16 An Economy-wide Assessment of a Forest Carbon Policy in the USA*

Grace Y. Wong,[1] Janaki R.R. Alavalapati[1] and Robert J. Moulton[2]
[1]School of Forest Resources and Conservation, PO Box 110410, University of Florida, Gainesville, FL 32611–0410, USA; [2]USDA Forest Service, Washington Office Staff, Southern Research Station, PO Box 12254, 3041 Cornwallis Road, Research Triangle Park, NC 27709, USA (retired)

Introduction

There is now a general consensus that the Earth's climate is changing as a result of the rising concentration of greenhouse gases in the atmosphere. Using the range of emission scenarios determined by the Intergovernmental Panel for Climate Change (IPCC), General Circulation Models (GCMs) have projected global warming of between 1 and 5°C by 2100 (IPPC, 2000). The United Nations Framework Convention for Climate Change (UNFCCC) was established to express this concern, and under the 1997 Kyoto Protocol, set forth binding targets for developed countries to reduce their emissions of greenhouse gases to an average of 5.2% below the amount they emitted in 1990 by 2012.

Forests play a prominent role in the global carbon cycle by absorbing atmospheric CO_2 (carbon dioxide), a greenhouse gas, through photosynthesis and storing carbon in the form of biomass and soils. Land-use change accounts for about one-third of total anthropogenic CO_2 emissions through forest clearing and timber harvesting activities, and fossil fuel consumption accounts for the remaining two-thirds (IPPC, 2000). The Kyoto Protocol specifically recognizes that terrestrial sources and sinks of carbon attributable to afforestation, reforestation and deforestation activities are to be counted in achieving these emission reductions. This recognition has come under considerable criticism (see Schlamadinger and Marland (2000) for a review of the critical issues and country positions), and is a key divisive issue throughout the negotiating process towards implementing the Protocol.

It is perhaps not surprising that nations with large forest areas (and significant forest carbon opportunities), such as the USA and Canada, strongly support the inclusion of forestry activities as a means to achieve their Kyoto Protocol emission reduction targets (Moulton, 1998). In contrast, nations in the tropics who are drawing down their forests due to social and economic pressures, and nations with limited land areas available for forestry, such as Japan and most European Union (EU) nations, tend to oppose the inclusion and/or would limit the extent to which forestry activities can be used to offset fossil fuel emissions.

* Funding for this study was provided by the USDA Forest Service Southern Research Station under Project UPN 99051401.

Objective

Given the number of contentious issues surrounding the use of forests as a strategy to mitigate CO_2 emissions, a consequence of interest to policy makers is the potential distributional and economy-wide impacts. Tree plantations to sequester carbon could be established by direct government intervention, through the use of a forest subsidy paid to the landowner to grow trees, or by providing credits based on the amount of carbon sequestered by a forest. Both approaches have the potential to dramatically change the current land-use base in the forest sector. Forest subsidies are likely to affect industrial forest planting decisions, and credit payments for carbon sequestered could influence investment, forest management decisions, rotation lengths (van Kooten *et al.*, 1995; Solberg, 1997; Stainback and Alavalapati, 1999) and land prices.

This study does not examine the exact incentive system used to establish the carbon plantations. It is assumed that carbon plantations would be established in accordance with their financial potential as industrial timber enterprises. An example would be if the government simply used tax monies to undertake forest plantation projects, or subsidized private entities to establish carbon forests on lands not already established in commercial forests. Given that land is a fixed resource, such a policy could induce significant changes in land-use, land cover and intensity of land management.

Of particular interest are the impacts of such a policy on the forestry and agriculture sectors. Both sectors generally compete for the same fixed land base, which in addition, is also increasingly pressured by demands such as urban sprawl and other development uses. The USDA's Natural Resource Inventory estimated that 0.89 million ha of rural land were developed each year between 1992 and 1997, with forestland being the largest source (USDA PNW, 2001). This chapter's primary objective is to examine the economy-wide implications of a forest carbon policy, focusing on trade-offs between the forestry and agriculture sectors, and examining the effects on land-use reallocation, commodity prices and output.

Recent research in the area of climate change and forestry has largely focused on assessing the economic impacts to the forest sector and timber markets. Several of the methodologies include the Forest and Agricultural Sector Optimization Model (FASOM) (Adams *et al.*, 1996), the Cintrafor Global Trade Model (CGTM) (Perez-Garcia *et al.*, 1997) and the Dynamic Timber Supply Model (DTSM) (Sohngen and Mendelsohn, 1998). FASOM examines the interactions between the forest and agriculture sectors but is limited in that it only covers the USA. Both CGTM and DTSM are single-sector analyses with global coverage, and DTSM has the added advantage for monitoring timber inventories by virtue of its optimal control framework.

Here, we use a dynamic version of Darwin *et al.*'s (1996) Future Agricultural Resources Model (FARM) to examine the interactions between newly created carbon plantations and other land uses in the USA. The impacts of a forest carbon policy are not limited to the forest sector. In a national economy, the producing sectors are linked through markets in their purchase of production factors (capital, labour and inputs) and sale of finished goods to households. The major advantage of FARM's computable general equilibrium (CGE) framework is that it accounts for linkages between different sectors within an economy, and trade linkages between countries. Hence, the CGE framework is ideal for examining economy-wide impacts as changes in prices (or other market conditions) can be translated into changes in aggregate well-being of consumers and producers in order to understand distributional consequences.

There is one major limitation of the current model, however. In its current state, FARM's CGE framework does not contain forest growth dynamics. As such, timber supply is interpreted as a steady-state output period by period, and details on carbon stored in forest stocks are unavailable. This is the major effort to be undertaken in the next step towards an integrated model (elaborated in the Conclusions).

Modelling Framework

The Future Agricultural Resources Model (FARM) was originally developed at the USDA's Economic Research Service (ERS) to evaluate the impacts of global climate change on the world's agricultural system (Darwin *et al.*, 1996). FARM links a computable general equilibrium (CGE) model with a geographical information system (GIS) to allow one to study the impact of various phenomena on natural resource factors and sectors within a dynamic global framework, taking into account the interaction between economic activities and ecological effects (illustrated in Fig. 16.1). In this chapter, we use a dynamic version of FARM, developed by Ianchovichina (2000). Dynamic FARM[1] retains the environmental and climate characteristics of the original model, but is enriched with asset ownership and investment theory to enable longer-term projections (Ianchovichina and McDougall, 2000).

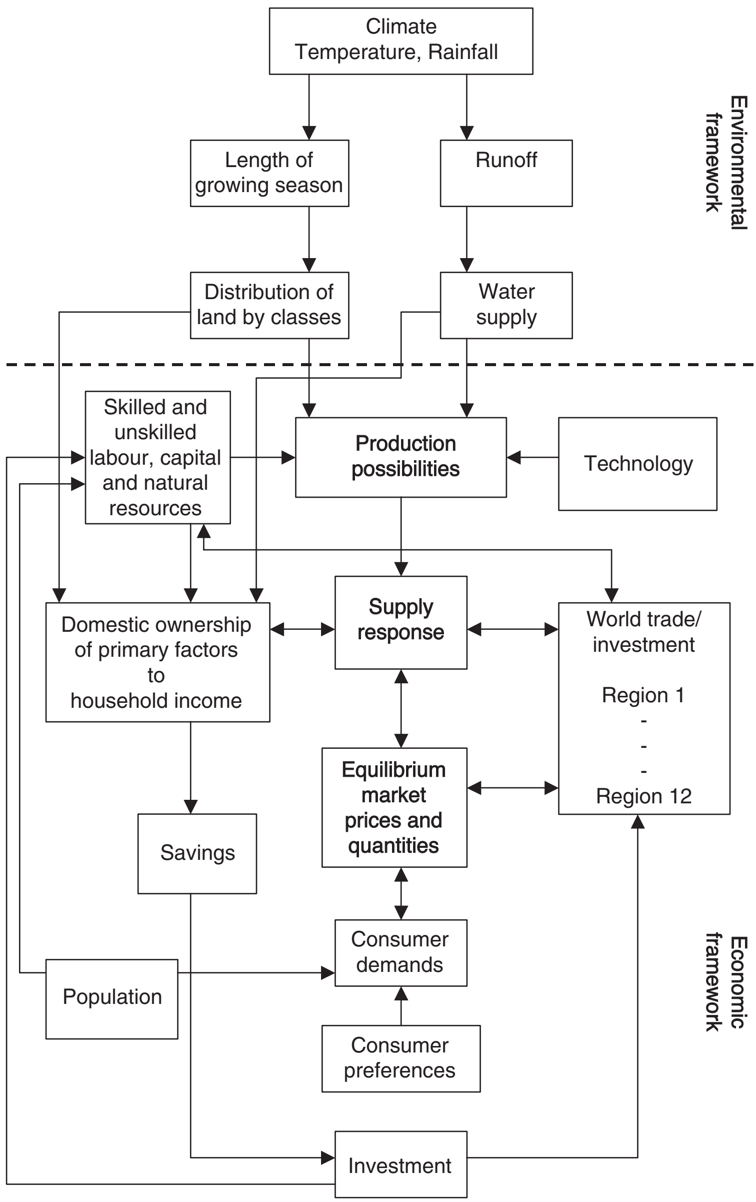

Fig. 16.1. FARM Framework.

Environmental framework

Climate is the dominant factor in FARM's environmental framework. The GIS component links climate with production possibilities in each region (Darwin *et al.*, 1996), featuring water supply and heterogenous land endowments as production inputs, and capturing productivity differences among land resources. These broad differences in land productivity are obtained by differentiating each region's land into six classes based on climate characteristics and length of growing seasons.[2] Table 16.1 presents some features of the land classes and the percentage distribution of the six land classes in the USA.

Land class differences in primary productivity are also revealed by the distribution of Olson's world ecosystem complexes across the six land classes, as shown in Table 16.2. In general, ecosystem productivity is correlated with the length of the growing season. Land Class (LC) 1 occurs where cold temperatures limit growing seasons – mainly polar and alpine areas such as the Arctic Circle, and is composed of polar deserts, semi-desert tundra, northern taiga and conifer forest. LC 2 has a similar growing season to LC 1 but is limited by low rainfall rather than low temperatures, and consists of mostly grass–shrub–herb complexes and desert. Conifer forests, crops and settlements, and mixed forests are prevalent in LC 3, which comprises 13% of the global land area. LC 4 has a growing season of between 166 and 250 days and is composed of crops and settlements, savannas, broad-leaved forests and mangroves. LC 5 is only 7.7% of global land area, and is largely broad-leaved forests and savannas. LC 6 accounts for 20% of all land and has a year round growing season. It is predominantly tropical forests, crops and settlements, and mangroves. LC 5 and 6 are mostly located in Africa, Latin America and Asia.

This structure can also be used to capture climate change effects by allowing land to shift from one land class productivity to another based on changes in length of growing season at that locale (primarily determined by regional rainfall, water runoff and soil temperatures).

Economic framework

The economic framework in FARM is a CGE model that simulates interactions between producers and consumers (both domestic and foreign) and thus accounts for all responses by economic agents under various scenarios. This model retains all the features of the Global Trade Analysis Project (GTAP) model (Hertel, 1997) and dynamic GTAP (Ianchovichina and McDougall, 2000). These include a perfectly competitive market structure, a constant returns to scale technology, the Armington international trade flow determination, a constant difference of elasticities (CDE) consumer demand representation, and the

Table 16.1. Land class boundaries in the FARM model.

Land class	Length of growing season (days)	Principal crops and cropping patterns	Sample regions	% of USA total land area (sample area)
1	0–100[a]	Sparse forage for rough grazing	Greenland	13.14 (Northern Alaska)
2	0–100[b]	Millets, pulses, sparse forage for rough grazing	Sahara Desert	32.83 (Mojave Desert)
3	101–165	Short season grains, forage, one crop per year	Southern Manitoba	12.68 (Western Nebraska)
4	166–250	Maize, some double cropping possible	Northern European community	21.69 (Corn belt)
5	251–300	Cotton, rice, double cropping common	Zambia, Northern Thailand	7.52 (Tennessee)
6	301–365	Rubber, sugar cane, double cropping common	Indonesia, much of the tropics	12.14 (Florida)

Source: Darwin *et al.* (1996).
[a]125 days or less where soil temperatures are above 5°C; [b]more than 125 days where soil temperatures are above 5°C.

investment theory. Producer behaviour in the model is driven by profit maximization, assuming competitive markets.

The CGE framework consists of 12 regions, 18 commodities and 11 sectors (see Table 16.3 for the regional and commodity aggregation). All sectors, except for the crop sector, produce one commodity. The crop sector is multi-output, producing eight different agricultural commodities. All regions produce, consume and trade the 18 commodities. The primary factor endowments of land, water, labour and capital are determined exogenously and are region-specific; that is, one region's primary factors cannot be used in another region. Water, labour and capital are homogeneous and perfectly mobile across all economic sectors within a region. Each factor has a regional price. Regional supplies of the factors are perfectly inelastic. Water is supplied to the crops, livestock, forestry and services sectors. Land, labour and capital are supplied to all sectors. Regional demands for the primary factor endowments are sums of sectoral demands for the produced goods, and are downward-sloping.

Land productivity differences are generated in two ways: (i) based on length of growing season (as elaborated in the previous section), and (ii) by assuming that land supplies are derived from constant elasticity of transformation (CET) functions.[3] The latter captures competition for land among sectors in the economy, by allowing for a structure of differing land rents based on its use, and allowing land to shift between sectors in response to changing economic conditions while still maintaining the productivity differences inherent in the land class. Figure 16.2 illustrates the supply of land in the model.

Each land class supplies to the 11 commodity producing sectors. Eight of these sectors are in manufacturing and services. The crop, livestock and forestry sectors are segregated into sub-sectors which use only its specific land type. For example, land class (LC) 1 supplies to the crop sector 1, livestock sector 1 and forestry sector 1, and to the other eight sectors. This way, the manufacturing and services sectors use all six land classes but the crop, livestock and forestry sub-sectors use only the one corresponding land class. Just as the land classes are associated with distinct ecosystem mixes, they are similarly associated with distinct land-use and product mixes. For example, cropland is relatively rare on LC 1 (northern Alaska), but relatively common on LC 4 (the USA Corn Belt). LCs 1 and 3 (high latitude areas) and LC 6 (tropics) contain the

Table 16.2. Olson's world ecosystem complexes, by land class.

	% dominant cover by land class					
Ecosystem	1	2	3	4	5	6
Polar desert	100.0	0.0	0.0	0.0	0.0	0.0
Ice	99.8	0.0	0.2	0.0	0.0	0.0
Northern taiga	88.8	0.6	10.4	0.3	0.0	0.0
Wooded tundra – heath	82.6	2.0	8.6	4.2	1.3	1.2
Semi-desert – tundra	44.3	51.4	3.1	0.6	0.1	0.5
Deserts	5.0	91.8	2.0	0.8	0.2	0.2
Scrub – woods	0.5	66.5	12.7	10.1	8.0	2.2
Shrub – tree	1.3	48.3	13.5	17.5	11.4	8.0
Grass – shrub – herb	8.5	54.1	9.2	7.3	5.7	15.3
Conifer forest	42.4	8.2	43.1	4.0	0.2	2.2
Conifer rainforest	22.6	3.2	52.7	21.5	0.0	0.0
Mixed forest	15.6	8.9	39.6	13.6	8.6	13.7
Wetlands	11.8	16.9	26.8	7.5	5.9	31.0
Crop – settlement	1.3	20.7	15.9	25.4	14.6	22.1
Forest/field	0.9	12.4	26.2	20.5	11.1	28.8
Field/woods – savanna	0.7	14.9	11.8	22.0	15.1	35.5
Broad-leaved forest	1.1	9.2	14.9	24.2	28.8	21.7
Mangrove	0.0	0.0	9.5	35.3	12.9	42.4
Tropical forest	0.3	0.7	1.0	4.0	9.2	84.8

Source: Darwin *et al.* (1995), Olson (1989–1991).

Table 16.3. Regions, sectors and commodities in dynamic FARM.

Regional aggregation	Commodity aggregation
1. USA	1. PDR – Paddy rice
2. CAN – Canada	2. WHT – Wheat
3. ANZ – Australia and New Zealand	3. GRO – Other grains
4. JPN – Japan	4. VF – Vegetables, fruits, nuts
5. OEA – Other East Asia: Korea, China, Hong Kong, Taiwan	5. OSD – Oilseeds 6. CB – Sugar cane and sugar beet
6. SEA – Southeast Asia: Indonesia, Malaysia, Philippines, Thailand, Singapore	7. PFB – Plant-based fibres 8. OCR – Other crops
7. EU – European Union	9. LIV – Livestock
8. FSU – Former Soviet Union	10. FOR – Forestry
9. OEU – Other Europe	11. COG – Coal, oil and gas
10. LAM – Latin America	12. MIN – Other minerals
11. AFR – Africa	13. FMM – Fish, meat and milk
12. ROW – Rest of World	14. OPF – Other processed foods
Endowments	15. TCF – Textiles, clothing and footwear
1 – 6. Land (six classes)	16. NMM – Other non-metallic manufacturing
7. Water	17. OMN – Other metallic manufacturing
8. Skilled labour	18. SRV – Services and utilities (electricity, gas, water, construction, trade and transport, other services)
9. Unskilled labour	
10. Capital	
11. Natural resource factor	

Note: Commodities 1–8 are collectively known as the crop sector.

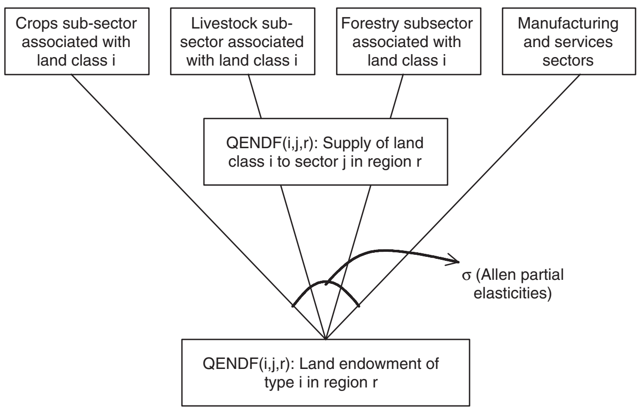

Fig. 16.2. Supply of land in dynamic FARM.

largest proportions of forest land. The mix of possible agricultural commodities in a land class is limited by its growing season and water availability.

A commodity is produced from a composite input obtained by combining primary factors with composite intermediary inputs in fixed proportions (the Leontief technology). The composite primary factor is derived from a constant elasticity of substitution (CES) cost function with Allen partial elasticities. The composite intermediate input consists of 18 possible commodity inputs, either domestic or imported. Each of the 18 composite commodity inputs are derived from nested CES cost functions – one for determining the amount to be imported from each region and another for choosing the import–domestic mix in the composite intermediate product. The Allen partial elasticities of substitution used for these CES functions are obtained from the GTAP version 4E database (McDougall *et al.*, 1998).

The data

The economic data are from the GTAP version 4E database (McDougall *et al.*, 1998) and are aggregated into 12 regions, 18 tradeable commodities and 11 sectors (as indicated in Table 16.3). Allen partial elasticities for primary factors, imported intermediates and the price and income elasticities for private consumption in dynamic FARM are also inherited from GTAP (Hertel, 1997; Ianchochivina, 2000). Since there are few estimates of Allen partial elasticities of substitution for crop supplies, their values are set to −1. This reduces the CET functions to Cobb-Douglas, meaning that the revenue shares received for wheat, other grains, and non-grains by crop producers within a region are constant, but not equal, across all levels of revenue (Darwin *et al.*, 1996).

The Base Case and Policy Scenario

The first step is to develop and run the base case for 20 years into the future. A calibrated equilibrium database for the year 2000 (Ianchochivina, 2000) serves as a starting point for base case projections to the future. In order to capture the effects of a carbon policy on land-use reallocation, a base case scenario is developed to trace the growth of the world economy till 2020. The baseline utilizes estimates of annual growth rates in regional population, skilled and unskilled labour, gross domestic product (GDP), and gross domestic investment (GDI). These estimates (listed in Table 16.4) are based on a review of the literature and include most recent estimates of population growth (UN Population Division, 2001) and GDP projections (World Bank, 2001). It should be noted that the base case scenario developed here is very general; it only considers standard macro-aggregates and does not provide alternative optimistic or pessimistic growth scenarios.

The alternate policy scenario involves endogenous creation of 50 million ha of carbon plantations in North America and Europe.[4] The simulation assumes that plantations are created at an even rate throughout the first 10 years. Following Dixon *et al.* (1994a,b), these scenarios are well within the estimates of land considered to be technically suitable for establishing forest systems (see Table 16.5). Timber is expected to be harvested from the carbon plantations on a financially optimal rotation and sold on the global timber market, but these impacts are not adequately captured by this model. Since there are no forest growth dynamics

Table 16.4. Base case macroeconomic scenario, 2000–2020 (average annual percentages).

Region	Population growth[a]	Labour force[b]	Unskilled[c]	Skilled[c]	GDP[b]	GDI[c]
ANZ	0.87	0.8	1.10	0.93	2.9	4.5
CAN	0.66	0.6	0.97	0.98	2.9	3.3
USA	0.66	0.9	0.97	0.98	3.3	1.7
JPN	–0.02	–0.3	–0.12	–0.62	2.2	2.0
OEA	0.78	1.1	0.58	3.25	6.3	7.3
SEA	0.78	1.1	1.44	6.21	5.9	6.6
EU	–0.37	0.0	–0.24	–0.04	3.0	3.2
FSU	1.03	0.5	0.74	0.89	4.2	7.0
OEU	–0.37	0.5	0.09	0.25	3.2	4.9
OAS	1.03	2.1	2.44	5.12	3.6	5.0
LAM	0.88	2.0	1.33	5.54	4.3	5.4
AFR	1.85	2.5	2.77	3.20	3.6	6.1

[a]UN Population Division (2001), [b]World Bank (2001), [c]Walmsley *et al.* (2000).

Table 16.5. Estimate of land technically suitable for establishing forest systems, when considering edaphic and climatic factors (10^6 ha).

Africa	S. Asia	S. America	N. America	Former Soviet Union	Global
300–440	130–225	65–380	90–140	>100	1600

Source: Dixon *et al.* (1993, 1994b).

in the model, we assume the policy shocks to take effect immediately and timber harvests are interpreted as steady-state output in each period.

Model run descriptions

Baseline scenario

No carbon plantations. Refer to Table 16.4 for details on the baseline projections.

Policy shock

The establishment of carbon plantations in temperate regions over first 10 years, 2000–2010 (50 million ha total)

USA Pacific Northwest: 1 million ha
USA South: 30 million ha
Canada Temperate: 5 million ha
EU Nordic: 2 million ha
Former USSR: 6 million ha
Other Europe: 6 million ha

Results

Given our assumptions of the global economic and population growth, as reflected in the macroeconomic projections in the base case, the base case scenario predicts a small decrease in all croplands (–0.13%) and an increase (+2.75%) in grazeland or livestock pastures in the USA by the year 2020.[5,6] Forestland decreases slightly over all land classes, with the largest decline in LC 5 (–7.97%) and LC 6 (–7.86%).[7] Figure 16.3 illustrates this trend for the farm (crops and livestock) and forest sectors. Land-use trends are mixed in the non-farm sectors. Land shrunk in the food processing, textile and non-metallic manufacturing sectors, but expanded in the mineral and metallic manufacturing sectors. The largest land-use expansion is projected for the coal, oil and gas industry, from 9.62% in LC 2 to 24.32% in LC 4.

In addition, there does not appear to be any shortage of food crops over the next two decades. The aggregate price of food crops is expected to decline about 10% relative to savings,[8] the numeraire in the model, while aggregate crop output increases by almost 23% over the next 20 years (Table 16.6). In a similar trend, forest products are estimated to increase by 24% in output, while prices decline by 11%. The results also suggest an intensified use of capital in the farm sectors (Table 16.7). The demand for capital increases by almost 68% in the base case, while demand for other primary factors (land, water and labour) only increases by approximately 3%.

The one commodity that appears likely to experience shortage is fossil fuels. The price for coal, oil and gas is estimated to shoot 87% beyond its current price by 2020, while total output is only expected to increase by 18%. The model does not have a structure for fuel or energy substitution and, hence, projects a future economy whose growth is primarily dependent on the continued use of fossil fuels.

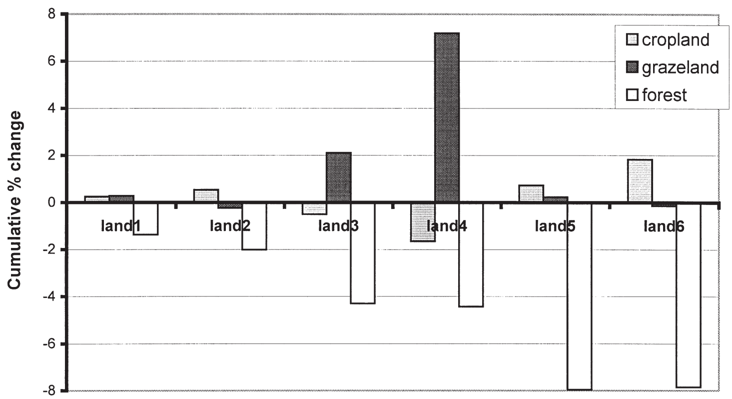

Fig. 16.3. Quantity of land demanded by the Crops, Livestock and Forest sectors in USA, cumulative % changes in base case scenario, 2020.

Table 16.6. USA prices and production by commodity, cumulative % changes in 2020.

	Base case scenario		Change from base case due to policy shock	
Commodity	Price	Output	Price	Output
Pdr – Paddy rice	–10.23	23.10	–0.87	0.23
Wht – Wheat	–7.06	27.16	–0.08	0.31
Gro – Other grains	–12.65	17.65	–0.25	0.22
v_f – Vegetables, fruits, nuts	–11.04	21.11	–0.33	0.22
Osd – Oilseeds	–10.03	22.68	–0.40	0.29
c_b – Sugar cane and beet	–13.02	18.58	–0.62	0.38
Pfb – Plant-based fibres	–4.30	35.35	–0.29	0.27
Ocr – Other crops	–7.85	26.71	–0.45	0.58
Liv – Livestock	–11.27	14.64	–0.18	0.10
For – Forestry	–11.25	24.33	–3.14	1.77
Cog – Coal, oil and gas	87.42	18.26	0.26	0.01
Min – Other minerals	–3.53	30.74	–0.00	0.02
Fmm – Fish, meat and milk	–10.91	9.58	–0.11	0.06
Opf – Other processed foods	–9.22	7.43	–0.06	0.04
Tcf – Textiles and clothing	–9.14	18.67	–0.04	0.02
Nmm – Other non-metallic mnf	4.44	13.68	0.00	0.02
Omn – Other manufacture	–10.58	51.48	–0.02	–0.01
Srv – Services	–11.88	8.66	–0.02	–0.01

Table 16.7. Use of primary factors by the farm sectors[a] in the USA, cumulative % changes in 2020.

	Base case scenario	Change from base case due to carbon plantations
Land	0.49	0.49
Water	3.47	–0.41
Unskilled labour	2.85	0.01
Skilled labour	2.87	0.01
Capital	67.63	0.02
Crop output (sum of all eight crop commodities)	22.61	0.29

[a]The farm sector comprises both the crops and livestock sectors.

Carbon policy impacts

To assess the impacts of establishing 31 million ha of carbon plantations in the USA, we exogenously increased the supply of land in LCs 3, 5 and 6 to the forest sector at a constant annual rate over the first 10 years of the model horizon. Thus, a comparison of the base case results with the policy simulation reveals the possible effects of the forest carbon policy.

As expected, the policy shock induces some small shifts in land re-allocation among the crop, livestock and forest sectors from the base case due to the fixed land base (see Fig. 16.4). Given that our base case had predicted rather sizeable decreases in forestland over all land classes (see Fig. 16.3), the policy to establish carbon plantations merely reclaims some of these areas back to forests. A leakage effect is observed; although the total area of forests increased, forestland shrinks in the other land classes by approximately 2.15 million ha where no policy shock was imposed. This is considered as a trade-off effect from the policy shock, as the expected influx in supply of timber from carbon plantations drives down prices and forestland rents, leading to a shift to other land uses. In aggregate, crop and grazelands increase by less than 0.5%, and the prices for farmland decline slightly (–1.90%).

The policy scenario has a mixed impact on commodity prices and outputs. As expected, the expansion of forests induces a small increase (+1.77%) in output and a decline in price (–3.14%) for forest products relative to the base case. A similar trend of higher output and lower prices is also projected for all the crop commodities (columns 3 and 4, Table 16.6). In general, crop output expands slightly (+0.29% overall) as crop

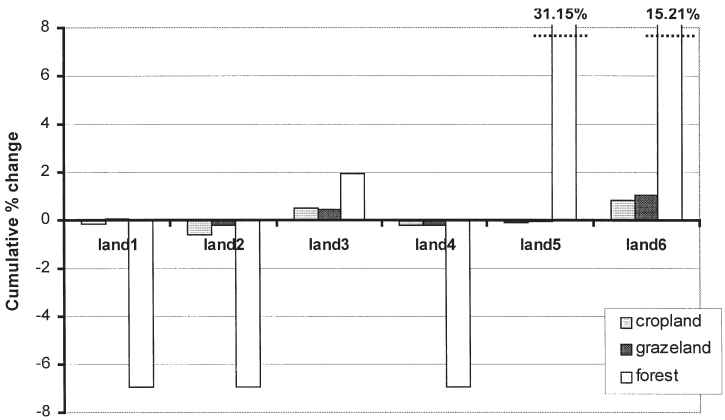

Fig. 16.4. Land use in the Crops, Livestock and Forest Sectors in USA, cumulative % changes from base case as a result of carbon plantations, 2020. The peaks for the forest sector in land classes 3, 5 and 6 are a result of an exogenous increase of 31 million ha of carbon plantations.

Table 16.8. Select welfare variables for the USA, cumulative % changes as a result of carbon plantations, 2020.

Variables	Cumulative % change from base case
Farmland income (land rent)	–1.41
Primary factor income from farm and forest sectors	–0.91
Household income	–0.03
Average wages	–0.04
Per capita household utility	–0.01
GNP	–0.01
Trade balance (US$ millions)	1807.50
Aggregate welfare effect (US$ millions)	–518.94

production continues to intensify, as suggested by the increased use of primary factors by the farm sectors (Table 16.7). Land base for the farm sectors increases slightly relative to the base case (but is allocated across different land classes), and more labour (both skilled and unskilled) and capital were employed in farm production. Use of water resources declines slightly (–0.41%), but that is probably a feature of the different mix of land class acreage from the base case.

The manufacturing and services sector continue to expand as well, possibly fuelled by the increased supply of food crops and forest products. Output from the food processing sectors increased between 0.04–0.06%, while their prices decreased between 0.06–0.11% (columns 3 and 4, Table 16.6). Land-use in these sectors increases between 0.20–1.70% from the base case scenario. A modest increase in output from the energy sectors (coal, oil and gas, and other minerals) is observed, and the price for coal, oil and gas continues its upward trend by 0.26%. In general the policy shock has a small but negative effect on the national economy (Table 16.8) relative to the base case. Household income decreased by 0.03%, average wages by 0.04%, and the aggregate welfare effect was estimated to be US$518.94 million lower. The forest and farm owners are made worse off as farmland income (farmland rents) and primary factor income for the farm and forest sectors decline by 1.41 and 0.91%, respectively.

Conclusions and Directions for Future Research

This study uses a dynamic computable general equilibrium model to examine the trade-offs between the forestry and agricultural sectors in the USA with the scenario of establishing carbon plantations as a CO_2 mitigation strategy. Results of our policy scenario indicate that carbon plantations will lead to a slight redistribution of land to the agricultural and livestock sectors in different areas of the USA, but these effects are not expected to have a significant impact on output from these sectors within the 20 year projection period. Food security remains stable, and the manufacturing and services sectors maintain a positive growth. The policy scenario is likely to have a small adverse impact on both consumer and national economic welfare in the USA, with the latter largely driven by changes in terms of trade. Thus, the question that could be posed is this: Is this loss of welfare an acceptable price to pay for averting or delaying the global impacts of climate change?

In order to be able to discern the true impacts of carbon plantations on the forest sector and on terrestrial carbon storage, the current modelling framework will have to improve on both its economic and ecological elements. In particular, our immediate research plan is to enhance the forest sector in the CGE framework with details on forest growth dynamics so that we can estimate future timber supply and prices more accurately. Such a structure would allow us to determine the direct implication of an economic incentive on changes in harvests, management and trade, and the fluxes of carbon arising from such changes. This is crucial information for estimating cumulative gains (or losses) in forest carbon storage over the long term, and for comparing the efficiency of various carbon policies in sequestering CO_2.

In addition, economic details in the extended framework will link CO_2 emissions to economic activities based on the amounts and types of energy consumed by an industry, and incorporate a substitution structure for energy use so that alternative energy resources (such as biomass) can be used to substitute for the expensive and higher CO_2-emitting fossil fuels. Coupling the energy details with those in the forest sector will provide a more complete picture of CO_2 fluxes in the economy, and allow for more flexible policy scenarios using either price incentives or regulations on CO_2 limits. The ecological aspect in the model could also be expanded to simulate climate change effects on changes in growing seasons and land class distribution. Incorporation of these capabilities and details will lead to more fully integrated economic–ecological analyses.

Endnotes

[1] See Ianchovichina *et al.* (2001) for a recent application with dynamic FARM.

[2] Growing season length is the primary constraint to crop choice and crop productivity within a region, and is defined as the longest continuous period of time in a year that soil temperature and moisture conditions support plant growth (Darwin *et al.*, 1996).

[3] A Cobb-Douglas revenue function is a constant elasticity of transformation (CET) function with Allen partial elasticities equal to −1.0.

[4] This is to maintain consistency with the Kyoto Protocol, where commitments to reduce CO_2 emissions are currently required of the OECD countries only. Sedjo and Sohngen (2000) used a similar scenario in their study of long-term economic impacts in the global timber markets.

[5] The total land area in each land class is fixed. This implies that neither the composition nor availability of total land in the model will change.

[6] Although the base case and policy simulations are on a global scale, results reported in this chapter are those for the USA only.

[7] The percentage changes must be interpreted with care. Readers should keep in mind that the percentages reported for the different sectors are not equal, that is, they are relative to the size of the sector's land base in the economy.

[8] All results depict changes in real, not nominal, prices. All prices in the CGE model are normalized relative to the price of a global savings commodity, the numeraire.

References

Adams, D.M., Alig, R.J., Callaway, J.M., McCarl, B.A. and Winnett, S.M. (1996) *The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Applications*. PNW-RP-495. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Darwin, R., Tsigas, M., Lewandrowski, J. and Raneses, A. (1996) Land use and cover in ecological economics. *Ecological Economics* 17, 157–181.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. and Wisniewski, J. (1993) Carbon pools and flux of global forest ecosystems. *Science* 263, 185–190.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. and Wisniewski, J. (1994a) Carbon pools and flux of global forest ecosystems. *Science* 263, 185–190.

Dixon, R.K., Winjum, J.K., Andrasko, K.J., Lee, J.J. and Schroeder, P.E. (1994b) Integrated land-use systems: assessment of promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration. *Climatic Change* 27, 71–92.

Hertel, T.W. (ed.) (1997) *General Trade Analysis Modeling and Applications*. Cambridge University Press, New York.

Ianchovichina, E. (2000) *Introducing Natural Resource Detail into Dynamic GTAP*. GTAP Technical Paper. Center for Global Trade Analysis Project, Purdue University, West Lafayette, Indiana.

Ianchovichina, E. and McDougall, R. (2000) *Theoretical Structure of Dynamic GTAP*. GTAP Technical Paper No. 17. Center for Global Trade Analysis Project, Purdue University, West Lafayette, Indiana.

Ianchovichina, E., Darwin, R. and Shoemaker, R. (2001) Resource use and technological progress in agriculture: a dynamic general equilibrium analysis. *Ecological Economics* 38, 275–291.

IPPC (2000) Watson, R., Noble, I.R., Berlin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds) *Land Use, Land-Use Change, and Forestry*. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

McDougall, R.A., Elbehri, A. and Truong, T.P. (1998) *Global Trade, Assistance and Protection: The GTAP 4 Data Base*. Center for Global Trade Analysis Project, Purdue University, West Lafayette, Indiana.

Moulton, R.J. (1998) Forestry in U.S. climate change action plans: From the Arch to Kyoto. In: Abt, K.L. and Abt, R.C. (eds) *Proceedings of the 1998 Forest Economics Workshop*. Williamsburg, Virginia, pp. 204–207.

Olson, J.S. (1989–1991) *World Ecosystems (WE1.3) Digital Raster Data on Global Geographic (lat/long) 360 × 720 grid*. NOAA National Geophysical Data Center, Boulder, Colorado.

Perez-Garcia, J., Joyce, L.A., Binkley, C.S. and McGuire, A.D. (1997) Economic impacts of climate change on the global forest sector: an integrated ecological/ economic assessment. *Critical Review in Environmental Science and Technology* 27, s123–s138.

Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (1999) *World Population Prospects: the 2000 Revision*. http://www.un.org/esa/population/wpp2000.htm

Schlamadinger, B. and Marland, G. (2000) *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol*. Pew Center on Global Climate Change, Arlington, Virginia, 54 pp.

Sohngen, B. and Mendelsohn, R. (1998) Valuing the impact of large scale ecological change in a market: the effect of climate change on US timber. *American Economic Review* 88, 686–710.

Sedjo, R. and Sohngen, B. (2000) *Forestry Sequestration of CO_2 and Markets for Timber*. Discussion Paper 00-35. Resources for the Future, Washington, DC, 83 pp.

Solberg, B. (1997) Forest biomass as carbon sink – economic value and forest management/policy implications. *Critical Reviews in Environmental Science and Technology* 27, s323–s333.

Stainback, G.A. and Alavalapati, J.R.R. (1999) The economics of Florida slash pine and carbon sequestration. Southern Forest Economics Workers Annual Conference, April 19–20, 1999, Biloxi, Mississippi.

USDA PNW (2001) Finite land, infinite futures? Sustainable options on a fixed land base. *Science Findings* 31, 1–5.

van Kooten, G.C., Binkley, C.S. and Delcourt, G. (1995) Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services. *American Journal of Agricultural Economics* 77, 365–374.

Walmsley, T.L., Dimaranan, D.V. and McDougall, R.A. (2000) *A Base Case Scenario for the Dynamic GTAP Model*. Paper developed for the 2000 Short Course on Dynamic Model, Center for Global Trade Analysis Project, Purdue University, West Lafayette, Indiana.

World Bank (2001) *Global Economic Prospects and the Developing Countries 2001*. World Bank, Washington, DC.