Carbon Sequestration Through Tree Planting on Agricultural Lands

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Abstract

One way to mitigate the effects of greenhouse gas emissions is to sequester carbon through afforestation of agricultural land. For this study, a price-endogenous agricultural sector model (ASM) was modified to estimate both the amount of carbon that can be sequestered on agricultural land under alternative subsidy levels and the total value of the consumers' and producers' surplus losses that occur at each subsidy level. This paper will also explore the effects which farm programs in the U.S. have on the financial and social costs of sequestering carbon. In addition, the paper will examine the carbon consequences and social costs associated with diverting payments from existing farm programs into programs to sequester carbon. Finally, the paper will present directions for future work in this area and discuss, briefly, the development of a new model by the authors to address the weaknesses inherent in the current analysis. This model will link the forest and agricultural sectors in a dynamic, optimization framework so that policy makers can better understand how consumers and producers in both sectors will react to different types of programmatic objectives and incentives.

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I. Introduction

Policies to plant trees are a frequently discussed way of sequestering carbon and mitigating the environmental effects of greenhouse gas emissions (National Academy of Sciences, 1991; Center for Strategic and International Studies,1991). A number of appraisers have argued that planting trees to sequester carbon is an inexpensive alternative with broad based benefits (Moulton and Richards 1990; Sedjo and Solomon 1983; Dudek and LeBlanc 1990). However, Adams et al. (1993) argued that large scale tree planting programs were more costly than the previous studies suggested. They also found major implications for the forestry sector showing the potential expansion in agricultural based timber harvest could swamp forest product markets.

This paper presents results and discussion based on an ongoing EPA sponsored project examining tree planting programs and potential policy in terms of: a) the sensitivity of cost and timber supply impacts to differences in carbon and timber yield assumptions; b) the effects of carbon sequestration losses at the time of harvesting and during the life cycle of wood products; c) the interaction between agricultural programs and tree planting policies; and d) the amount of net carbon sequestered due to changes in planting and harvesting decisions on commercial timberlands.

This project involves two distinct phases, the first involving appraisals largely within the context of the agricultural sector with a broad based examination of forestry sector implications and the second with detailed examinations of implications for both sectors. Empirical work will be reported here from the first study phase. Later we will discuss the conceptual formulation of the model for the second phase of the study.

II. Long Run Agricultural and Forestry Implications of Tree Planting

The first study phase concentrated on the agricultural sector using a long run agricultural sector model - ASM (Chang and McCarl, 1990; Chang et al., 1992) - integrated with forestry data from the Timber Assessment and Market study (Adams and Haynes, 1980). The ASM base model was set up for 1990 conditions.

The ASM represents production and consumption of 24 primary agricultural commodities, including both crop and livestock products in 63 U.S. regions. Processing of agricultural products into 36 secondary commodities is also included. A forestry component was added to ASM during the Adams et al (1993) study by introducing tree planting possibilities on agricultural land and then entering forest product market characteristics adapted from Adams and Haynes (1980). The net effect is that the resultant integration can simulate the long run agricultural and forestry sector consequences of displacement of agricultural land use by trees. Water resources are disaggregated in the model into surface and ground water available in each of the 63 regions. Surface water is available for a constant price up to a prespecified quantity, but pumped ground water is provided according to a supply schedule in which the unit price increases with increasing rates of withdrawal. The model assumes a large number of individuals make up both production and consumption sectors, each operating under competitive market conditions, and thus maximizes the area under the demand curves less the area under the supply curves. This area is a measure of economic welfare or net social benefit. Both domestic and foreign consumption (exports) are considered. This model structure allows projection of the effects of carbon sequestration on; 1) the regional agricultural and timber economies across the United States; 2) irrigated versus dryland cropping tradeoffs in response to regional water demand and availability; 3) producer welfare at the regional and national level, as well as consumption effects for both domestic and foreign consumers; and 4) supply of logs from the traditional forest sector and agricultural sector sequestration activity.

The resultant model is used herein to generate information on the subsidy costs required to meet various carbon suggestion targets. The carbon targets used range from 0 to 508 million megagrams (Mg). The cost estimates include: a) the cost of establishing trees, which is computed exogenously; and b) the endogenous change in land opportunity costs as agricultural commodities are displaced by trees. The specific analysis involved varying:

1. Carbon and timber yields based on differing authors estimates of these yields;
2. The assumptions that trees would be harvested or left standing; and
3. The incidence of the Farm Program.

All analyses at this stage are done under 1990 conditions with and without the 1990 farm program. The discussion herein is a summary of that in Callaway and McCarl (1992).

A. Analysis Setup

The literature contains differing estimates regarding both timber and carbon yields as a result of agriculturally based tree planting programs. Three sets of timber and carbon yields were used:

1. The yields used in Adams et al (1993), based on Moulton and Richards (1990), but modified to reflect emerging judgements about timber yields under non-plantation conditions.
2. A revised set of yields, developed by Richards (1992), correcting previous errors in Moulton and Richards (1990) carbon yields.
3. The yields reported by Birdsey (1991), based on timber yields used in the 1989 RPA assessment (USDA Forest Service, 1990).

Most studies of carbon sequestration assume that trees, once planted, will not be harvested. This is plausible only if a small amount of land is afforested so that harvest is irrelevant or the program assures the land will be a permanent timber reserve. If a permanent reserve is not assured, then the cost of carrying the trees will lead to harvest. When trees are harvested, carbon sequestration will be affected for three reasons:

- carbon in the soil, limbs, roots, understory etc. will dissipate soon after harvest;
- carbon in wood products will be released as those products undergo processing, use and disposal[1]; and
- carbon sequestration on commercial timberlands may be reduced due to reduced timber holdings in response to market forces.

In the empirical work, we consider losses of 17-22% depending on region, where the carbon in the roots and the above ground woody debris is lost based on Birdsey's (1991) estimates.

B. Analysis Results

The results discussion is organized by harvesting assumption where both no harvesting and harvesting optional cases were run. The first results shown are those from the No Farm Program Case.

1. No Harvest No Farm Program

The no harvest cases adopt the assumption that trees planted on agricultural land grow indefinitely

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[1] Phase 1 of the study does not deal with wood products post-harvest losses.

following the assessment assumption in Moulton and Richards, 1990; and Parks and Hardie, 1992. Table 1 contains results for the various carbon scenarios[2]. The data given in the table are: 1) cost per megagram (Mg) - the marginal cost of producing the last megagram of carbon associated with a specific carbon target; 2) hectares of trees planted - the amount of land, in million hectares, that it takes to achieve this sequestration; 3) net social benefits - the change in net social benefit measured as the difference between the base case agricultural producers' and consumers' surplus without any tree planting and the same quantity associated with a specific carbon target (a negative indicates value cost to society, but note that the benefits of reduced atmospheric carbon are not factored in); and 4) carbon production cost - a measure of the marginal cost of having the trees planted, which equals the marginal cost of carbon times the carbon times the carbon target level. An example of the nature of the results can be found by examining the marginal cost of sequestering the 39th Mg/yr. of carbon. In particular using the yields from Adams et al (1993) the sequestration of this volume would cost society $13.52/Mg/yr, would require 6.03 million hectares, costing 429 million in subsidization and reducing welfare by 419 million without counting the benefits of less atmospheric carbon.

The marginal cost estimates include both the annualized establishment cost and the opportunity costs of land due to the displacement of crops by trees. At low average levels of carbon sequestration, the marginal cost is dominated by establishment costs; however, as the carbon target increases more and more land is drawn out of agricultural production, and the opportunity cost component dominates.

The different yield estimates do not have a very pronounced effect on the marginal cost estimates at the 31.8 or 63.5 million Mg/yr. carbon targets. Furthermore at these low levels the opportunity costs found herein are close to those obtained by Moulton and Richards (1990) and others although at higher targets the results here are consistent with Adams et al (1993) is higher costs.[3] However, starting at the 127 million Mg/yr. carbon target, the yield assumptions begin to have a significant effect on the results. In particular, the marginal costs and land area

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[2] Note a range of sequestration targets is used here in identifying the scenarios as the target level of sequestration has not been determined and is an ongoing subject of debate.

[3] The range of estimates for 31.8 million Mg, just about spans the estimates developed by Moulton and Richards (1990) - $13.52/Mg, by Richards (1992) - $16.77/Mg, and Parks and Hardie (1992) - $18.22/Mg, for the same case.

requirements estimated using Birdsey's yields begin to increase rapidly becoming about twice the next highest estimate for the 254 million Mg/yr. carbon three times at 380.9 Mg and by 507.9 Mg/yr. the Birdsey based estimate ($726.57/Mg) is 13 times higher.[4] The marginal cost curve for carbon associated with the revised Moulton and Richards (Richards 1992) yields also lies above the curve based on Adams et al (1993). However, the differences are not nearly so great.

Table 1 also presents estimates for the changes in net social benefits and carbon production costs. For the 31.8 million Mg/yr. level, the welfare cost estimates range from $515 million/yr. to $442 million/yr., while the corresponding range of carbon production cost estimates is from $429 million/yr to $572/million/yr. To achieve the 63.5 million Mg target would cost society about twice as much in terms of lost welfare and carbon production costs. After that point, the costs estimated using Birdsey's yields are again substantially higher than those estimated with the remaining sets of yields. Three final points stand out in the results. First, between zero and the 254 Mg/yr. target, a doubling in the target results, roughly, in a doubling of both the opportunity and carbon production costs. Beyond that point, costs begin to increase more rapidly largely due to the opportunity costs. Second, as the carbon target increases, the carbon production costs rise more rapidly than do the welfare costs. Third, the welfare cost estimates give the minimum level of benefits which the rest of society must gain from sequestering this quantity of carbon.

2. Harvesting Allowed Cases - NonFarm Program

Here, we assume that farmers can harvest trees. Thus the planting decision is based on both stumpage price and carbon subsidy considerations. We also introduce carbon harvest losses. There are three confounding effects introduced by such a setup. The first is that by introducing carbon losses, more land is needed to sequester an equivalent volume driving up the cost. Second, the tree establishment and agricultural land opportunity cost are partially offset by revenues from harvesting trees. Third, the more trees harvested the lower the harvesting revenues since the timber prices fall, thus the harvesting revenue offset falls as with increases in tree planting, and

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[4] The fact that it costs so much more and takes more land to sequester carbon using Birdsey's yields is due primarily to the lower yields associated with Birdsey's work. On average, Birdsey's carbon yields are about one-half the magnitude of those in Moulton and Richards (1990).

sequestering targets.

Estimates of the changes caused by the harvest scenario are presented in Table 2. At the lowest first few target levels, all timber is harvested and the sequestration costs are reduced relative to the no harvest case. For example, using the revised Moulton and Richards yields, the carbon production cost estimates are $339 million/yr. and $966 million/yr for the lowest and highest scenarios under no harvest case, the corresponding cost estimates are $552 million/yr. and $1117 million/yr. However, at the higher carbon target levels, the carbon production costs in Table 2 become much closer to the no harvest case.

The effects on the forestry sector are significant (Table 3). Under existing conditions, combined annual harvests of sawtimber and pulpwood equal 177 million cubic meter/yr. The results show estimated agricultural harvest levels can increase to as much as 78.5% of this total. The dramatic increase in harvest is accompanied by sharp decreases in stumpage prices. These stumpage price decreases range from about 20 to 25% for wood products for the 31.8 million Mg/yr. carbon target but fall as much as 48% across the scenarios. Increasing carbon targets lead to a U-shaped response in timber harvested and timber prices. This occurs since dropping timber prices, and increasing agricultural opportunity costs increase the carbon price which makes the harvest time carbon losses unattractive and this reduces the proportion harvested.

One important factor not incorporated into the carbon cost calculation is the potential reduction in carbon grown on existing timberland. Given the reductions in forest product prices and commercial harvest, existing timberland owners would have substantial incentives to undertake actions like: harvest existing stands earlier than usual; reduce the level of management intensity in existing and newly regenerated stands; and move lands out of forestry. The second phase of this project embodies an effort to develop a dynamic forest and agricultural sector model that will account for such factors.

C. Effects of the Farm Program and Farm Program/Sequestration Policy Tradeoffs

The model was also run under existing farm programs and under farm program reductions. Table 4 contains the results of the current farm program run for the revised Moulton and Richards and Birdsey yield. The entries largely have the same conceptual basis as in Table 1. The new government farm payments row, is the amount of money that the Federal Government pays for farm programs. The sixth row entry, total payments, is the sum of the carbon production cost and the farm program payments. It represents the financial cost the Government would have to pay to farm bill and carbon sequestering payments. The results show that the sequestration consequences are virtually identical to the non-farm program supply curves shown above and do not merit much more discussion.

However the results do reveal that there are policy tradeoffs between tree planting and farm programs which merit examination.

1. Trading off Farm Program Elimination with Tree Planting

Comparisons of the with and without farm program runs in Tables 1 and 4 indicates that current farm programs cost tax payers (and benefit farmers by) about $8.2 billion/yr. Current farm programs cost society about $1.9 billion/yr in terms of lost welfare. Thus, if current farm programs were abolished and no programs were put in their place, government budget exposure would be reduced by $8.2 billion/yr., and societal welfare would increase by $1.9 billion/yr.

Now, consider a policy that would eliminate farm programs and plant trees until the welfare costs of planting trees equaled the welfare costs of farm programs. Such a policy could afford to sustain a $1.9 billion welfare loss. To find what size sequestration program this would be, one can refer to Table 1, and look for the size program (by yield source) which satisfies this criterion. In all yield cases, the tree planting policy sequesters between 63.5 and 127 million Mg. For example, in the case of the revised Moulton and Richards yields, a 63.5 million Mg/yr. program costs society approximately $1.1 billion/yr., while a 127 million Mg/yr. program costs society about $2.3 billion/yr. The corresponding land area requirements and marginal cost per megagram estimates can also be interpolated from the table. The interpolated estimates for the program levels and carbon production costs are:

Yield Case	**Carbon Target (million Mg/yr.)**	**Carbon Prod. Cost ($million/yr.)**
Revised Moulton & Richards	110	2018

Birdsey	98	2526

These results mean that farm programs could be replaced with tree planting programs that could sequester from 98 to 109.8 million Mg of carbon/yr at the same welfare cost to society as current farm programs[5].

On the other hand, if one targets for equal government cost, one finds that a program in the range of 127-254 million Mg is consistent with a carbon production cost equal to the farm program cost ($8.2 billion), depending on the yield assumption. However, societal welfare is lower with such a policy than under the current farm bill by an amount equal to the net social benefit for the carbon sequestration program less the $1.9 billion welfare cost of current farm programs. Notice that these welfare costs can be high. For example, under the revised Moulton and Richards yields, the application of this rule leads to a program slightly bigger than 254 million Mg, but the additional social cost would exceed $3.0 billion/yr (i.e., $4.919 billion/yr. versus $1.9 billion/yr. The interpolated estimates for the program levels and carbon production costs are.

Yield Case	**Carbon Target (million Mg/yr.)**	**Welfare Cost ($million/yr.)**
Revised Moulton & Richards	283	3881
Birdsey	182	2867

2. Trading off Farm Program Reduction with Tree Planting

A second policy approach involves fixing the size of the carbon sequestration target one wants to achieve and then finding the percentage reduction in the size of the current farm program that will make society as a whole or government cost no worse off. The calculations for welfare compensation indicate the following for the two sets of yields used in this part of the analysis:

1. **Revised Moulton and Richards Yields**. For the 31.8 million Mg/yr. program, a reduction of

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[5] Note this would have quite different distributional consequences. Since the incidence of tree payments and farm program payments would be quite different.

about 5% in current farm program target prices would hold welfare constant at current farm program levels. The combined program cost for this option lies between $4.1 and $2.4 billion/yr. For a 63.5 million Mg program it would take more than a 10% reduction in current farm program while a 127 million Mg program would require about a 15% reduction in target prices. Programs larger than 127 cannot be matched even by farm program elimination.

2. **Birdsey Yields** For a 31.8 million Mg program, it would take a reduction in farm program target prices of greater than 5% to hold welfare constant at farm program levels. For a 70 MTC program a reduction of 20% or more is required. Program levels greater than 70 cannot be matched by farm program reductions

If, on the other hand, policy could be revised to hold the sum of tree subsidy and farm program payments constant. there is a tradeoff between farm program payments and carbon sequestrations cost. By uniformly reducing program target prices, the amount of carbon that can be sequestered at a given cost level increases. At the same time, the farm program cost falls, so does the welfare cost to society in terms of the change in net benefits. For example, using the revised Moulton and Richards yields, going from a 2% to a 5% reduction in program target prices, almost doubles the amount of carbon that can be sequestered (208.3 million Mg vs. 120.4 million Mg) at the same level of cost. The size of government payments to farmers under existing programs falls from about $6 billion/yr. to $3 billion yr., while payments for carbon increase by an offsetting amount to hold the total fiscal cost of the two sets of programs constant at $8.2 billion/yr. In the process, welfare losses just about double, increasing from about $1.5 to 3 billion/yr.

D. Summary and Conclusion

The empirical analysis shows six major things. The costs of sequestration continue to be higher particularly at the levels above 63.5 million Mg than the estimates developed before Adams et al (1993).   Second, the uncertainty in yields between the Birdsey (1991) and Richards (1992) estimates is a significant factor in the program cost estimation. Third, the costs appear to be yet higher than the Adams et al (1993) costs under Richards

(1992) revised estimates and there is potential for them to rise yet more if one subscribes to Birdsey's (1991) estimates. Fourth, the inclusion of harvest losses makes these costs even higher. Fifth, the harvest scenario has major implications for the forest sector. Sixth, the farm program and tree subsidy programs are two different ways of transferring money to the agricultural sector and can be used in a substitute fashion to achieve a targeted levels of funds transfer or welfare.

III. Toward a More Detailed Forest Sector Appraisal

The purpose of the second, ongoing project phase is to incorporate tree growth dynamics and to project the response of private timberland owners. Timberland owners, in the face of a large agricultural planting program, could reduce the size of their inventory holdings harvesting more timber sooner and replanting fewer harvested stands or change managements regimes. Furthermore, Haynes, Alig and Moore (1992) found dynamic considerations dampened the changes in stumpage prices.

Consideration of the above items requires adoption of a dynamic framework which depicts both the forest and agricultural sectors. This led to the conceptualization and ongoing development of the **F**orest and **A**gricultural **S**ector **O**ptimization **M**odel (**FASOM --** Callaway et al., 1993). FASOM is a dynamic, open, nonlinear programming model of the United States forest and agricultural sectors . It is being developed for EPA to evaluate the welfare and market impacts of alternative policies for sequestering carbon in trees. The model is also being designed to help aid in the appraisal of a wider range of forest and agricultural sector policies. The principal characteristics of FASOM are it:

1. **includes a detailed forest sector representation**. The forest sector is depicted as open to trade, producing sawlogs, pulpwood, and fuelwood from both hardwood and softwood sources. Forest lands are dissaggregated regionally by species, age cohort of trees, cover type, site condition, management regime, land suitability and private non-industrial or industrial ownership. Public forest harvest policy is included as an exogenous influence. In addition an inventory projection component is used to describe the current sector as well as project future tree growth, wood yields, carbon sequestration quantities, and management actions. This is based on the Forest

Service's Timber Assessment Database model and Birdsey's (1991) carbon sequestration data.

2. **includes a detailed agricultural sector.** The model simulates the production of 36 primary crop and livestock commodities and 39 secondary, or processed, commodities with competition for land, labor and irrigation water in an open economy. The model also includes farm program policies. The agricultural model follows the existing ASM structure (Chang and McCarl, 1990) in all aspects except that the regions are aggregated.
3. **is a regionally-based model.** Eleven regions are included: Pacific Northwest-West, Pacific Northwest-East, Pacific Southwest, Rocky Mountains, Northern Plains, Southern Plains, Lake States, Corn Belt, South Central, Northeast, and Southeast.
4. **covers a 120 period**. The model incorporates the 120 year period with explicit accounting on a decade by decade basis plus terminal conditions for in process timber stands.
5. **is based on a dynamic, price-endogenous, spatial equilibrium market structure.** Prices for agricultural and forest sector commodities are endogenously determined in domestic and foreign markets given product demand and factor supply functions. FASOM is dynamic in that it solves jointly for the multi-market equilibrium in each product and factor market included in the model, over time. The agricultural sector and the forest product sectors are unified as drawing from a common land base. The structure of the two sectors will be based on those modeled in the existing TAMM (Adams and Haynes, 1980) and ASM (Chang and McCarl, 1990) models.
6. **includes welfare accounting.** Changes in total welfare, and the distribution of welfare is computed. Welfare is accounted for agricultural producers, timberland owners, consumers of agricultural products and purchasers of stumpage.
7. **incorporates expectations of future prices.** Farmers and timberland owners are able to foresee the consequences of current behavior (when trees are planted) on future stumpage and agricultural product prices. That information is used in determining sectoral land allocation.
8. **accounts for potential changes in land use.** Land can shift between sectors over time, based on future prices. For example, tree planting policy can cause upward pressure on agricultural prices

and downward pressure on stumpage prices, thus there is the potential to convert forest land into agricultural land.

9. **includes detailed carbon accounting**. Accounting is present for carbon accumulation in existing forest stands, as well as, in regenerated and afforested stands. Post harvest losses are also included covering losses in non-merchantable carbon pools associated with harvested stands and carbon decay over time in wood products.

10. **is easily modifiable.** The model system will be developed in the GAMS modeling system (Brooke, Kendrick and Meeraus 1988) which allows easy model modification for policy evaluation.

A. FASOM Solution Information

The FASOM solution information depicts a multi-period simulation of economic activity. Timber planting and harvest decision variable solutions will tell where and when existing stands are harvested. In turn the decision to regenerate, idle or move land between sectors will occur. As such the FASOM solution will provide national and regional information by decade on:

- Consumer and producer welfare
- Agricultural production and prices
- Forestry harvest and replanting by species
- Forest product and prices
- Land and forest asset values
- Land utilization by sector and intersectoral movement
- Carbon sequestration amounts and costs.

B. Anticipated Policy Applications

The initial motivation behind FASOM was to develop a model to evaluate alternative carbon sequestration policies in an economic framework including projections of the reaction of consumers and producers. Subsequently, it became clear that FASOM could also be used to evaluate the consequences of a wide range of forest and agricultural policies, not just those intended to promote carbon sequestration. FASOM potentially could be used to evaluate a wide ranging set of policies such as:

- Agricultural lands based tree planting programs
- Substitution of tree planting subsidies for farm program payments
- Significant changes in forest and agricultural product trade policies
- Reforestation and forest management programs
- Changing harvest levels on national forest land
- Increases in paper recycling and wood processing technology
- Climate change induced alterations in forest and agricultural product yields
- Changes in erosion limits on agricultural lands

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TABLE 1. Changes due to Carbon Sequestration - No Harvesting, No Harvest Losses, No Farm Programs

	Total Carbon Sequestered (million Mg carbon/yr.)					
	39	77	154	308	463	617
Adams et al Yields						
Cost/Mg[a]	13.52	14.23	14.87	19.48	26.92	38.97
Hectares/trees Planted[b]	6.03	11.5	22.9	44.7	66.1	89.1
Net Social Benefit[c]	-419	-860	-1786	-3894	-6849	-10905
Carbon Prod. Cost[d]	429	903	1889	4947	10257	19799
Revised Moulton and Richards Yields						
Cost/Mg Carbon	17.40	17.59	18.61	35.50	53.66	100.71
Hectares/trees planted	5.9	11.9	24.3	74.9	100.0	125.2
Net Social Benefit	-515	-1067	-2219	-4919	-8686	-14262
Carbon Prod. Cost	552	1117	2363	6620	13522	27254
Birdsey Yields						
Cost/Mg Carbon	18.03	22.43	27.36	56.56	121.72	727.12
Hectares/trees planted	10.3	19.1	37.6	75.8	115.3	157.3
Net Social Benefit	-442	-1086	-2601	-7595	-17902	-312053
Carbon Prod. Cost	572	1424	3475	14365	46372	369319

[a] dollars
[b] million hectares
[c] million dollars
[d] in dollars

TABLE 2. Effects of Carbon Sequestration - with Harvest Possible with Harvest Losses, No Farm Program

	Total Carbon Sequestered (Million Mg carbon/yr.)					
	39	77	154	308	463	617
Adams et al Yields						
Cost/Mg[a]	6.99	10.75	14.83	19.43	27.07	40.04
Hectares/trees planted[b]	6.8	13.8	26.0	47.0	69.6	90.6
Net Social Benefit[c]	-129	-413	-1296	-3386	-6426	-10620
Carbon Prod. Cost[d]	222	683	1883	4933	10313	20338
Revised Moulton and Richards Yields						
Cost/Mg	10.67	15.20	18.58	25.71	36.88	55.42
Hectares of Trees	7.01	14.12	27.60	51.51	77.19	101.72
Net Social Benefit	-194	-629	-1749	-4459	-8293	-14070
Carbon Prod. Cost	339	966	2359	6529	14047	28151
Birdsey Yields						
Cost/Mg	12.77	22.44	27.99	56.28	121.72	--[e]
Hectares of Trees	12.3	22.7	40.5	77.2	115.2	--
Net Social Benefit	-230	-798	-2317	-7473	-17872	--
Carbon Prod. Cost	405	1425	3541	14293	46369	--

[a] dollars

[b] million hectares

[c] million dollars

[d] in dollars

[e] This solution is infeasible.

TABLE 3. Timber Effects (million m^3) - Optional Harvests, High Harvest Losses, No Farm Program

	Total Carbon Sequestration (million Mg carbon/yr.)						
	0	39	77	154	308	463	617
Adams et al Yields							
Commercial Harvest[a]	177	156	139	128	132	129	144
Agricultural Harvest[a]	0	55	97	131	119	128	82
Total Harvest[a]	177	211	236	259	251	257	226
Sawtimber Price[b]	18,204	14,977	10,395	7,737	8,918	8,355	11,806
Pulp Price[b]	6,024	4,628	4,588	4,588	4,588	4,588	4,588
Moulton & Richards Yields							
Commercial Harvest	177	151	135	126	131	137	144
Agricultural Harvest	0	67	109	139	120	101	83
Total Harvest	177	218	244	265	251	238	227
Sawtimber Price	18,204	13,726	9,612	7,455	9,076	10,675	12,137
Pulp Price	6,024	4,588	4,588	4,588	4,588	4,588	4,588
Birdsey Yields							
Commercial Harvest	177	159	140	144	152	177	177
Agricultural Harvest	0	48	93	83	63	0	0
Total Harvest	177	207	233	227	215	177	177
Sawtimber Price	18,204	15,348	10,662	11,831	14,077	18,202	18,204
Pulp Price	6,024	4,712	4,588	4,588	4,628	6,024	6,024

[a] million cubic meters

[b] $ per 1000 cubic meter

TABLE 4. Changes due to Carbon Sequestration- No Harvesting, No Harvest Losses Under Farm Program

	Total Carbon Sequestered (million Mg carbon/yr.)			
	39	77	154	308
Revised Moulton and Richards Yields				
Cost of Carbon/Mg	17.38	17.38	19.75	25.96
Hectares	6.2	13.0	26.1	49.5
Change in Net Social Benefits[a]	-497	-1036	-2086	-3835
Carbon Prod. Cost	552	1103	2508	6595
Gov. Farm Pymts.	8234	8222	8108	7067
Total Pymts.	8786	9325	10616	13662
Birdsey Yields				
Cost of Carbon/Mg	19.39	21.73	29.81	63.53
Hectares	10.4	20.0	38.1	75.7
Change in Net Social Benefits[a]	-451	-1102	-2400	-4106
Carbon Prod. Cost	616	1380	3785	14453
Gov. Farm Pymts	8171	8141	7891	4502
Total Pymts.	8787	9521	11676	18955

[a] Welfare change is measured in relation to estimated welfare under current farm programs.
Note the units are as defined in Table 2