baseline net revenue of production. For each activity, eligible lands include all lands in regions where that activity is currently practiced. Again, estimates of the carbon-sequestration rates that provide the basis for the incentive payments are based on the IPCC inventory methodology.

Model Baseline and Simulation Scenarios

Our carbon-sequestration incentives are assumed to begin in 2010. To establish the baseline scenario, we calibrate USMP to approximate the supply, demand, production, acreage, tillage, Government program, input cost, and other conditions projected in the USDA baseline for 2010.[13] Simulation results should be interpreted as reflecting differences relative to 2010, when there are no new incentive programs targeting carbon sequestration. To trace out the marginal cost curve for sequestered carbon, we run each scenario with six alternative payment levels—these payments are based on the assumption that the value of a metric ton of carbon emissions reduction is $10, $25, $50, $75, $100, and $125.[14] Each year during the contract period, participants are paid for the additional metric tons of carbon they sequester that year.

With USMP calibrated to reflect the agricultural-sector conditions projected in the USDA baseline for 2010, we simulate four alternative incentive scenarios (see box on simulation scenarios). In scenario 1, our reference scenario, carbon payments are for carbon rental, compensating for storage during the commitment period only. The incentive program covers a 15-year contract period. At the 5-percent discount rate employed in the analysis, 15 years of storage is equivalent to 0.354 times the "full" asset value for carbon-emissions reduction (see table 2.5). Hence, for carbon emissions reductions valued at $10, $25, $50, $75, $100, and $125 per metric ton, payments to farmers for 15 years of storage are $3.54, $8.85, $17.70, $26.55, $35.40, and $44.25, respectively, per mt of carbon sequestration. (For permanent storage, the present discounted value of the total payments farmers will receive under the rental payment format will equal the full asset value of permanent carbon sequestration paid at the time the carbon was put in storage.) For purposes of clarity, in comparing the results of different scenarios, we will refer to the six payment levels in terms of the full asset value of emissions reductions or permanent carbon sequestration—that is, $10, $25, $50, $75, $100, and $125 per metric ton.

Summary of Simulation Scenarios

Scenario 1: *Reference scenario.*

Rental payment for net sequestration during contract period only, with no cost-share supplement.

Scenario 2: *A common approach to permanence in the early literature.*

Asset-value payment (assuming permanent sequestration) for net sequestration, no cost-share supplement.

Scenario 3: *A standard feature of USDA conservation subsidy programs.*

Rental payment for net sequestration, *with cost-share supplement.*

Scenario 4: *Exploring the potential for emissions "leakage" within cropland management.*

Rental payment *for gross sequestration*, no cost-share supplement.

Another key feature of scenario 1 is that payments reflect *net* carbon sequestration. In other words, the farm sector is credited for changes in land uses and/or practices that sequester carbon and is debited for related changes in land uses and production practices that increase carbon emissions. Scenario 1 serves as a reference scenario because of its incentive structure: It accounts for the permanence issue (it pays only for the

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[13] Calibration of USMP to the USDA baseline projections for 2010 is not exact. The differences between prices and quantities in USMP's 2010 baseline and the USDA's 2010 estimates for most commodities are less than 1 percent. The major exceptions to this are for beef, pork, and dairy where USMP price and quantity values more closely approximate the USDA's estimates for 2005.

[14] In our analysis, carbon payment levels are set exogenously and provided to USMP as given. The range of payments analyzed was chosen to be consistent with the payment levels considered in previous studies.

value of sequestration occurring during the commitment period), it accounts for farm-sector leakage (it pays only for net sequestration), and it is consistent with the C-stock equilibrium issue (again, it pays only for the value of sequestration occurring during the commitment period).

Scenario 2 employs an incentive structure similar to structures employed in many previous studies (app. 1). Specifically, rather than receiving rental payments covering storage during the contract period only, farmers receive full payments for permanent storage. As in scenario 1, farmers receive payments when the carbon is added to the soils or biomass, and farmers are paid only for net sequestration.

The payment structure in scenario 2 implicitly assumes that any sequestering activity that receives a payment is permanent. Still nothing prevents farmers from reverting to carbon-emitting land uses and production practices when their contracts expire. In this case, society would receive less carbon sequestration—and emissions offsets—than it paid for. Specifically, society would pay for permanent carbon storage but receive a sequestration stream in which the carbon sequestered in year 1 is stored for 15 years, the carbon sequestered in year 2 is stored for 14 years, and so forth until year 15, when the incremental carbon sequestered is stored only for 1 year.

On the other hand, the sequestration outcomes of the rental program are independent of the assumption about permanence. If sequestration is maintained permanently, farmers will ultimately receive the same present discounted value of sequestration payments. A comparison of the costs between scenarios 1 and 2 provides insights on the cost effectiveness of implementing carbon sequestration incentives based on the assumption of permanence, if that assumption turns out to be faulty.[15]

Scenario 3 reverts to the rental payment structure but adds a 50-percent cost-share payment to help landowners offset the startup costs of the desired land-use changes—that is, afforesting cropland or pasture and converting cropland to grasses.[16] We include this scenario because USDA conservation programs often include cost-share assistance to help farmers establish conservation practices. For example, the CRP allows for a 50-percent cost-share payment to help landowners cover tree-establishment costs in afforestation agreements, in addition to the annual land rental payment. Hence, scenario 3 will provide insights on the cost effectiveness of adding a cost-share payment to the annual per ton carbon payment for different levels of carbon payments. To simplify the modeling, we annualize the value of the cost-share payment for the afforestation activity and add it to the yearly per ton payment and the annualized end-of-program timber value. Payments are again based on net sequestration.

Scenario 4 drops the cost-share provision and keeps the rental payment structure but offers payments for *gross* sequestration rather than *net* sequestration. In other words, the per ton carbon payments credit farmers for changes in land uses and/or practices that sequester carbon but do not penalize them for related changes in land uses and production practices that increase carbon emissions. With this scenario, we can explore the potential for farm-sector carbon leakage related to activities that farmers undertake in response to, but which are not included in, the sequestration incentive set. These activities include switching lands under conventional tillage to no-till while simultaneously switching to conventional tillage on land currently under no-till, or shifting lands into trees or grasses while simultaneously bringing idle land into production.

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[15] The differential costs of using this payment system when the true assumption is one of permanence most likely will be reflected in a different time path of transaction costs because payments will be made throughout the full storage period, rather than simply in the years in which carbon is accumulating. The result is likely to be higher total transaction costs.

[16] Historically, USDA has not provided farmers with cost-share payments for changes in production practices. Hence, our analysis does not consider cost-share payments for changes in tillage practices or rotations.