FOREST CARBON SINKS: COSTS AND EFFECTS OF EXPANDING THE CONSERVATION RESERVE PROGRAM

Ian W. Hardie
Department of Agricultural and Resource Economics
University of Maryland
College Park, Maryland, USA 20742

Peter J. Parks
Agricultural Economics and Marketing
Cook College, Rutgers University
New Brunswick, New Jersey, USA 08903

Working Paper No. 95-15
Department of Agricultural and Resource Economics
July 1995

Scientific Article No. _____, Contribution No. _____, Maryland Agricultural Experiment Station. Work supported in part by the U.S. Department of Agriculture under Agreement No. 43-3AEM-0-80061. Any opinions, findings, conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture. Senior authorship is not assigned.

That global warming is an international issue is evident from the gathering of 120 nations to discuss mitigating carbon dioxide emissions in Berlin this year, and from the meeting of the Intergovernmental Panel on Climate Change in Geneva in 1994 (Hourcade et al. 1995). Proposals to sequester atmospheric carbon by planting new forests appear as alternatives to mitigating emissions in these meetings, in large part because growing trees is seen as a feasible and cost-effective alternative to the abatement of fossil fuel combustion (Dudec and LeBlanc 1990; National Academy of Sciences 1991; Sedjo and Solomon 1989). This view also has gained currency in the United States, where sequestering carbon through the forestation of agricultural lands has become an explicit element of U.S. climate policy (U.S. Department of Energy 1991; Clinton and Gore 1993).

The possibility that forestation might be a cost-effective way to reduce atmospheric carbon levels has encouraged analysts to develop cost curves that relate government expenditure on forestation to tons of carbon sequestered. Cost schedules for the United States have been developed by Moulton and Richards (1990), Adams et al. (1993) and by Richards et al. (1993). Parks and I (1995) have contributed to this effort by simulating cost curves for an expansion of the Conservation Reserve Program (CRP), a land use program established by the U.S. Congress in 1985.

The CRP provides financial incentives to private landowners who remove highly erodible cropland from farm production and plant it to grasses or trees. By 1993, some 2.3 million acres had been planted to trees under this program. If these plantations last for 50 years, they will sequester an estimated average of 0.73 million English tons (2000 pounds) of carbon per year. This is only about 0.05 percent of the total annual carbon emissions of the U.S., so the existing CRP would have to be substantially expanded before it became an effective carbon sequestration program.

Expansion of the existing program could be accomplished either by increasing incentives to enroll currently eligible acreage or by expanding the pool of eligible land and owners. We do not study the first alternative in our cost analysis. Instead we keep financial incentives at the same general magnitude as existing CRP payments and increase the pool of eligible acreage. Because incentives are not increased, enrollment of currently eligible land should not be materially affected. But total enrollment should increase because land that did not qualify for the existing CRP would become eligible for enrollment in the expanded program.

Since financial incentives are not materially changed, participation rates in an expanded program should be similar to participation rates in the existing CRP. In this paper, we present two sets of cost schedules. One shows the potential of a carbon sequestration program in which all owners participate and all eligible acreage is enrolled. The other shows what might be expected from a voluntary program in which participation rates parallel those experienced in the current CRP.

A Potential Carbon Sequestration Supply Curve

Except for Adams et al., the U.S. carbon sequestration cost studies use an engineering simulation approach.[1] They: (1) divide the U.S. into geographic regions, (2) determine the potential acreage available for forestation in each region, (3) transform this acreage into tons of sequestered carbon, and (4) estimate the subsidies needed to get the potential land in each region converted into a carbon sink. Cost schedules are produced by first arranging the geographic units in ascending order of the cost to the government of getting a ton of carbon sequestered (or an acre converted) and then plotting unit or total costs as a function of total carbon sequestered. If government expenditures are taken as given, the resulting cost curves may be inverted and interpreted as supply curves for sequestered carbon.

The geographic regions used in our simulation are based on the Major Land Resource Areas (MLRA) defined by the U.S. Department of Agriculture Soil Conservation Service (USDA 1965). The MLRA's are constructed to be homogeneous in land use, soils, climate, elevation, topography, and potential natural vegetation. We omitted 47 of the 156 regions defined for the contiguous United States because they did not include the natural ranges of hardwood and softwood species deemed useful for carbon production (Eyre 1980). The remaining MLRA's were subdivided along state boundaries so state-level farm rental rates could be used in the simulation.

Eligible acreage within each geographic region was restricted to less productive subclasses of farmland. Land was considered to be potentially available for carbon production if it was classified as being in Soil Capability Class III or higher by the Soil Conservation Service (USDA 1961). Acreage in these classes has limitations that restrict cultivation, timing of planting, tillage, harvesting and choice of crops. Class III and IV land was included only if it had poor soil structure or climate problems. Class VIII acreage was omitted because soils in this class are too poor to support forest vegetation.

The location and amount of eligible acreage defined in the simulation are shown in Figures 2 and 3. Figure 1 locates three major and ten subregions on a map of the United States. Acreage is aggregated for this presentation into these regions. Figure 2 shows the acreage identified for each of the major regions, and Figure 3 shows how this acreage is allocated

---

[1]The Adams et al. analysis extends an existing agricultural sector programming model by including carbon production activities. It uses a total carbon tonnage constraint to force these carbon sequestration activities to enter an economic surplus maximizing land use solution. Thus government is presumed to set a carbon tonnage target and land use to change until this target is reached. Costs are measured as shadow prices of the marginal land units removed from the country's agricultural land base. A cost schedule is developed by solving the sector model for different carbon tonnage targets.

among the subregions. As can be seen, nearly 55% of the eligible acreage is located in the North, a third is in the South, and only 12% is located in the West. Within the northern region, over 58% of the identified acreage is in the Corn Belt, and in the South, over 53% is in Appalachia. Although they are large in size, the subregions in the West have the smallest amounts of eligible acreage.

The financial incentives built into our simulation include a 50% sharing of the costs of planting trees plus a series of ten annual rental payments for the converted acreage. Annual rents are "engineered" values, derived from crop budgets developed by the U.S Department of Agriculture Soil Conservation Service and from reported rental payments for land in pasture. Simulated rents are set at values that would make a profit-maximizing farmer who is farming the highest-quality eligible acreage in each of the study's 433 geographic groupings indifferent between participating or not participating in a carbon production program. A theoretical justification for this particular level of estimated rents is provided in Parks and Hardie (1995).

Per-acre costs to the government are defined as 50% of the planting costs plus the present value of a ten year series of rental payments. Government costs are reduced by the present value of any expected revenues from harvesting the trees. A 4% discount rate is used to convert future values to present values. Total costs are estimated by multiplying per-acre costs by the number of enrolled acres.

Costs per ton of carbon sequestered are estimated by dividing total costs by the total tonnage of carbon sequestered over the growth period of the trees. Since experience with previous tree planting programs indicates that most owners will leave their land in trees after the ten year program period (Alig et al. 1980), the growth period for the trees is established by solving the Faustmann-Pressler-Ohlin optimal rotation problem for the species expected to be planted in each geographic region. Timber yields are converted to carbon yields using conversions developed by Birdsey (1992).

Reasonableness of the engineered costs is validated by re-estimating costs per ton of carbon sequestered using actual values experienced during the 1986-1993 CRP sign-ups in place of the engineered rents and simulated cost-share payments. Figure 4 shows that the engineered cost estimates are of the same magnitude as the estimates derived from the observed maximum allowable rental rates and cost-share payments. The average cost across the 64 MLRA's for which the comparison could be made is $493 per ton for the engineered estimates and $502 per ton for the CRP-based estimates. Estimates also correlate well: the simple correlation coefficient between the engineered and CRP-based estimates is 0.932. The fitted regression line shown in Figure 4 indicates that the CRP-based estimates are somewhat higher for MLRA's in which the costs to the government of sequestering carbon are low and somewhat lower for MLRA's in which the costs to the government of sequestering carbon are high. Despite this slight "tilt", the figure shows that the simulated costs represent estimates that might have been negotiated as part of the existing government CRP.

Figure 5 shows a total cost schedule derived from our simulation under the assumption that all of the eligible acreage is forested. This schedule shows that a maximum of slightly less than 149 million tons of carbon could be sequestered in an average year of growth if all of the identified eligible acres were planted to trees. The growth of the new forests would remove slightly over 10% of estimated U.S. carbon emissions in that average growth year. Estimated direct costs to the government would be $67.4 billion, about 1% of 1994 Gross Domestic Product.

Figure 6 shows average and marginal costs for the same simulation. The most important aspect of this figure is the rapid rise in the cost of the marginal ton sequestered when program levels become more than 90-100 million tons. Costs to sequester the marginal ton are found to be approximately $340 when approximately 90 million tons are sequestered in the average growth year. This cost rises rapidly to over $2300 per ton when 149 million tons are sequestered. Thus the cost effectiveness of forestation as a means of reducing atmospheric carbon decreases rapidly once sequestration levels are pushed beyond certain magnitudes.

Figures 7 and 8 provide an explanation for this decreasing cost effectiveness. Figure 7 shows that a program expenditure of $30 billion would result in virtually all of the eligible acreage in the West and South being placed into carbon production. Additional sequestration resulting from larger government expenditures would be located almost entirely in the North. Figure 8 shows that this additional sequestration would be accomplished almost entirely by converting acreage in the Corn Belt, a subregion where farming has a considerable advantage over forestry. The rapid increase in the cost of the marginal ton sequestered reflects the difficulty the government would face in convincing landowners in this region to forego farm production and to plant trees on their land.

Figure 7 also shows that the South has a greater capacity to sequester carbon. Although only a third of the eligible acreage is located in this region, it accounts for more tonnage than either the West or the North at any program expenditure level. At a $50 billion expenditure level, the South would account for nearly half of the total carbon sequestered.

Carbon Sequestration Cost Schedules Based on CRP Participation Rates

As Richards et al. note, a 100% rate of participation is unlikely in a carbon sequestration program in which eminent domain or public taking powers are not exercised (pp. 911-912). Since incentives in our simulated program are comparable to those of the CRP, we may expect participation rates to be similar to those experienced in the existing program. Here we report a probit analysis model which can be used to predict these participation rates, and present some carbon sequestration cost schedules based on them. The schedules are derived by using predicted participation rates to scale down the eligible acreage in each the study's geographic regions. Costs and tonnages then are re-computed and the ascending order of the regions comprising the schedule is re-established.

The probit model is based on proportions of eligible acreage that were planted to trees under the CRP. Participation consequently is measured in terms of acres instead of owners. Proportions data are available for 1618 counties, as are total crop acreage, CRP maximum allowable rental rates and negotiated cost-share payments.[2] Probabilities that acres will be planted are made a function of the percent of cropland in a county that is eligible for CRP payments and of the average level of subsidy paid to county landowners by the government. Subsidies are computed as they are in the carbon sequestration simulation but are left on a per-acre basis, since carbon sequestration is not an overt part of the CRP. Heteroscedasticity induced by using counties instead of acres as observation units is adjusted for by weighting the model's observations by county crop acreage. The model is estimated using maximum likelihood.

Parameter estimates for the model are presented in Table 1. As is noted in that table, the estimates are jointly significant; asymptotic t-statistics also indicate that each is individually significant. Signs are negative and remain negative when marginal values are extracted. This indicates that participation rates are lower in counties with higher percentages of eligible cropland and in counties with higher CRP payments. Both signs are consistent with the idea that participation decreases when a farm operator's opportunity cost of removing the land from farming is higher.

To gain some insight into the effect of the explanatory variables on the predicted participation rates, we estimated partial elasticities of participation at the weighted sample means. A 1% increase in the percent of eligible land (to 22.8%) results in a 0.445% decrease in the weighted sample mean participation rate of 7.5%. Counties with CRP payments 1% higher than the weighted sample mean of $612 per acre have predicted participation rates that are 2.16% lower (about 7.34%).

Estimated participation rates were introduced into the carbon sequestration simulation by averaging predicted participation rates from the probit analysis model over the counties in each MLRA. Predictions also were averaged over states, and state averages were used to fill in missing values for MLRA's that were in the simulation but not in the CRP data. We also have developed cost schedules based on the maximum participation rate predicted for the set of counties in each MLRA (or in the relevant states). This alternative specification is derived from the notion that, if the MLRA are sufficiently homogenous land units, differences in participation might be ascribable to differences in promotion and administration of the CRP. Use of the maximum participation rates then would simulate an administratively effective carbon sequestration program.

---

[2]Data for estimation of the probit model was kindly provided by Tim Osborn of the U.S. Department of Agriculture Economic Research Service.

Total cost schedules resulting from the introduction of the predicted participation rates are shown in Figure 9. Reductions in both cost and sequestration are dramatic. When the average participation rates are used, the maximum quantity sequestered reduces from a potential value of 149 million tons to a simulated value of 14.67 million tons. Maximum program cost reduces from $67.4 billion to $3.6 billion. Instead of 10%, this program would sequester about 1% of total U.S. carbon emissions in an average growth year.

The simulated total cost schedule for the "administratively effective" program has maximum values of 27.2 million tons and $7.4 billion. Tonnage is increased by 1.9 times and program cost is slightly more than doubled when compared to the average participation program. If the notion is correct that the maximum predicted participation rate represents an administratively effective program, development of an effective program would result in a worthwhile increase in carbon sequestration.

Figure 10, The final figure in this presentation, shows the marginal and average cost schedule for the case where the average predicted participation rates are employed. Costs of the marginal ton sequestered almost assume a reverse-L shape in this figure. From a cost effectiveness viewpoint, one would certainly not want to try to sequester the last million tons in this simulated program.

Conclusions

Three major conclusions seem warranted by this study. They are as follows.

(1) Carbon sequestration by forestation of farmland appears to have the potential to significantly abate carbon emissions in the United States. Significant amounts of atmospheric carbon can be removed at total costs that are within the realm of possible.

(2) The country's geography places natural limits on this type of program. Cost effectiveness decreases rapidly once carbon sequestration levels exceeds these limits.

(3) Potential carbon supply curves are dramatically larger than curves based on response experienced in the tree planting component of the CRP. Increased financial incentives or even some public taking may be necessary if acreage enrollment in a carbon sequestration program is to approach potential levels.

One limitation also needs to be stressed. A program that would convert millions of acres of farm to forest would affect the U.S. and possibly the world economy. These effects have not been considered here.

Cited References

Adams, R.M., D.M. Adams, J.M. Callaway, C.-C. Chang and B.A. McCarl 1993. "Sequestering Carbon on Agricultural Land: Social Costs and Impacts on Timber Markets." *Contemporary Policy Issues* 11(1):76-87.

Alig, R.J., T.J. Mills and R.L. Shackleford 1980. "Most Soil Bank Plantings in the South Have Been Retained: Some Need Follow-Up Treatments." *Journal of Applied Forestry* 4(1):60-64.

Birdsey, R.A. 1992. *Carbon Storage and Accumulation in United States Forest Ecosystems.* U.S. Department of Agriculture, Forest Service General Technical Report WO-59. Washington D.C.

Clinton W.J. and A. Gore Jr. 1993. *The Climate Change Action Plan.* Washington D.C., White House Office of Environmental Policy.

Dudec, D. and A. LeBlanc 1990. "Offsetting New CO_2 Emissions: A Rational First Greenhouse Policy Step." *Contemporary Policy Issues* 8(3):29-42.

Eyre, H., ed. 1980. *Forest Cover Types of the United States and Canada.* Washington D.C., Society of American Foresters.

Hourcade, J.C., R. Richels and J. Robinson 1995. "Estimating the Costs of Mitigating Greenhouse Gases." *Intergovernmental Panel on Climate Change, Report of Working Group III*, Geneva, Switzerland.

Moulton, R.J. and K.R. Richards 1990. *Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States.* U.S. Department of Agriculture Forest Service General Technical Report WO-58. Washington D.C.

National Academy of Sciences 1992. *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base.* Washington D.C., National Academy Press.

Parks P.J. and I.W. Hardie 1995. "Least Cost Forest Carbon Reserves: Cost-Effective Subsidies to Convert Marginal Agricultural Land to Forests." *Land Economics* 71(1):122-136.

Richards, K.R., R.J. Moulton and R.A. Birdsey 1993. "Costs of Creating Carbon Sinks in the United States." *Energy Conversion and Management* 34(11):905-912.

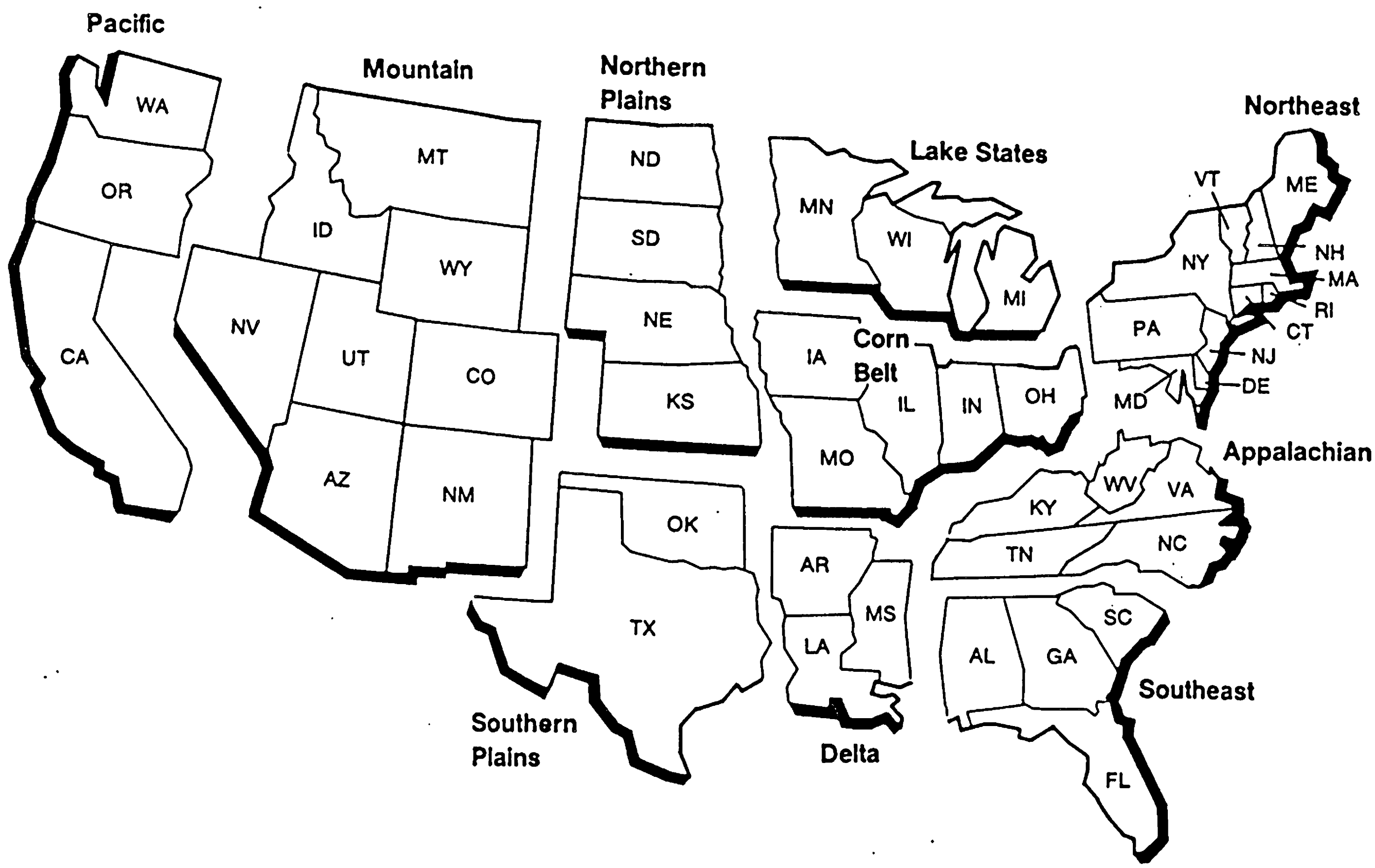
Sedjo, R.A. and A.M. Solomon 1989. "Climate and Forests." *Greenhouse Warming: Abatement and Adaptation*, N.J. Resenberg, W.E. Easterling III, P.R. Crosson and J.Darmstadter, eds. Washington D.C., Resources for the Future.

U.S. Department of Agriculture 1965. *Land Resource Regions and Major Land Resource Areas of the United States*. Soil Conservation Service Agricultural Handbook 296, Washington D.C.

U.S. Department of Agriculture 1961. *Land Capability Classification*. Soil Conservation Service Agricultural Handbook 210, Washington D.C.

U.S. Department of Energy 1991. *National Energy Strategy: Powerful Ideas for America*. Washington D.C.

Figure 1



NORTH:	Northeast (NE) Lake States (Lake) Corn Belt (Corn)
SOUTH:	Appalachian (Appl) Southeast (SE) Delta (Delt)
WEST:	Northern Plains (NP) Southern Plains (SP) Mountain (Mtn) Pacific (PC)

Figure 2

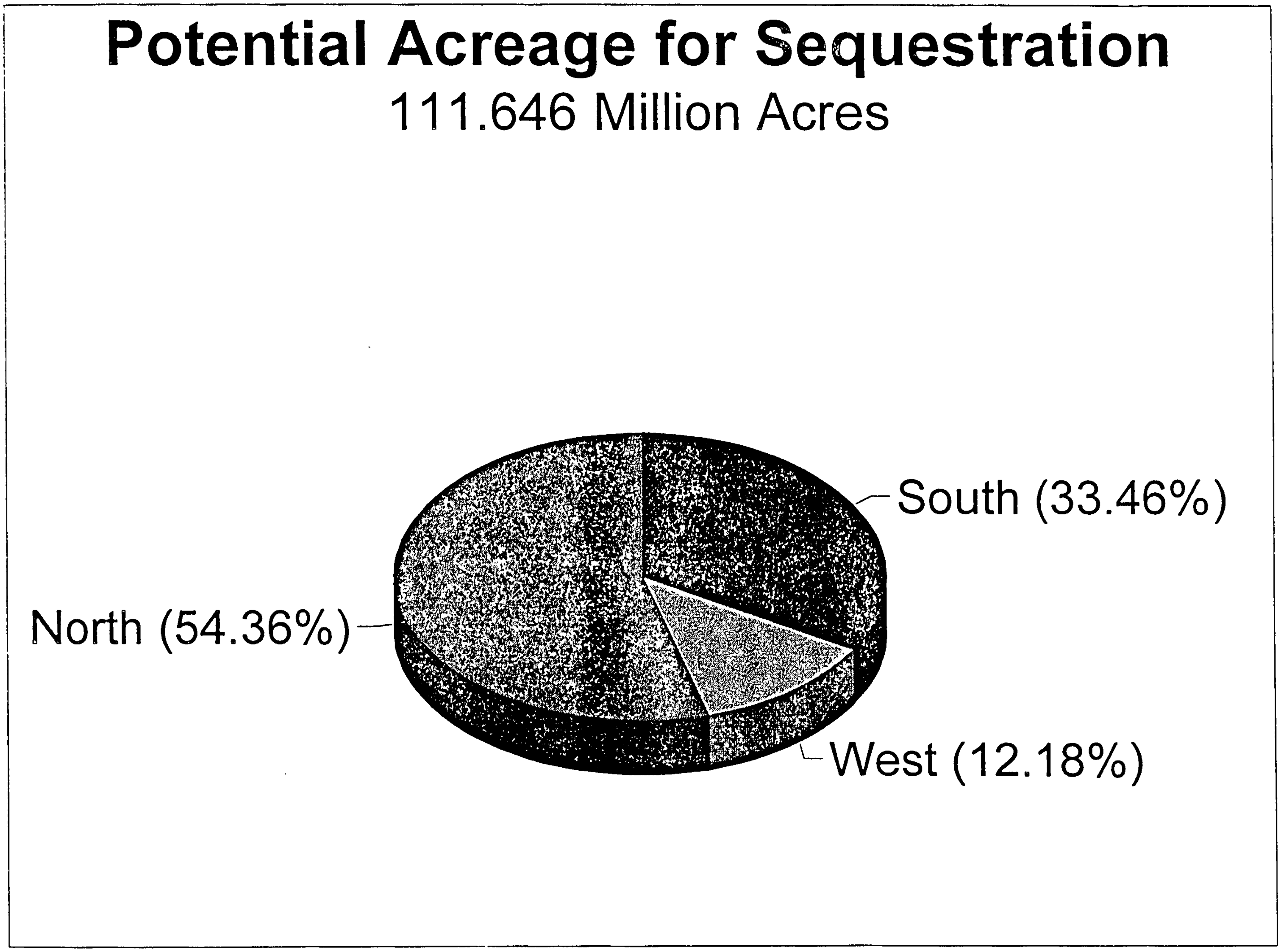
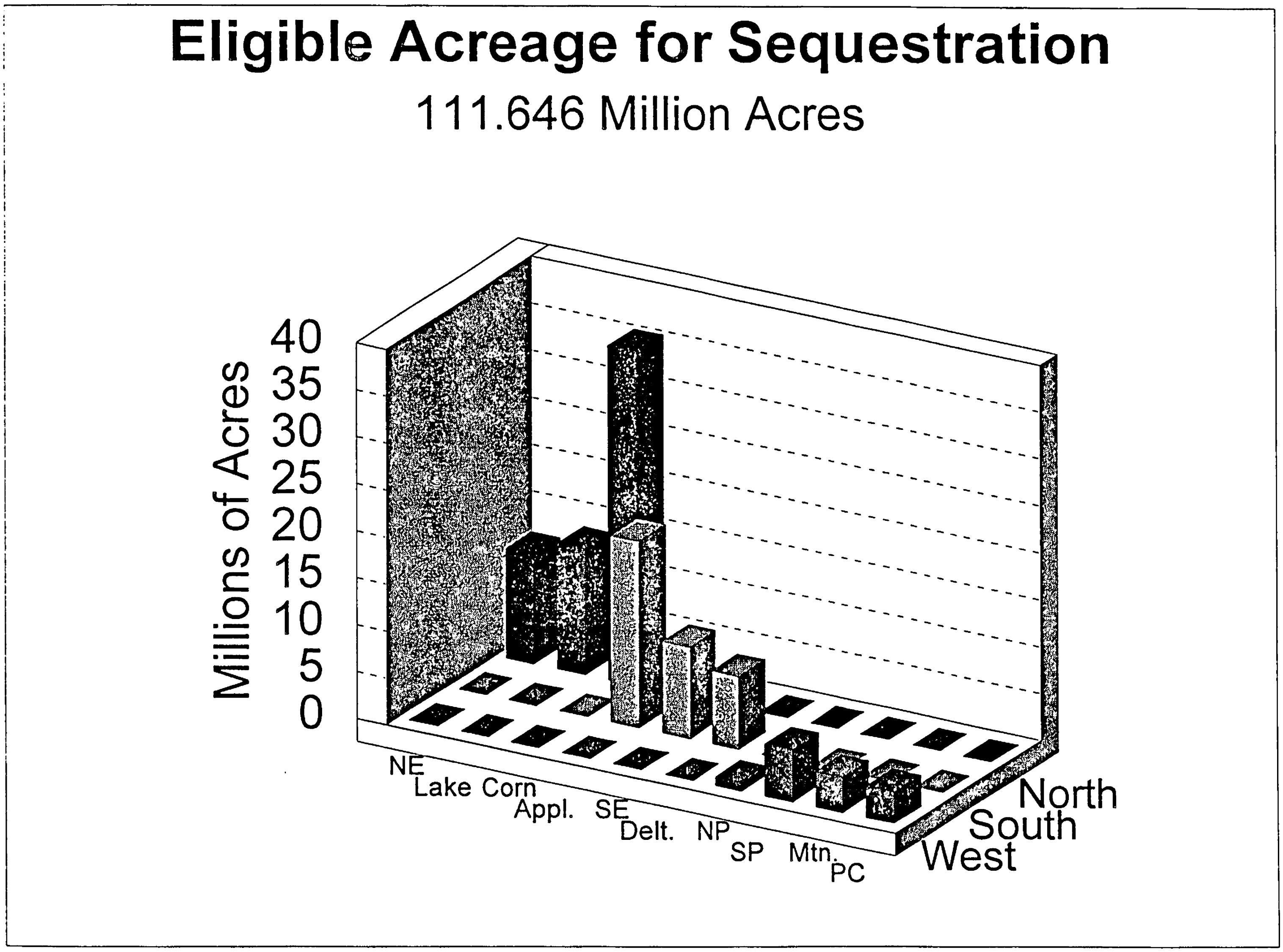
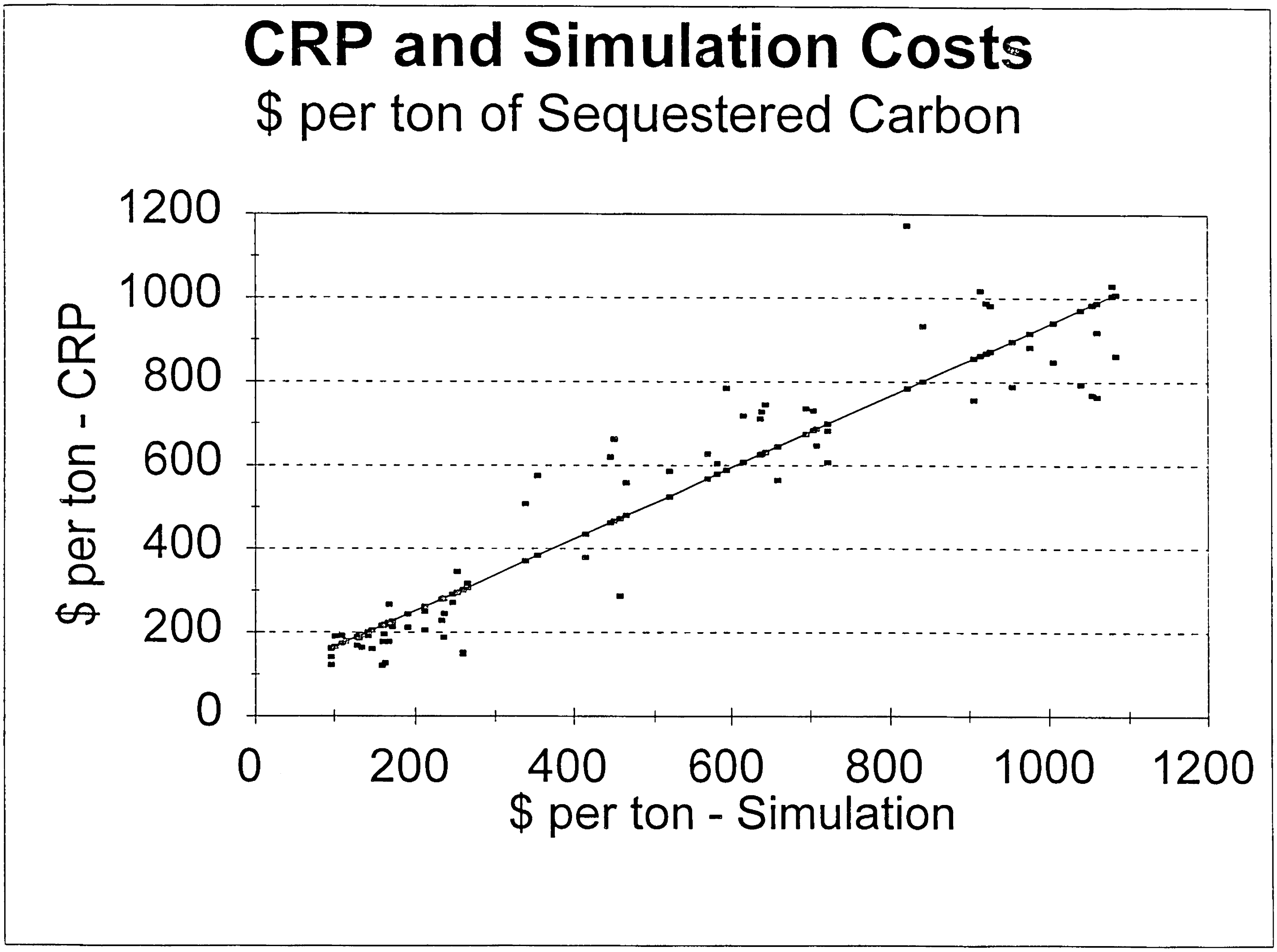

Potential Acreage for Sequestration
111.646 Million Acres
South (33.46%)
North (54.36%)
West (12.18%)

Figure 3



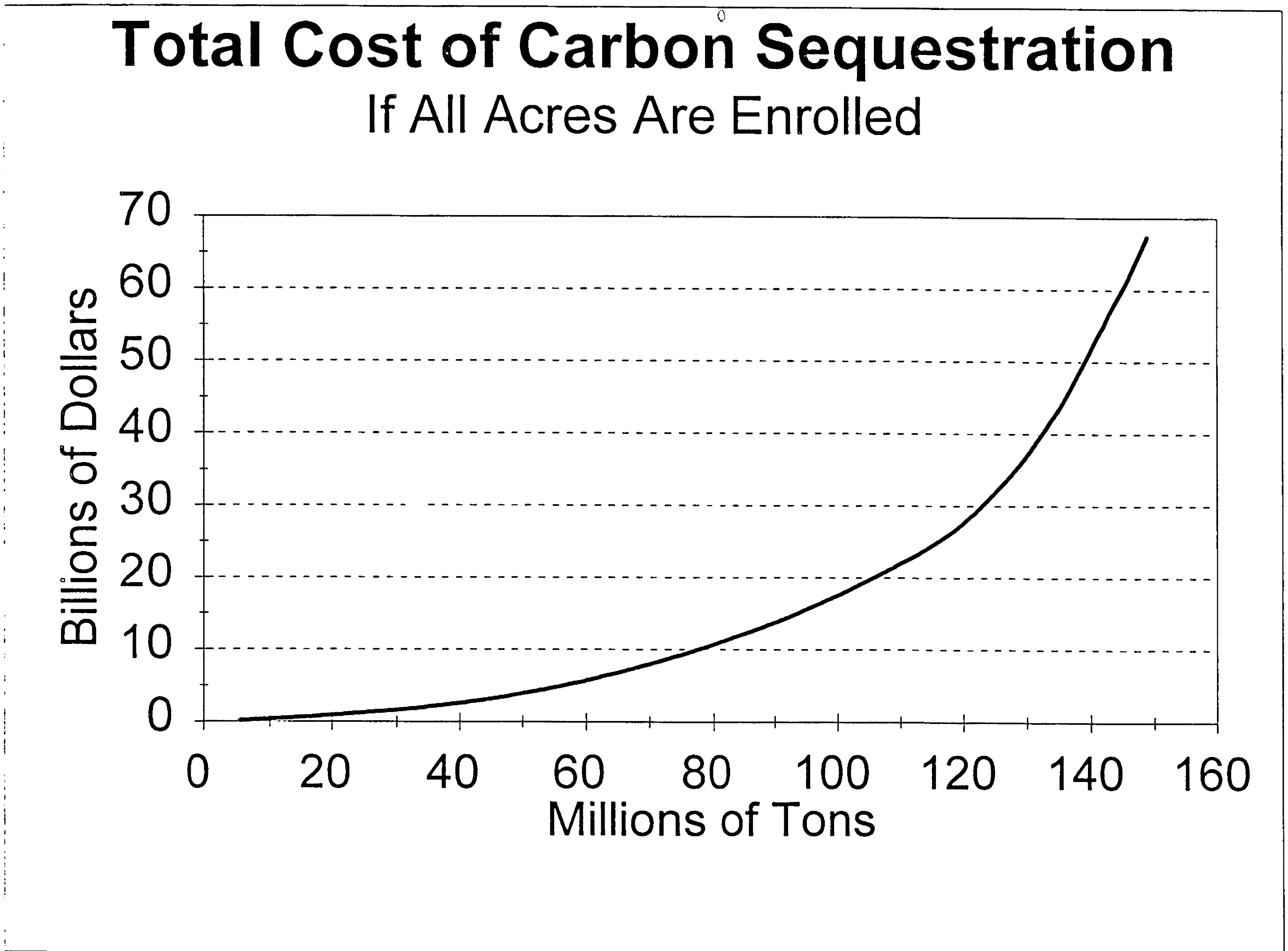
Eligible Acreage for Sequestration
111.646 Million Acres
Millions of Acres
0
5
10
15
20
25
30
35
40
NE
Lake
Corn
Appl.
SE
Delt.
NP
SP
Mtn.
PC
North
South
West

Figure 4



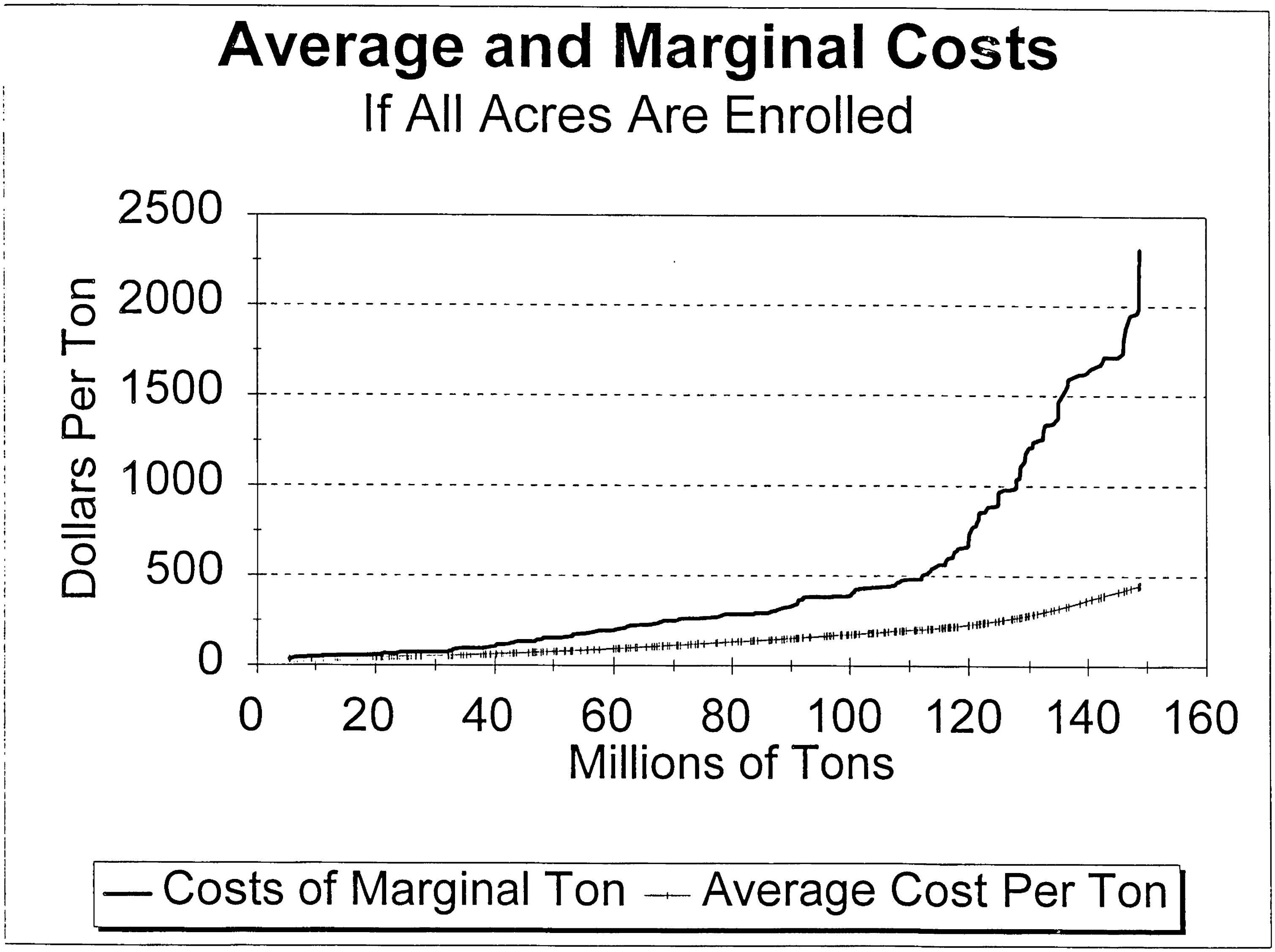
CRP and Simulation Costs
$ per ton of Sequestered Carbon
$ per ton - CRP
0
200
400
600
800
1000
1200
$ per ton - Simulation

Figure 5



Total Cost of Carbon Sequestration
If All Acres Are Enrolled
Billions of Dollars
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
Millions of Tons

Figure 6



Average and Marginal Costs
If All Acres Are Enrolled
2500
2000
1500
1000
500
0
Dollars Per Ton
0
20
40
60
80
100
120
140
160
Millions of Tons
Costs of Marginal Ton
Average Cost Per Ton

Figure 7

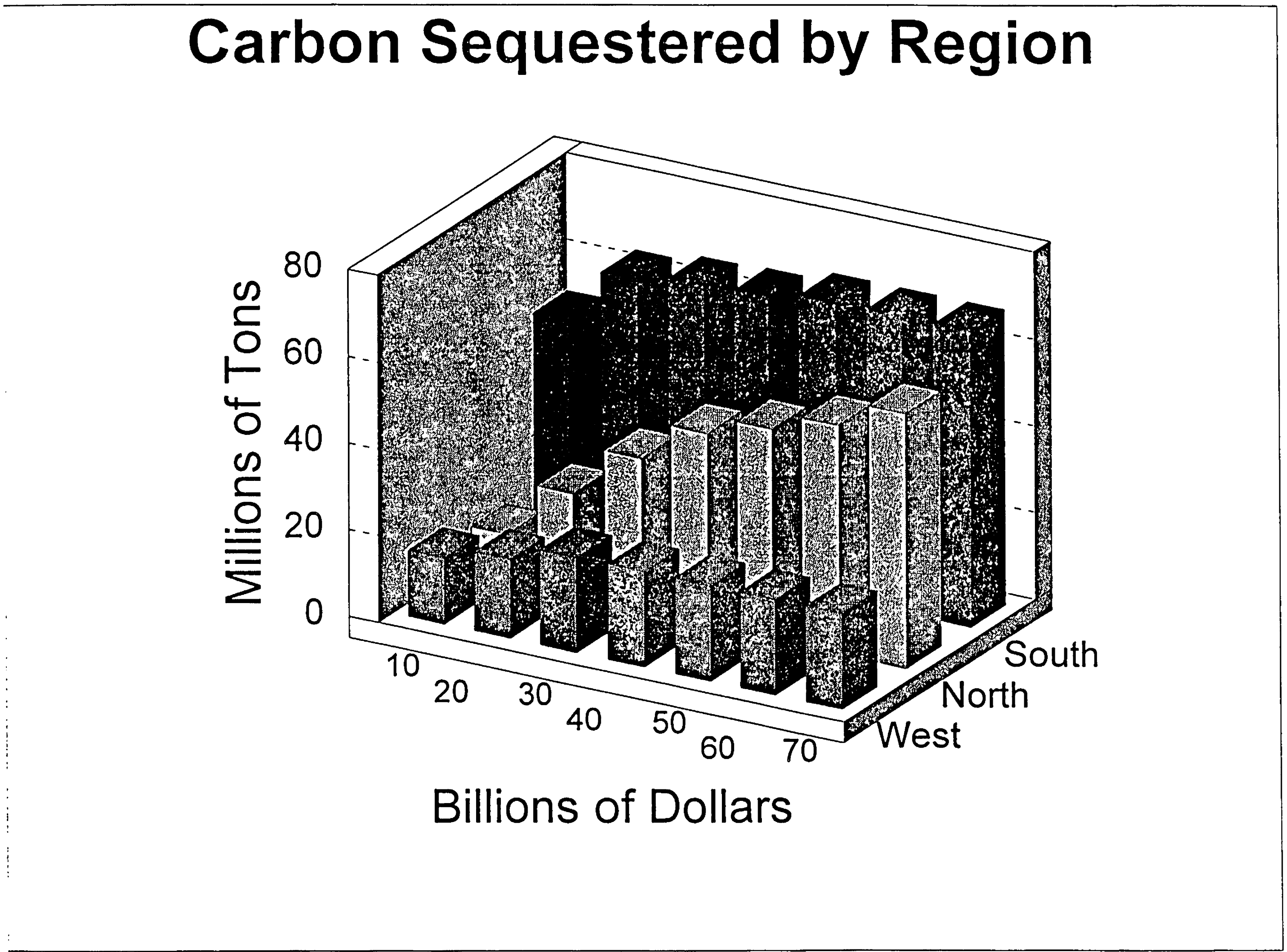
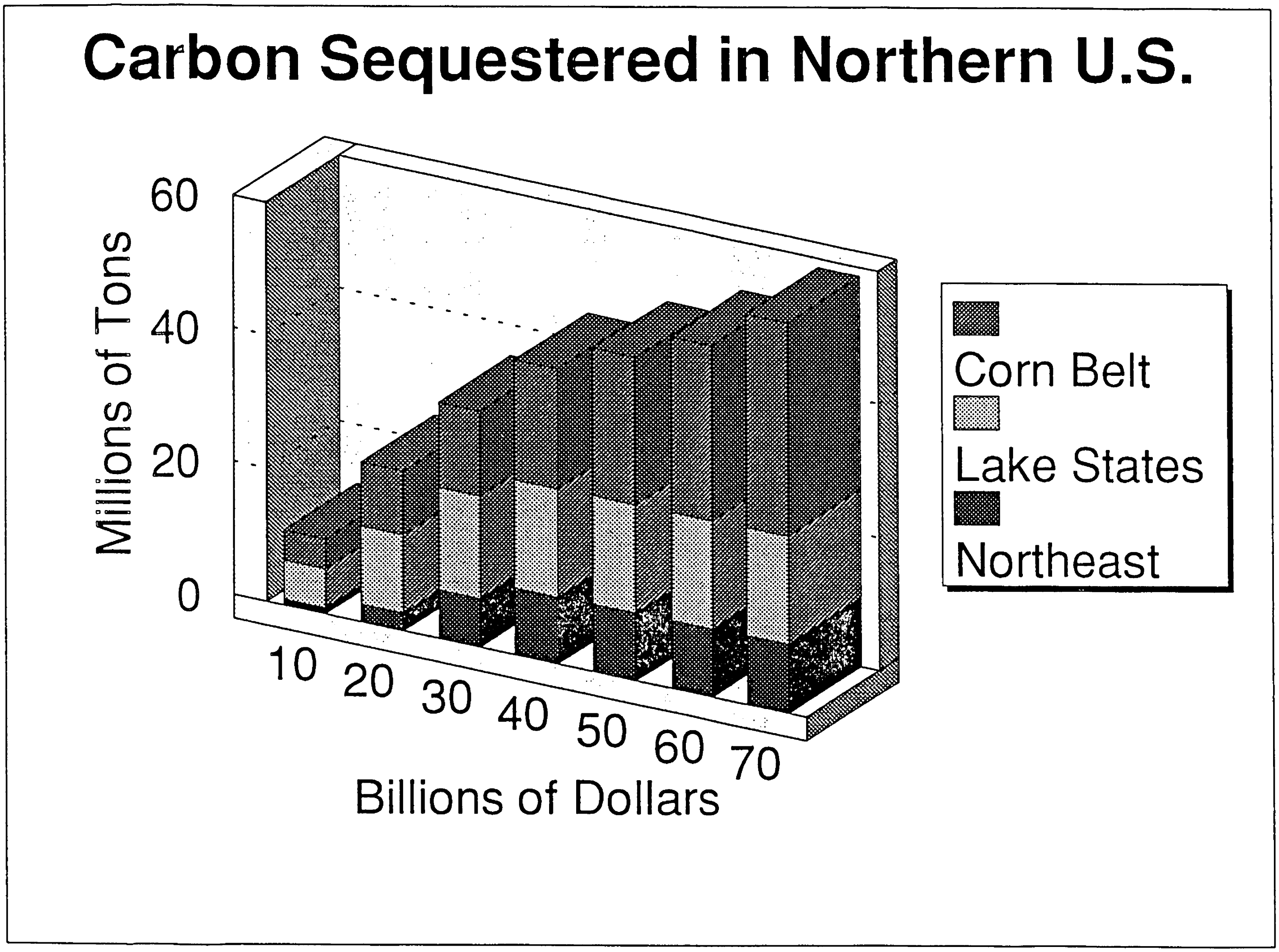

Carbon Sequestered by Region
Millions of Tons
80
60
40
20
0
10
20
30
40
50
60
70
Billions of Dollars
South
North
West

Figure 8



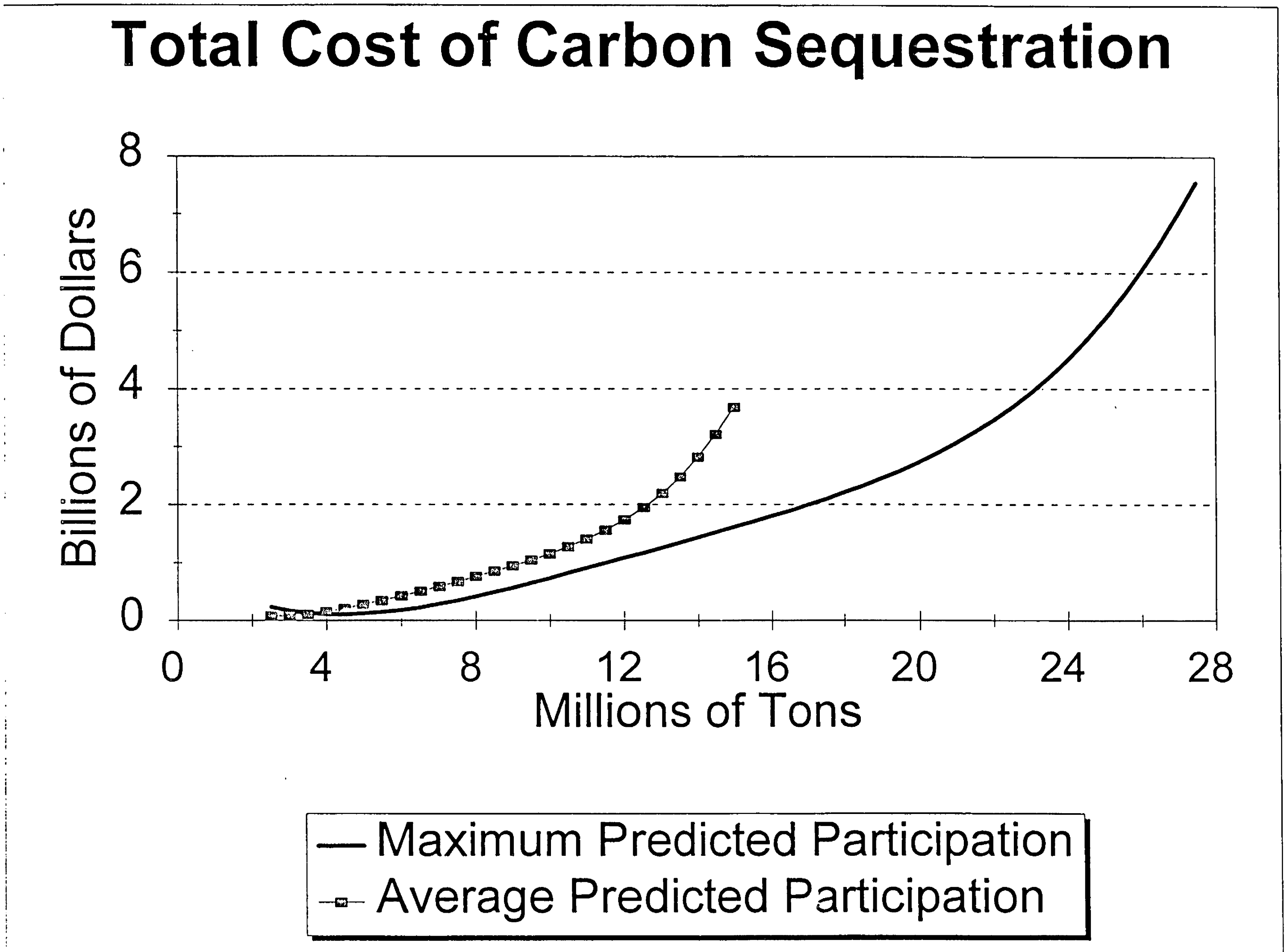
Carbon Sequestered in Northern U.S.
Millions of Tons
60
40
20
0
10
20
30
40
50
60
70
Billions of Dollars
Corn Belt
Lake States
Northeast

TABLE 1
Parameter Estimates for Probit Model

Variable	Coefficient	Standard Error	Asymptotic t Statistic
Constant	1.341	0.312	4.30
Percent Eligible Farmland	-0.02433	0.00461	-5.28
Per-Acre Cost to Government	-0.00480	-0.00064	-7.52

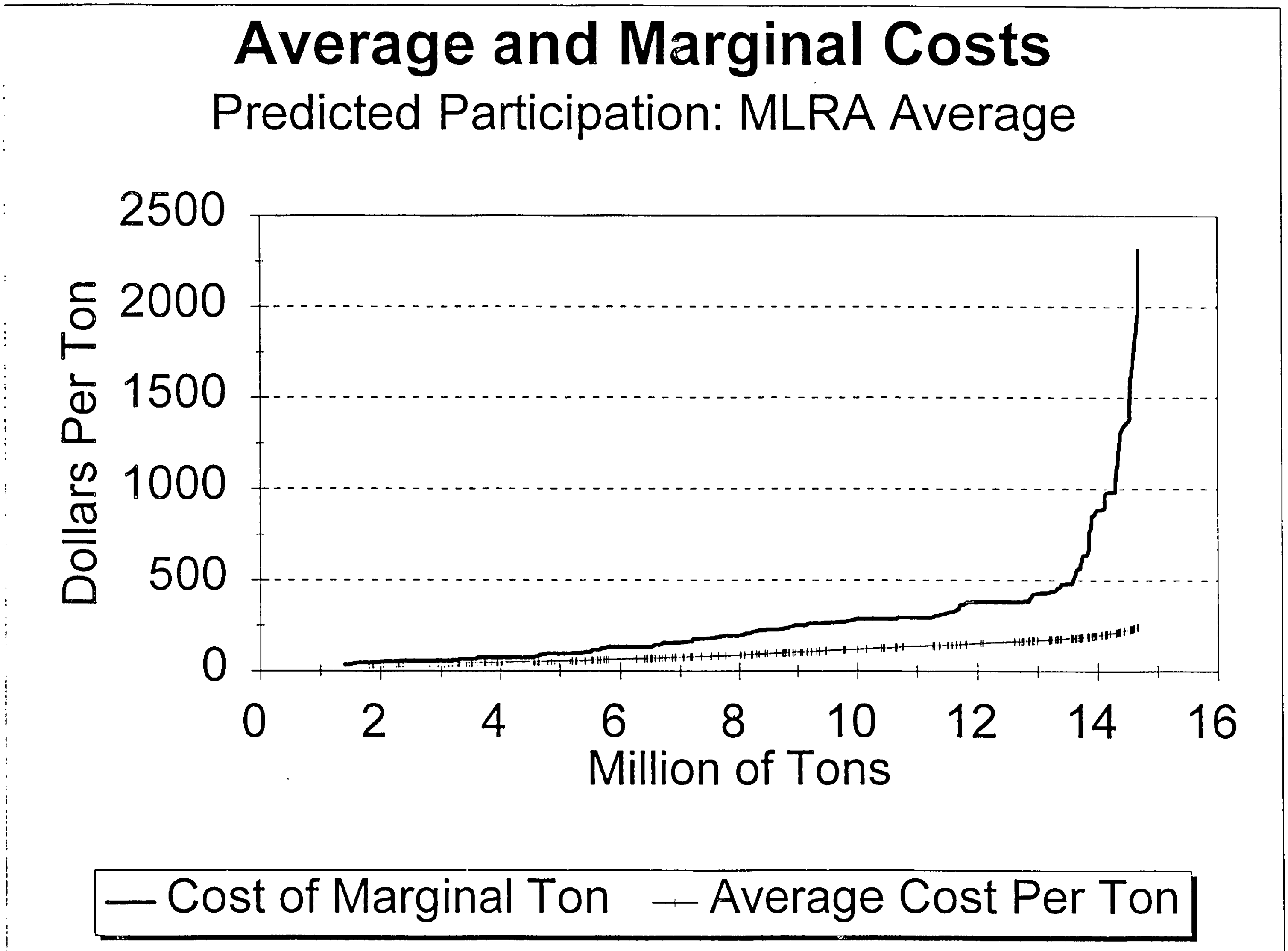
Dependent variable is ratio of acres planted to acres eligible for tree planting in CRP.
Observations are for counties - Number of observations is 1618.
Computed Chi-Squared statistic for the test of joint parameter significance is 179.
Tabled value for the 0.995 precentile of the Chi-Squared Distribution is 10.60.
Mean sample value of "Percent Eligible Farmland" is 21.78, Std. Dev. is 18.94.
Mean sample value for "Per-Acre Cost to Government" is 612.45, Std. Dev. is 202.72.
Observations are weighted by crop acres in county: this will affect sample statistics.

Figure 9



Total Cost of Carbon Sequestration
Billions of Dollars
0
2
4
6
8
Millions of Tons
0
4
8
12
16
20
24
28
Maximum Predicted Participation
Average Predicted Participation

Figure 10


Average and Marginal Costs
Predicted Participation: MLRA Average
Dollars Per Ton
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
Million of Tons
Cost of Marginal Ton
Average Cost Per Ton