Analysis

Land use and cover in ecological economics

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Abstract

A basic premise of ecological economics is that the world economy is embedded in and dependent upon Earth's ecosystem. Because land is a basic source of mass and energy throughput in all terrestrial ecosystems, land use and cover represents an integrating element in ecological economics. We have developed a global model that captures this concept. We illustrate this concept's usefulness by showing how global changes in climate, human populations, and international trade policies might affect tropical forests. Results from our scenarios indicate that such changes would likely have adverse effects on the health and integrity of tropical forest ecosystems. Results from our scenarios also indicate that forest depletion in Southeast Asia can be correlated with numerous economic indicators. Whether the correlation with a particular economic variable is positive or negative depends on the global change scenario. This merely reflects the fact that interactions between economic and ecological phenomena are complex. Modeling capabilities can be expanded by adding economic and ecological detail, including more material on throughput, and developing methods for simulating dynamic analyses.

Keywords: Land use and cover; Tropical forest depletion; Global climate change; Population growth; Trade deregulation

1. Introduction

A basic premise of ecological economics is that the world economy is embedded in and dependent upon Earth's ecosystem. This dependence is captured by the concept of 'throughput' (Boulding, 1966) or 'entropic flow' (Georgescu-Roegen, 1971)—the one-way flow of energy and mass through an economy that begins with resources and ends with waste. A number of ways of formulating and using models that embody this concept have been suggested (see, for example, Van den Bergh and Nijkamp, 1991). Construction of models that actually simulate economic-ecological integration, however, has only just begun. We present a model that integrates economic-ecological activities with land use and cover.

Land use and cover can serve as an integrating element for a number of reasons. First, world ecosystem productivity is mainly governed by primary production—the amount of solar energy converted to chemical energy by photosynthesis. For terrestrial ecosystems, the main resource governing primary productivity can be defined in terms of land: that is, for any given level of solar radiation, the principal constraints to terrestrial primary productivity are the area of land available and its soil moisture character-
istics. Second, despite the successful substitution of land-based resources with fossil fuels and mineral resources in human economies since the Industrial Revolution (Mayumi, 1991), land remains the primary source of the energy and mass that compose our food and fiber. This explains why the agriculture and forestry sectors of an economy are land-intensive. Land also remains a primary factor of production in all other economic sectors where it provides mainly space. Third, the most important interaction between humans and other biological communities is the competition for land. Modeling this competition is fundamental to conducting integrated analyses of ecological-economic activities.

We illustrate the usefulness of this approach by showing how global changes in climate, human populations, and international trade policies might affect tropical forests. We focus on tropical forests for a number of reasons. First, tropical forests are an important source of fuel and fiber, providing, for example, approximately one billion cubic meters of industrial roundwood and fuelwood in 1990 (FAO, 1992). Second, because they support a disproportionately large share of the world’s plant and animal species, tropical forests are an important source of biodiversity (Myers, 1988).

Third, human activities threaten these resources. Forest depletion in tropical areas, for example, occurred throughout 1980–1990 (FAO, 1993). Also, because it releases carbon to the atmosphere, tropical forest depletion may contribute to global warming (Houghton et al., 1995). Fourth, depletion of tropical forests has recently been correlated with various economic variables (Kahn and McDonald, 1995; Capistrano and Kiker, 1995). We can compare these results with ours.

Global changes in climate, human populations, and international trade policies also have been subject to much research recently. By altering temperature and precipitation patterns around the world, increasing levels of heat-trapping gases in the Earth’s atmosphere could affect regional and world food systems (Parry et al., 1988; Kane et al., 1991; Rosenzweig and Parry, 1994; Darwin et al., 1995) or the distribution of the major ecosystems (Monserud et al., 1993). However, the economic and ecological effects of climate change are generally estimated independently of one another.

Over the next 30 years, global population is projected to grow from 5.5 to 8.5 billion (Livemash, 1994). Such projections have stimulated a growing but conflicting literature on population growth and land use and cover change (see Meyer and Turner, 1992, for a review). Interest in trade and the environment has been generated by the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) and the North American Free Trade Agreement. This led (among other works) to a special issue of *Ecological Economics* on trade and the environment (Folke et al., 1994). There, Daly and Goodland (1994) point out that increasing gross national product via trade, for any given level of throughput efficiency, will increase throughput and associated stresses on environmental sources and sinks.

Two general points before we proceed. First, the geographic scope of the changes we are investigating requires a global model, but the methodology is not limited to global analysis. It could be employed in a national or regional model when analyzing impacts of localized events or when focusing on local impacts of global events when potential feedback is not an issue. Second, the economic effects of the interactions generated by the changes evaluated here can only be adequately captured by a computable general equilibrium model (CGE)—i.e., a model that captures the major monetary flows in an economy or set of economies. Partial equilibrium models may give misleading descriptions of the economic impacts of exogenous shocks that, like global climate change, affect multiple sectors in a national economy (Kokoski and Smith, 1987) or affect multiple regions in a world economy (Tsiga et al., 1996).

2. Modeling framework

The Future Agricultural Resources Model (FARM) was developed at the U.S. Department of Agriculture’s (USDA) Economic Research Service to evaluate impacts of global climate change on the world’s agricultural system (Darwin et al., 1995).

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3 For a detailed description of the modeling framework, its data, calibration, solution algorithms, and sensitivity, see Darwin et al. (1995).
Fig. 1. FARM modeling framework.
### Table 1
Land class boundaries in the Future Agricultural Resources Model

<table>
<thead>
<tr>
<th>Land class</th>
<th>Length of growing season</th>
<th>Days with soil temperatures above 5°C</th>
<th>Principle crops and cropping patterns</th>
<th>Sample regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 to 100</td>
<td>125 or less</td>
<td>sparse forage for rough grazing</td>
<td>US: northern Alaska</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>World: Greenland</td>
</tr>
<tr>
<td>2</td>
<td>0 to 100</td>
<td>more than 125</td>
<td>millets, pulses, sparse forage for rough grazing</td>
<td>US: Mojave Desert</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>World: Sahara Desert</td>
</tr>
<tr>
<td>3</td>
<td>101 to 165</td>
<td></td>
<td>short-season grains, forage: one crop per year</td>
<td>US: Palouse, western Nebraska</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>World: southern Manitoba</td>
</tr>
<tr>
<td>4</td>
<td>166 to 250</td>
<td></td>
<td>maize: some double cropping possible</td>
<td>US: Corn Belt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>World: northern European Community</td>
</tr>
<tr>
<td>5</td>
<td>251 to 300</td>
<td></td>
<td>cotton, rice: double cropping common</td>
<td>US: Tennessee</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>World: Zambia, nonpeninsular Thailand</td>
</tr>
<tr>
<td>6</td>
<td>301 to 365</td>
<td></td>
<td>rubber, sugar cane: double cropping common</td>
<td>US: Florida and southeast coast</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>World: Indonesia</td>
</tr>
</tbody>
</table>

### Table 2
Current land class endowments, water runoff, water supplies, and elasticities of water supply with respect to runoff, by region

<table>
<thead>
<tr>
<th>Item</th>
<th>Region</th>
<th>United States</th>
<th>Canada</th>
<th>EC</th>
<th>Japan</th>
<th>OEA (^{a})</th>
<th>SEA (^{b})</th>
<th>ANZ (^{c})</th>
<th>Rest-of-world</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land class (million hectares) (^{d})</td>
<td></td>
<td>120.45</td>
<td>504.10</td>
<td>3.10</td>
<td>0.22</td>
<td>225.57</td>
<td>0.00</td>
<td>3.55</td>
<td>1431.10</td>
<td>2270.09</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>300.97</td>
<td>79.11</td>
<td>7.07</td>
<td>0.00</td>
<td>308.40</td>
<td>0.00</td>
<td>506.47</td>
<td>2985.81</td>
<td>4187.82</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>116.21</td>
<td>309.72</td>
<td>33.27</td>
<td>9.62</td>
<td>121.71</td>
<td>1.34</td>
<td>91.13</td>
<td>1014.91</td>
<td>1697.91</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>198.80</td>
<td>29.18</td>
<td>117.63</td>
<td>18.62</td>
<td>87.56</td>
<td>4.36</td>
<td>91.48</td>
<td>785.08</td>
<td>1332.71</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>68.96</td>
<td>0.00</td>
<td>45.07</td>
<td>7.64</td>
<td>69.31</td>
<td>39.80</td>
<td>29.04</td>
<td>748.14</td>
<td>1007.95</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>111.26</td>
<td>0.00</td>
<td>16.69</td>
<td>1.54</td>
<td>130.07</td>
<td>249.48</td>
<td>69.58</td>
<td>2003.79</td>
<td>2582.42</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>916.66</td>
<td>922.10</td>
<td>222.82</td>
<td>37.65</td>
<td>942.61</td>
<td>294.98</td>
<td>791.24</td>
<td>8930.83</td>
<td>13078.89</td>
</tr>
<tr>
<td>Water runoff (km(^3)) (^{e})</td>
<td></td>
<td>2.478</td>
<td>2.901</td>
<td>818</td>
<td>547</td>
<td>2863</td>
<td>3420</td>
<td>740</td>
<td>26940</td>
<td>40707</td>
</tr>
<tr>
<td>Water supply (km(^3)) (^{e})</td>
<td></td>
<td>467</td>
<td>42</td>
<td>254</td>
<td>108</td>
<td>471</td>
<td>88</td>
<td>19</td>
<td>1791</td>
<td>3240</td>
</tr>
<tr>
<td>Elasticity (unitless) (^{f})</td>
<td></td>
<td>0.469</td>
<td>0.448</td>
<td>0.342</td>
<td>0.426</td>
<td>0.412</td>
<td>0.279</td>
<td>0.341</td>
<td>n/a (g)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

\(^{a}\) Other East Asia (China, including Taiwan; Hong Kong; and South Korea).

\(^{b}\) Southeast Asia (Thailand, Indonesia, Philippines, Malaysia, and Singapore).

\(^{c}\) Australia and New Zealand.

\(^{d}\) Growing season lengths for land classes are as follows: (1) less than 100 days and cold; (2) less than 100 days and dry; (3) 101 to 165 days; (4) 166 to 250 days; (5) 251 to 300 days; (6) more than 300 days.

\(^{e}\) Source: WRI (1990).

\(^{f}\) Estimated from regression analysis.

\(^{g}\) Elasticities of Rest-of-world include those for the former USSR (0.453), Europe outside the European Community (0.299), Western and Southern Asia (0.324), Latin America (0.318), and Africa (0.223).
Land Class (length of growing season)

- LC 1 (0-100 days and cold)
- LC 2 (0-100 days and dry)
- LC 3 (101-165 days)
- LC 4 (166-250 days)
- LC 5 (251-300 days)
- LC 6 (301-365 days)

Fig. 2. Land classes under current climate.

FARM is composed of a geographic information system (GIS) and a CGE economic model. The GIS links climate variables with land and water resources in FARM's environmental framework. In FARM's economic framework, the CGE model links land, water, and other primary factors with production, trade, and consumption of 13 commodities in eight regions. An overview of the whole framework is depicted in Fig. 1.

2.1. Environmental framework

FARM's environmental framework is dominated by climate. Broad differences in land productivity are obtained by dividing each region's land into classes based on length of growing season, a measure highly correlated with primary production. Length of growing season is defined as the longest continuous period of time in a year that soil temperature and moisture conditions support plant growth. Growing season lengths were computed from monthly temperature and precipitation data (Lemans and Cramer, 1991) using the method of Newhall (1980) and provided to FARM's GIS by the World Soil Resources Office of USDA's Natural Resources Conservation Service. The land classes are described in Table 1. Information on the location of land classes is presented in Table 2 and Fig. 2.

Land Classes (LC's) 1 and 2 have growing seasons of 100 days or less. LC 1 occurs where cold temperatures limit growing seasons—mainly polar and alpine areas. High latitude regions (such as Canada and the former Soviet Union) contain 79.3 percent of the world's stock of LC 1. LC 2 occurs where growing seasons are limited by low precipitation levels. Africa and Asia contain 56.6 percent of the world's stock of LC 2. Australia and the Former Soviet Union contain another 27.2 percent of LC 2. LC 3 has growing seasons of 101–165 days. About
half (50.3 percent) is located in Canada and the Former Soviet Union. It is 13.0 percent of all land. Growing seasons on LC 4 range from 166 to 250 days. It is relatively scarce—10.2 percent of all land. Africa contains 28.9 percent of LC 4. Another 27.6 percent is located in the United States and Europe. LC 5, which is only 7.7 percent of all land, has growing seasons of 251–300 days. Most (78.8 percent) is located in Africa, Latin America, and Asia. Year-round growing seasons (i.e., longer than 300 days) characterize LC 6. LC 6 accounts for 20 percent of all land; 87.2 percent of LC 6 land is

Table 3
Olson's world ecosystem complexes, by land class

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Land class *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Percent dominant cover by land class</td>
<td></td>
</tr>
<tr>
<td>Polar desert</td>
<td>100.0</td>
</tr>
<tr>
<td>Ice</td>
<td>99.8</td>
</tr>
<tr>
<td>Northern taiga</td>
<td>88.8</td>
</tr>
<tr>
<td>Wooded tundra–heath</td>
<td>82.6</td>
</tr>
<tr>
<td>Semidesert–tundra</td>
<td>44.3</td>
</tr>
<tr>
<td>Deserts</td>
<td>5.0</td>
</tr>
<tr>
<td>Scrub–woods</td>
<td>0.5</td>
</tr>
<tr>
<td>Shrub–tree</td>
<td>1.3</td>
</tr>
<tr>
<td>Grass–shrub–herb</td>
<td>8.5</td>
</tr>
<tr>
<td>Conifer forest</td>
<td>42.4</td>
</tr>
<tr>
<td>Conifer rainforest</td>
<td>22.6</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>15.6</td>
</tr>
<tr>
<td>Wetlands</td>
<td>11.8</td>
</tr>
<tr>
<td>Crop–settlement</td>
<td>1.3</td>
</tr>
<tr>
<td>Forest/field</td>
<td>0.9</td>
</tr>
<tr>
<td>Field/woods–savanna</td>
<td>0.7</td>
</tr>
<tr>
<td>Broadleaf forest</td>
<td>1.1</td>
</tr>
<tr>
<td>Mangrove</td>
<td>0.0</td>
</tr>
<tr>
<td>Tropical forest</td>
<td>0.3</td>
</tr>
<tr>
<td>Percent dominant cover within land class</td>
<td></td>
</tr>
<tr>
<td>Polar desert</td>
<td>1.7</td>
</tr>
<tr>
<td>Ice</td>
<td>8.9</td>
</tr>
<tr>
<td>Northern taiga</td>
<td>17.0</td>
</tr>
<tr>
<td>Wooded tundra–heath</td>
<td>5.6</td>
</tr>
<tr>
<td>Semidesert–tundra</td>
<td>34.2</td>
</tr>
<tr>
<td>Deserts</td>
<td>2.0</td>
</tr>
<tr>
<td>Scrub–woods</td>
<td>0.1</td>
</tr>
<tr>
<td>Shrub–tree</td>
<td>0.2</td>
</tr>
<tr>
<td>Grass–shrub–herb</td>
<td>8.1</td>
</tr>
<tr>
<td>Conifer forest</td>
<td>15.5</td>
</tr>
<tr>
<td>Conifer rainforest</td>
<td>0.1</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>3.4</td>
</tr>
<tr>
<td>Wetlands</td>
<td>1.3</td>
</tr>
<tr>
<td>Crop–settlement</td>
<td>0.9</td>
</tr>
<tr>
<td>Forest/field</td>
<td>0.2</td>
</tr>
<tr>
<td>Field/woods–savanna</td>
<td>0.3</td>
</tr>
<tr>
<td>Broadleaf forest</td>
<td>0.3</td>
</tr>
<tr>
<td>Mangrove</td>
<td>0.0</td>
</tr>
<tr>
<td>Tropical forest</td>
<td>0.1</td>
</tr>
</tbody>
</table>

* Growing season lengths for land classes are as follows: (1) less than 100 days and cold; (2) less than 100 days and dry; (3) 101 to 165 days; (4) 166 to 250 days; (5) 251 to 300 days; (6) more than 300 days.
located in tropical areas of Africa, Asia, and Latin America.

Land-class-based differences in primary productivity are revealed by the distribution of Olson's world ecosystem complexes (Olson, 1989-1991) across the 6 land classes (Table 3). In general, the least productive ecosystems (i.e., tundra, deserts, scrub—woods) are located where growing seasons are short while the most productive ecosystems (i.e., broadleaf and tropical forest) are located where growing seasons are long. LC 1, for example, is composed primarily of semidesert—tundra, northern taiga, and conifer forest. The most important ecosystems on LC 2 are grass—shrub—herb complexes (sometimes referred to as range), semidesert—tundra, and desert. Conifer forest, crops and settlements, grass—shrub—herb complexes, and mixed forest are prevalent on LC 3. LC 4 consists primarily of crops and settlements, fields and woods (or savanna), grass—shrub—herb complexes, and broadleaf forests. Important ecosystems on LC 5 are crops and settlements, broadleaf forests, fields and woods (or savanna), grass—shrub—herb complexes, and tropical forests. LC 6 consists primarily of tropical forest, fields and woods, crops and settlements, and grass—shrub—herb complexes.

Climate also determines a region's water runoff and water supplies (Table 2). Water runoff is that portion of annual precipitation that is not evaporated back to the atmosphere. Runoff limits a region's water supply, thereby constraining its ability to irrigate crops, generate hydropower, and provide drinking water. FARM's benchmark water runoff and water supplies are derived from country-level data compiled by the World Resources Institute (WRI, 1990). Changes in a region's water supply are linked to changes in runoff by elasticities of water supply (Table 2). These elasticities indicate percentage changes in regional water supplies that would be generated by 1 percent increases in runoff. Runoff elasticities are positive, implying that water supplies increase when runoff increases. Regional differences in elasticities are related to differences in hydropower capacity. Production of hydropower depends on dams, which enable a region to store water temporarily. The ability to store water allows people within a region to consume water during both dry and rainy seasons.

2.2. Economic framework

FARM's economic framework consists of a multi-region, multi-sector, CGE model. The CGE model explicitly accounts for all domestic and international money flows for 1990. Households are assumed to own the four primary factors of production (land, water, labor, and capital). They use the revenues from the sale of these factors to purchase consumer goods and services from the producing sectors in domestic and international markets (Fig. 1). Accounting for this circular flow enables CGE models to provide comprehensive measures of economic activity. For surveys of computable general equilibrium studies, see Shoven and Whalley (1984) and Robinson (1989, 1990).

FARM's CGE model is an aggregation and extension of the Global Trade Analysis Project (GTAP) model (Hertel, 1993). GTAP provides researchers with a well-documented global database and modeling structure. FARM's major extensions to GTAP are (1) the inclusion of land as a primary input in all producing sectors, (2) the introduction of water as a primary input in the crops, livestock and service sectors, and (3) the modeling of crop production as a multi-output sector. Including land as a primary input in all producing sectors enables us to simulate changes in land use.

2.2.1. CGE model specification

The CGE model contains 8 regions—the United States, Canada, European Community (EC: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and United Kingdom), Japan, other East Asia (China, including Taiwan; Hong Kong, and South Korea), Southeast Asia (Indonesia, Malaysia, Philippines, Singapore, and Thailand), Australia and New Zealand, and the rest of world (Table 4). Because of data limitations, we were not able to disaggregate the rest-of-world region (i.e., Latin America, Africa, West Asia, much of South Asia, the former Soviet Union, and the rest of Europe).
Table 4
Regions, sectors, and commodities in the Future Agricultural Resources Model

<table>
<thead>
<tr>
<th>Item</th>
<th>World product / Percent of total dollar value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regions *</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>100.0</td>
</tr>
<tr>
<td>Australia and New Zealand</td>
<td>22.2</td>
</tr>
<tr>
<td>Canada</td>
<td>1.6</td>
</tr>
<tr>
<td>Japan</td>
<td>2.7</td>
</tr>
<tr>
<td>Other East Asia:</td>
<td></td>
</tr>
<tr>
<td>China, including Taiwan;</td>
<td>14.8</td>
</tr>
<tr>
<td>Hong Kong; South Korea</td>
<td></td>
</tr>
<tr>
<td>Southeast Asia:</td>
<td>4.2</td>
</tr>
<tr>
<td>Thailand, Indonesia, Philippines, Malaysia, Singapore</td>
<td>1.4</td>
</tr>
<tr>
<td>European Community:</td>
<td>25.3</td>
</tr>
<tr>
<td>Belgium, Denmark, Federal</td>
<td></td>
</tr>
<tr>
<td>Republic of Germany, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, United Kingdom</td>
<td>11.9</td>
</tr>
<tr>
<td>Rest-of-world</td>
<td>27.7</td>
</tr>
<tr>
<td>Sectors (and commodities)</td>
<td>88.1 b</td>
</tr>
<tr>
<td>Crops</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>2.5</td>
</tr>
<tr>
<td>Other grains</td>
<td>0.2</td>
</tr>
<tr>
<td>Nongrain crops</td>
<td>1.4</td>
</tr>
<tr>
<td>Livestock</td>
<td>1.4</td>
</tr>
<tr>
<td>Forestry</td>
<td>0.4</td>
</tr>
<tr>
<td>Coal, oil, and gas</td>
<td>2.0</td>
</tr>
<tr>
<td>Other minerals</td>
<td>1.2</td>
</tr>
<tr>
<td>Fish, meat, and milk</td>
<td>1.8</td>
</tr>
<tr>
<td>Other processed foods</td>
<td>4.1</td>
</tr>
<tr>
<td>Textiles, clothing, and footwear</td>
<td>2.6</td>
</tr>
<tr>
<td>Other nonmetallic manufactures</td>
<td>11.8</td>
</tr>
<tr>
<td>Other manufactures</td>
<td>13.3</td>
</tr>
<tr>
<td>Services</td>
<td>47.0</td>
</tr>
</tbody>
</table>

* The regions listed are for FARM’s computable general equilibrium model. In FARM’s geographic information system, the Rest-of-world is divided into the former USSR (plus Mongolia), Other Europe, Other Asia and Oceania, Latin America, and Africa.

b Saving (equal to investment) is 11.9 percent.

The crops sector produces three crop commodities (i.e., wheat, other grains, and nongrains). Each of the other sectors produces one commodity.

Union plus Mongolia, and countries in Europe outside the EC) when we began our research. Despite its great geographic size, however, the rest-of-world region is about the same economic size as the EC or United States. It should not, therefore, distort our overall economic results. It does limit, however, what we can say about where in the rest-of-world region the economic effects of the global changes we are investigating might occur.

Fortunately, other aspects of the framework, like the location of specific land classes, help reduce this limitation. Almost all LC 6 in the rest-of-world region, for example, is located in tropical areas of Latin America, Africa, and those parts of Asia and Oceania not contained in other FARM regions (Fig. 2). Changes on LC 6’s forest land in the rest-of-world region, therefore, apply primarily to tropical forests because they are the dominant forest ecosystems on LC 6 (Table 3). FARM also includes Southeast Asia, a region where, in 1990, tropical forests covered more than 50 percent of the land and where tropical silviculture’s output represented 1.4 percent of gross domestic production (GDP), about three and a half times the world average. This permits the evaluation of interactions between tropical forests and various economic variables in more detail.

Each region has 11 producing sectors—crops; livestock; forestry; coal, oil, and gas; other minerals; fish, meat, and milk; other processed foods; textiles, clothing, and footwear; other nonmetallic manufactures; other manufactures; and services. Except for the crops sector, each sector produces one commodity. The crops sector is multi-output, producing wheat, other grains, and nongrains. This structure results in a straightforward relationship between the major land-intensive sectors (crops, livestock, and forestry) and the FAO’s land use and cover categories (cropland, permanent pasture, and forest land). It also exposes the secondary processing sectors (fish, meat, and milk; other processed foods) that rely heavily on land-intensive sectors for inputs. All regions produce, consume, and trade the 13 commodities.

Additional information about the composition of the agricultural and silvicultural commodities can be inferred from the region in which they are raised.

6 Cropland consists of arable land plus land in permanent crops (orchards, rubber, etc.). See Meyer and Turner (1992) for an evaluation of FAO land use and cover data.
Table 5
Major components of agricultural and silvicultural production, by region

<table>
<thead>
<tr>
<th>Region</th>
<th>Crops</th>
<th>Nongrains</th>
<th>Livestock</th>
<th>Forest products</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Other grains</td>
<td>Produces soybeans, sugar</td>
<td>Cattle, pigs</td>
<td>Percent</td>
</tr>
<tr>
<td>US</td>
<td>Maize</td>
<td>Produce, soybeans, sugar</td>
<td>Cattle, pigs</td>
<td>34 17</td>
</tr>
<tr>
<td>Canada</td>
<td>Barley, Maize</td>
<td>Oils, produce, roots and tubers</td>
<td>Cattle, pigs</td>
<td>10 4</td>
</tr>
<tr>
<td>EC</td>
<td>Maize</td>
<td>Produce, sugar</td>
<td>Sheep and goats, pigs, cattle</td>
<td>32 13</td>
</tr>
<tr>
<td>Japan</td>
<td>Rice</td>
<td>Produce</td>
<td>Pigs, cattle</td>
<td>34 1</td>
</tr>
<tr>
<td>OEA c</td>
<td>Rice, Maize</td>
<td>Produce, roots and tubers</td>
<td>Pigs, sheep and goats</td>
<td>52 67</td>
</tr>
<tr>
<td>SEA d</td>
<td>Rice</td>
<td>Sugar, roots and tubers</td>
<td>Pigs, sheep and goats, cattle</td>
<td>100 69</td>
</tr>
<tr>
<td>ANZ e</td>
<td>Barley</td>
<td>Sugar</td>
<td>Sheep and goats</td>
<td>42 9</td>
</tr>
<tr>
<td>ROW f</td>
<td>Rice, Maize, Barley</td>
<td>Sugar, produce</td>
<td>Sheep and goats, cattle</td>
<td>69 62</td>
</tr>
</tbody>
</table>

a Commodities that make up more than 20 percent of the total are listed from most to least dominant.

b Does not include poultry.
c Other East Asia (China, including Taiwan; Hong Kong; and South Korea).
d Southeast Asia (Thailand, Indonesia, Philippines, Malaysia, and Singapore).
e Australia and New Zealand.
f Rest-of-world.

(Table 5). In the United States, for example, maize is a major component of other grains; produce (fruits and vegetables), soybeans, and sugar crops are major components of nongrains; and cattle and pigs are major components of livestock. The U.S. forestry sector produces mostly softwood products (derived from coniferous trees), and only 17 percent of the U.S. forestry harvest is used for fuel. In Southeast Asia, however, other grains is primarily rice, nongrains is sugar cane and roots and tubers (such as cassava), and livestock is pigs, sheep, goats, and cattle. All forest products in Southeast Asia are hardwood products (derived from deciduous trees), and 69 percent of the harvest is used for fuel.

A region's primary factor endowments of land, water, labor, and capital are determined exogenously and are region-specific: i.e., one region's primary factors cannot be used by another region's sectors. Water, labor, and capital are homogenous: i.e., within regions these factors are perfectly mobile across all economic sectors, and each has one regional price. Regional supplies of these factors are perfectly inelastic. Water is supplied to the crops, livestock, and services sectors. Land, labor and capital are supplied to all sectors. Regional demands for water, land, labor, and capital are sums of sectoral demands. They are downward-sloping (i.e., sensitive to prices).

Land productivity differences based on length of growing season are maintained by supplying land from each land class to all 11 sectors separately. Cropland, permanent pasture, and forest land are used by the crops, livestock, and forestry sectors, respectively. Other land, which includes urban land, is used by the manufacturing and services sectors. Additional land productivity differences are generated by assuming that land supplies are derived from Cobb-Douglas revenue functions. This restricts land's mobility between sectors, so for a given region and land class, cropland owners may receive higher rents than pasture land owners. This structure allows land to shift between economic sectors (i.e.,

7 A Cobb-Douglas revenue function is a constant elasticity of transformation (CET) function with Allen partial elasticities equal to -1.0.
into new uses) in response to changing conditions while simultaneously simulating productivity differences within land classes.

Producer behavior in FARM is driven by profit maximization assuming competitive markets. The land-intensive sectors—crops, livestock and forestry—are composed of subsectors, one for each land class. Production in the other sectors is not land-class-specific: i.e., there is not a unique production structure associated with each land class. Technology in each sector is assumed to be constant returns to scale. A commodity is produced from a composite input obtained by combining a composite primary factor with 13 composite commodity inputs in fixed proportions (i.e., using a Leontief technology).

The composite primary factor is assumed to be derived from a CES cost function for the primary factors (land, labor, capital, and, where appropriate, water). Each of the 13 composite commodity inputs is composed of domestically produced and imported versions of themselves. They are assumed to be derived from nested CES cost functions—one for determining the amount to be imported from each foreign region (creating an import composite), and another for choosing between the import composite and the domestically produced good. The Allen partial elasticities for these CES functions are presented in Table 6.

In single-output sectors, the final composite input is equal to sector output. In the crops subsectors, the final composite input is used to produce wheat, other grains, and nongrains. Supplies of these commodities are assumed to be derived from Cobb-Douglas revenue functions. Regional production of wheat, other grains, and nongrains is the sum of production across the 6 land-class-specific crops subsectors. Regional output of livestock and forestry products is the sum of production across their respective land-class-specific subsectors as well.

This production structure embodies a number of realities that are lacking in other CGE models. First, land is heterogeneous and is a primary factor in all economic sectors. Second, land is in fixed supply. One cannot increase cropland without reducing land in another category. Third, it is relatively difficult to substitute labor and capital for land in the land-intensive agricultural and silvicultural sectors (Table 6). This also means that it is relatively easy to substitute labor and capital for land in other sectors (i.e., increase urbanization by using more multi-storied buildings). Fourth, the Leontief structure for commodity inputs precludes substitution between primary and commodity inputs and between commodity inputs within a sector. The former means that land, labor, or capital cannot be substituted for throughput: i.e., saws cannot be substituted for lumber in the construction of housing (see Daly, 1986). The latter, however, means that linoleum cannot be substituted for hardwood flooring. Fifth, each region’s commodities are treated as separate goods when traded. This helps to maintain product differentiation (i.e., regional differences in the composition of commodities, including wheat).

The production parameters presented in Table 6

<table>
<thead>
<tr>
<th>Sector (commodity)</th>
<th>$\sigma_{PI}$</th>
<th>$\sigma_{II}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops (wheat, other grains, nongrains)</td>
<td>0.56</td>
<td>2.20</td>
</tr>
<tr>
<td>Livestock</td>
<td>0.56</td>
<td>2.78</td>
</tr>
<tr>
<td>Forestry</td>
<td>0.56</td>
<td>2.80</td>
</tr>
<tr>
<td>Coal, oil, and gas</td>
<td>1.12</td>
<td>2.80</td>
</tr>
<tr>
<td>Other minerals</td>
<td>1.12</td>
<td>2.80</td>
</tr>
<tr>
<td>Fish, meat, and milk</td>
<td>0.85</td>
<td>2.34</td>
</tr>
<tr>
<td>Other processed food</td>
<td>1.12</td>
<td>2.44</td>
</tr>
<tr>
<td>Textiles, clothing, and footwear</td>
<td>1.26</td>
<td>3.17</td>
</tr>
<tr>
<td>Other nonmetallic manufactures</td>
<td>1.26</td>
<td>2.06</td>
</tr>
<tr>
<td>Other manufactures</td>
<td>1.26</td>
<td>3.28</td>
</tr>
<tr>
<td>Services</td>
<td>1.39</td>
<td>1.94</td>
</tr>
</tbody>
</table>

*Elasticities are the same in all regions. Allen partial elasticities of substitution among imported commodities ($\sigma_{PI}$) are twice as large as the elasticities between domestic and imported commodities.*

Table 7
Compensated own price elasticities for private consumption in the Future Agricultural Resources Model at initial equilibrium, by region

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Australia and New Zealand</th>
<th>Canada</th>
<th>United States</th>
<th>Japan</th>
<th>Other East Asia a</th>
<th>Southeast Asia b</th>
<th>European Community</th>
<th>Rest-of-world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>-0.0705</td>
<td>-0.0638</td>
<td>-0.0657</td>
<td>-0.1380</td>
<td>-0.1505</td>
<td>-0.1063</td>
<td>-0.1490</td>
<td>-0.1201</td>
</tr>
<tr>
<td>Other grains</td>
<td>-0.0706</td>
<td>-0.0636</td>
<td>-0.0657</td>
<td>-0.1380</td>
<td>-0.1498</td>
<td>-0.1226</td>
<td>-0.1489</td>
<td>-0.1801</td>
</tr>
<tr>
<td>Nongrains</td>
<td>-0.0722</td>
<td>-0.0642</td>
<td>-0.0663</td>
<td>-0.1433</td>
<td>-0.1833</td>
<td>-0.1438</td>
<td>-0.1510</td>
<td>-0.2022</td>
</tr>
<tr>
<td>Livestock</td>
<td>-0.6347</td>
<td>0.5694</td>
<td>-0.5880</td>
<td>-0.4545</td>
<td>-0.3547</td>
<td>-0.2451</td>
<td>-0.5521</td>
<td>-0.3023</td>
</tr>
<tr>
<td>Forest products</td>
<td>-0.6287</td>
<td>0.5681</td>
<td>-0.5868</td>
<td>-0.4528</td>
<td>-0.3508</td>
<td>-0.2392</td>
<td>-0.5440</td>
<td>0.4003</td>
</tr>
<tr>
<td>Coal, oil, and gas</td>
<td>-0.6298</td>
<td>0.5703</td>
<td>-0.5876</td>
<td>-0.4528</td>
<td>-0.3496</td>
<td>-0.2346</td>
<td>-0.5456</td>
<td>0.4007</td>
</tr>
<tr>
<td>Other minerals</td>
<td>-0.6285</td>
<td>0.5672</td>
<td>-0.5867</td>
<td>-0.4528</td>
<td>-0.3496</td>
<td>-0.2348</td>
<td>-0.5436</td>
<td>0.4000</td>
</tr>
<tr>
<td>Fish, meat, and milk</td>
<td>-0.1011</td>
<td>0.0704</td>
<td>-0.0745</td>
<td>-0.2083</td>
<td>-0.2484</td>
<td>-0.1536</td>
<td>-0.1746</td>
<td>0.2042</td>
</tr>
<tr>
<td>Other processed food</td>
<td>-0.3044</td>
<td>0.2202</td>
<td>-0.2384</td>
<td>-0.2539</td>
<td>-0.2223</td>
<td>-0.1547</td>
<td>-0.2967</td>
<td>0.2474</td>
</tr>
<tr>
<td>Textiles, clothing, and footwear</td>
<td>-0.3639</td>
<td>-0.3912</td>
<td>-0.4131</td>
<td>-0.3384</td>
<td>-0.2320</td>
<td>-0.1448</td>
<td>-0.2923</td>
<td>0.1737</td>
</tr>
<tr>
<td>Other nonmetallic manufactures</td>
<td>-0.6840</td>
<td>-0.6098</td>
<td>-0.6375</td>
<td>-0.4787</td>
<td>-0.3649</td>
<td>-0.2533</td>
<td>-0.5955</td>
<td>0.4108</td>
</tr>
<tr>
<td>Other manufactures</td>
<td>-0.6318</td>
<td>-0.5712</td>
<td>-0.6057</td>
<td>-0.4477</td>
<td>-0.3153</td>
<td>-0.2119</td>
<td>-0.5333</td>
<td>0.3636</td>
</tr>
<tr>
<td>Services</td>
<td>0.2092</td>
<td>-0.1713</td>
<td>-0.1559</td>
<td>-0.1527</td>
<td>-0.4292</td>
<td>-0.3393</td>
<td>-0.2288</td>
<td>-0.2690</td>
</tr>
</tbody>
</table>

---

were obtained from a review of the literature. Parameters that were estimated for a limited number of countries, however, have been applied broadly. Empirical estimates of land and crop supply parameters were unavailable. We conducted a sensitivity analysis, therefore, to assess the importance of model results to parameter specifications (Darwin et al., 1995). This analysis indicated that measures of total or sectoral world product are not very sensitive to changes in parameters. The same holds for total or sectoral product in Southeast Asia or derived from LC 6 in the rest-of-world region. The signs of the changes, for example, remained the same in all cases.

Revenues from the sale of primary factors accrue as income to one super household in each region. This household is assumed to maximize a per-capita, Cobb-Douglas utility function for private consumption, government purchases, and savings (i.e., future consumption). Private consumption of composite commodities is modeled with Constant Difference of Elasticities (CDE) specifications (Hanoch, 1975; Hertel et al., 1991). Government purchases of composite commodities are derived with a Cobb-Douglas utility function. Composite commodity inputs to consumption are derived the same way as composite commodity inputs to production—from nested CES cost functions.

The CDE structure is less restrictive than the CES in that (1) elasticities of substitution between pairs of commodities can differ (i.e., one elasticity does not capture all substitution possibilities between commodities), and (2) income elasticities are not restricted to equal one. Own-price and income elasticities for consumption at initial equilibrium conditions are presented in Tables 7 and 8. The own-price and income elasticities of food products are generally smaller than those of nonfood products. This means that, compared with consumption of nonfood products, food consumption remains relatively stable when prices or incomes change.

Regional savings are pooled to form a global
Table 8
Income elasticities for private consumption in the Future Agricultural Resources Model at initial equilibrium, by region

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Region</th>
<th>Australia and New Zealand</th>
<th>Canada</th>
<th>United States</th>
<th>Japan</th>
<th>Other East Asia a</th>
<th>Southeast Asia b</th>
<th>European Community</th>
<th>Rest-of-world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td></td>
<td>0.9996</td>
<td>0.9997</td>
<td>0.9976</td>
<td>0.9997</td>
<td>0.8701</td>
<td>0.9959</td>
<td>0.9710</td>
<td>0.9447</td>
</tr>
<tr>
<td>Other grains</td>
<td></td>
<td>0.9962</td>
<td>0.9991</td>
<td>0.9941</td>
<td>0.9994</td>
<td>0.6817</td>
<td>0.9206</td>
<td>0.9729</td>
<td>0.8167</td>
</tr>
<tr>
<td>Nongrains</td>
<td></td>
<td>0.7736</td>
<td>0.7470</td>
<td>0.8511</td>
<td>0.8133</td>
<td>0.6426</td>
<td>0.7272</td>
<td>0.8723</td>
<td>0.6520</td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td>0.8966</td>
<td>0.9520</td>
<td>0.9689</td>
<td>0.9648</td>
<td>0.7957</td>
<td>0.9021</td>
<td>0.8356</td>
<td>0.8795</td>
</tr>
<tr>
<td>Forest products</td>
<td></td>
<td>1.0002</td>
<td>1.0031</td>
<td>1.0005</td>
<td>1.0000</td>
<td>1.0007</td>
<td>1.0302</td>
<td>1.0016</td>
<td>1.0076</td>
</tr>
<tr>
<td>Coal, oil, and gas</td>
<td></td>
<td>1.0015</td>
<td>1.0087</td>
<td>1.0002</td>
<td>1.0001</td>
<td>1.0397</td>
<td>1.0049</td>
<td>1.0066</td>
<td>1.0181</td>
</tr>
<tr>
<td>Other minerals</td>
<td></td>
<td>1.0001</td>
<td>1.0003</td>
<td>1.0003</td>
<td>1.0000</td>
<td>0.9899</td>
<td>1.0046</td>
<td>1.0003</td>
<td>1.0009</td>
</tr>
<tr>
<td>Fish, meat, and milk</td>
<td></td>
<td>0.4172</td>
<td>0.3477</td>
<td>0.5285</td>
<td>0.7239</td>
<td>0.8599</td>
<td>0.8921</td>
<td>0.4484</td>
<td>0.7889</td>
</tr>
<tr>
<td>Other processed food</td>
<td></td>
<td>0.4680</td>
<td>0.4478</td>
<td>0.4937</td>
<td>0.5265</td>
<td>0.7346</td>
<td>0.7246</td>
<td>0.5736</td>
<td>0.6417</td>
</tr>
<tr>
<td>Textiles, clothing, and footwear</td>
<td></td>
<td>0.9499</td>
<td>0.9431</td>
<td>0.9512</td>
<td>0.9539</td>
<td>0.9586</td>
<td>0.9610</td>
<td>0.9440</td>
<td>0.9489</td>
</tr>
<tr>
<td>Other nonmetallic manufactures</td>
<td></td>
<td>1.0828</td>
<td>1.0668</td>
<td>1.0362</td>
<td>1.0613</td>
<td>1.1780</td>
<td>1.1493</td>
<td>1.0812</td>
<td>1.1191</td>
</tr>
<tr>
<td>Other manufactures</td>
<td></td>
<td>1.0144</td>
<td>1.0045</td>
<td>1.0000</td>
<td>1.0058</td>
<td>1.0498</td>
<td>0.9697</td>
<td>1.0061</td>
<td>0.9385</td>
</tr>
<tr>
<td>Services</td>
<td></td>
<td>1.0972</td>
<td>1.0868</td>
<td>1.0503</td>
<td>1.0951</td>
<td>1.2342</td>
<td>1.1647</td>
<td>1.0971</td>
<td>1.1272</td>
</tr>
</tbody>
</table>

Notes:
a China, including Taiwan, Hong Kong, and South Korea.
b Thailand, Indonesia, Philippines, Malaysia, and Singapore.

aggregate. All savers see the same price—a global interest rate. Savings finance investment (i.e., the purchase capital goods in each region). Capital goods are aggregates of intermediate commodities provided by a region's producing sectors. From a global perspective, savings equals investment. The equality, however, need not hold in any given region (see Table 9). If domestic investment is greater than domestic savings, the region is accruing debt. If domestic investment is smaller than domestic saving, the region is paying off debt.

Moving goods between regions requires expenditures for international transportation services. Transportation requirements are route- and commodity-specific and are determined in fixed proportions to the quantities of goods shipped. The world price of transportation services is market-determined and equates the global demand for such services with the global supply; each region supplies a fixed value share of global transportation services.

FARM also has data on support and protection, but, like GTAP, these data contain gaps in the coverage of countries, industries, and types of policy. The rest-of-world region, for example, only contains support and protection data for agricultural sectors. Also, coverage for the service sector is generally absent in all regions while coverage for the other non-agricultural sectors is currently limited to

Table 9
Savings and investment in the Future Agricultural Resources Model at initial equilibrium, by region

<table>
<thead>
<tr>
<th>Item</th>
<th>Region</th>
<th>Australia and New Zealand</th>
<th>Canada</th>
<th>United States</th>
<th>Japan</th>
<th>Other East Asia a</th>
<th>Southeast Asia b</th>
<th>European Community</th>
<th>Rest-of-world</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving</td>
<td></td>
<td>87.2</td>
<td>141.9</td>
<td>703.8</td>
<td>1,085.1</td>
<td>227.0</td>
<td>111.2</td>
<td>1,451.0</td>
<td>1,484.1</td>
<td>5,291.4</td>
</tr>
<tr>
<td>Investment</td>
<td></td>
<td>77.4</td>
<td>121.3</td>
<td>793.2</td>
<td>947.4</td>
<td>218.7</td>
<td>91.4</td>
<td>1,177.0</td>
<td>1,865.1</td>
<td>5,291.4</td>
</tr>
</tbody>
</table>

Notes:
a China, including Taiwan, Hong Kong, and South Korea.
b Thailand, Indonesia, Philippines, Malaysia, and Singapore.
Fig. 3. Distribution of cropland, pasture, forest, and other land under current climatic conditions, by land class. Growing season lengths for land classes are as follows: (1) less than 100 days and cold; (2) less than 100 days and dry; (3) 101 to 165 days; (4) 166 to 250 days; (5) 251 to 300 days; (6) more than 300 days.

Agricultural policies, however, have been the topic of many measurement efforts. Producer and consumer subsidy equivalents, developed by the Organization for Economic Cooperation and Development and, separately, by USDA’s Economic Research Service, quantify tariff and nontariff policies for many agricultural products. These two sources estimate the effects that government policies have on producer and consumer prices by type of policy. This makes it possible to separate producer price impacts into border measures and domestic measures. Hence, three measures—import tariffs, export subsidies, and production subsidies—make up the agricultural component of the support and protection data.

2.2.2. Economic uses of land

Just as the land classes are associated with distinct mixes of ecosystems, so too are they associated with distinct land-use and product mixes. Land use differences associated with length of growing season are illustrated by the distribution of the FAO’s (1992) land use and cover categories across the 6 land classes (Fig. 3). Cropland is relatively rare on LC 1 (polar and alpine areas), but relatively common on LC 4 (western Europe and the U.S. Corn Belt). Pasture, primarily as range, makes up much of LC 2. LC’s 1 and 3 (high-latitude areas) and LC 6 (tropical areas) contain relatively large portions of forest land. Large quantities of other land (which includes deserts, ice fields, and tundra as well as land used in the non-agricultural sectors) are found on LC’s 1 and 2.

We use global information to demonstrate this point. Information on specific regions as well as a description of the methods used to allocate land, water, and other resources to crop, livestock, and forestry production by land class is in Darwin et al. (1995).
The distribution of crop, livestock, and forestry production follows a similar pattern (Fig. 4).

Differences in the economic productivity of land are illustrated by the distribution of land productivities across the 6 land classes (Fig. 5). In general, land productivity for crops increases with the length of the growing season, that is, productivity is greater on LC 6 than on LC 1. The major exception occurs on LC 2. Land productivity for crops on LC 2 is relatively high because of irrigation. Land productivity for livestock first increases, is greatest on LC 4, and then decreases with the length of growing season. This pattern is due to the high production of feed grains (primarily maize) on LC 4. Land productivity for forest products first increases and then remains about the same. Land productivity for forest products on LC's 5 and 6 is limited by accessibility.

The mix of crops and their associated land pro-

\[12\] Land productivity is output divided by the total amount of land used by the sector. For total crop (or livestock or forestry) production, land productivity is the same as yield. That is unlikely to be true for a particular crop (or livestock type or forest product). Yield for a particular crop is output divided by the amount of land planted (or harvested) to that crop. For forest products, land productivity has an implicit time dimension (i.e., wood per hectare per year). Hence, land productivity for forest products also represents a harvest rate.

\[13\] The distribution of irrigation water is determined by the amount of irrigated land in a given land class and the amount of irrigation water required per hectare. Sixty-six percent of the world’s irrigation water is allocated to LC 2 where agricultural land is more likely to be irrigated and require more water per hectare than agricultural land on other land classes. Another 21 percent is assigned to LC’s 5 and 6, which are heavily used for production of paddy rice and sugar cane. See Darwin et al. (1995) for more details.
Land productivity for crops, livestock, and wood in 1990, by land class. Crops, livestock, and wood are measured in metric tons per cropland hectare, head per pasture hectare, and cubic meters per forest hectare, respectively. Growing season lengths for land classes are as follows: (1) less than 100 days and cold; (2) less than 100 days and dry; (3) 101 to 165 days; (4) 166 to 250 days; (5) 251 to 300 days; (6) more than 300 days.

Productivities vary by land class as well (Fig. 6). The most striking aspect about crop mixes is that the share of nongrains generally increases with length of growing season. This reflects the importance of cassava, yams, sugar, fruits, and other specialty crops in tropical economies. Land productivity generally follows the pattern seen earlier. Land productivity for wheat, for example, generally increases with length of growing season. No wheat is grown on LC 6, however. Land productivity for other grains and nongrains also generally increases with length of growing season. The major exception, due again to irrigation, occurs on LC 2.

In summary, FARM's treatment of land embodies both ecological and economic concepts regarding land's productivity. And, because land use and cover is an integral component of the modeling framework, we can track how changes in land use and cover interact not only with the production of goods and services, but also with the ecological resources of a region.

3. Simulating global changes

FARM's CGE model embodies equilibrium conditions in 1990. Global changes are simulated by exogenously changing primary factor endowments or model parameters. This section describes how global changes in climate, population growth, and trade policies are translated into changes in endowments or parameters. The CGE model then calculates an alternative set of equilibrium conditions that reflect the new situation.

3.1. Climate change

We simulate global climate change with regional changes in (1) water supplies, and (2) the distribution...
Fig. 6. Land productivity for wheat, other grains, and nongrains in 1990, by land class. Growing season lengths for land classes are as follows: (1) less than 100 days and cold; (2) less than 100 days and dry; (3) 101 to 165 days; (4) 166 to 250 days; (5) 251 to 300 days; (6) more than 300 days.

of land across land classes (see Fig. 1). These changes, which are computed in FARM's GIS, are derived from changes in mean monthly temperature and precipitation generated by four commonly cited general circulation models (GCMs). GCMs mathematically simulate global weather and climatic processes over time for given levels of atmospheric carbon dioxide (CO₂).

The four climate change scenarios discussed here are based on equilibrium climate conditions under a doubling of current levels of atmospheric CO₂. Together they project increases in average global temperature and precipitation ranging from 2.8 to 5.2°C and from 7.0 to 15.0 percent, respectively. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that a doubling of trace greenhouse gases would lead to an increase in average global temperature of 1.5–5.0°C by 2020 (IPCC, 1992). The GCM scenarios considered here are in the upper end of the IPCC's range.

The major computational tasks for each scenario are as follows. First, the GCM results are used to modify current estimates of average monthly temperature and precipitation (Leemans and Cramer, 1991). Second, changes in regional runoff and water supplies are calculated. The latter are related to the former by elasticities that measure percentage changes in regional water supplies in response to 1 percent increases in runoff (Table 2). Third, new growing season lengths and regional changes in the distribution of land across land classes are computed. Results of these tasks—regional changes in water
### Table 10
Changes in water supplies and land class areas due to simulated climates, by region and general circulation model (GCM) *

<table>
<thead>
<tr>
<th>Item/GCM</th>
<th>Region</th>
<th>United States</th>
<th>Canada</th>
<th>EC</th>
<th>Japan</th>
<th>OEA b</th>
<th>SEA c</th>
<th>ANZ d</th>
<th>Rest-of-world</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Percent change</td>
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<td></td>
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<td>643.39</td>
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* Climates based on doubled atmospheric carbon dioxide levels and simulated by the GCM's of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU).

b Other East Asia (China, including Taiwan; Hong Kong; and South Korea).

c Southeast Asia (Thailand, Indonesia, Philippines, Malaysia, and Singapore).

d Australia and New Zealand.

e Growing season lengths for land classes are as follows: (1) less than 100 days and cold; (2) less than 100 days and dry; (3) 101 to 165 days; (4) 166 to 250 days; (5) 251 to 300 days; (6) more than 300 days.
supplies and in the distribution of land across land classes—are presented in Table 10.

A number of caveats and limitations to the climate change analysis should be noted. First, the climate change scenarios are restricted to one type and level of fossil fuel emissions: i.e., the regional cooling effects of tropospheric SO\textsubscript{2} are ignored and only a doubling of CO\textsubscript{2} is considered. Second, the well-documented, beneficial effects of higher concentrations of atmospheric CO\textsubscript{2} on plant growth and water use are not considered. There remains considerable debate about the magnitude of this effect. Third, the simulations of water resources do not capture all potential impacts. The potential effects of too much water, such as flooding or waterlogging of soils, for example, are not evaluated. Fourth, changes in socioeconomic conditions that might take place by the time climate changes occur were not considered. These limitations occur because the effects of global climate change are complex and their analysis is still in its infancy.\textsuperscript{16}

3.2. Population growth

Using a typical neo-classical approach, two world population growth scenarios are simulated. In the first, we simulate population growth with regional increases in population and labor. Because FARM uses a per-capita utility function, increases in a region's population causes direct increases in consumer demand for goods and services (see Fig. 1), which would, in turn, cause the demand for labor to increase. Because increases in a region's population would cause the supply of labor to increase as well, the labor force also would increase. In the second scenario, we also include regional increases in capital (equal to the increases in labor). This is based on the assumption that the labor force will grow only if capital grows as well. Regional estimates of population change and growth in the labor force for a 5-year period (see Table 11) were derived from 1985-1990 data in World Resources Institute (WRI, 1992).

The population growth analysis has two limitations that should be noted. First, population growth is generally accompanied by redistributions in the age-class structure of the population. The elderly, for example, might increase while the middle-aged might decrease. The consumer demands of such groups are not likely to be identical and changes in total demand should reflect any differences. Because we implicitly assume that each person in a region has the same utility function, these potential differences are not taken into account. Second, changes in labor and capital are exogenous; they are not derived endogenously with an explicit, population-dependent function based on household production theory.

3.3. Trade policy

We simulate changes in global trade policies by adjusting the wedges between producer and market prices (subsidies) and between domestic and foreign

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\textsuperscript{16} A comprehensive discussion of the limitations to climate change analysis as well as of the contributions that this approach makes is contained in Darwin et al. (1995).
prices (duties and tariffs) of wheat, other grains, nongrain, and livestock commodities. A 30 percent across-the-board cut in agricultural subsidies, duties, and tariffs is applied in all regions. We limit our trade policy analysis to the agricultural sectors because FARM's CGE model contains the necessary support and protection data for agricultural products in all regions. This will increase the comparative advantage of crop and livestock products in downstream processing sectors relative to inputs originating from other sectors: i.e., peanuts will become relatively cheaper than nuts gathered from tropical forests in food-processing sectors.

4. Results

We first look at how our climate change, population growth, and trade policy scenarios affect forests in moist tropical areas around the world. Then, using Southeast Asia as an example, we compare the forestry effects of these global changes with other economic effects. Results presented here are not predictions. Their main purpose is to show some of the ecological economic information that our framework generates. In so doing, we obtain a better understanding of the interrelationships among economic and ecological variables.

4.1. Effects on forests in moist tropical areas

In this section we show how global changes in climate, population, and trade policies might affect forests in moist tropical areas of Latin America, Africa, and Asia (i.e., on LC 6 in FARM's Southeast Asia and rest-of-world regions) (see Fig. 2). We use three measures to evaluate forest effects—changes in forest land, timber harvest rates, and per-hectare timber inventories. Changes in forest land represent direct measures of deforestation (i.e., the permanent conversion of forest land to other uses) and afforestation (deforestation's converse). Changes in timber harvest rates and per-hectare timber inventories provide information about the intensity with which forests are managed for economic outputs. Increases in harvests imply higher removal rates, while increases in inventories imply higher regeneration or timber growth rates.

Comparing changes in timber harvest rates with changes in per-hectare timber inventories provides information about the economic depletion of forests: i.e., when harvest rates increase more than regeneration rates, economic depletion of forests increases (or economic accretion of forests decreases). Note that this holds only for the long run. In our model, capital can move freely and instantaneously between sectors. In the real world, however, trees require years to reach harvestable size. Our results regarding capital investment (i.e., timber inventories) in the forestry sectors, therefore, should be interpreted as what would be desired, not what would actually occur. Hence, even when our equilibrium results indicate no long-term economic depletion of forest resources, we should expect increases in timber harvest rates to exceed increases in per-hectare timber inventories in the short and intermediate run when both are indicated.

The measures also contain ecological information. Changes in forest land indicate changes in the spatial extent and distribution of forest ecosystems, while changes in timber harvest rates and per-hectare timber inventories imply changes in the health and integrity of existing forest ecosystems. Generally speaking, increases in either timber harvest rates or per-hectare timber inventories will have a detrimental impact on natural forest ecosystems. This is because both divert a greater proportion of existing forest resources to human uses, leaving fewer forest resources for other organisms.

In tropical areas, for example, increases in harvest rates often mean increased logging of old-growth forests. Increases in per-hectare timber inventories are generally associated with the removal of dead wood, imperfect (i.e., rot-infected) trees, or undesirable species from existing stands, or with the establishment of timber plantations, typically monocrop cultures, after clearcutting existing stands. Each of these practices reduces wildlife habitat. It should be noted, however, that, given enough time and the

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17 Percent changes in timber harvest rates and per-hectare timber inventories are estimated by subtracting percent changes in forest land from percent changes in, respectively, forest output and forest capital (capital in the forestry sector is primarily timber inventory).
proper institutional framework, tree plantations may reduce our reliance on natural stands in the long term. If so, then the ecological health of natural stands would begin to improve.

4.1.1. Effects of global climate change

In the climate change scenarios evaluated here, warming in tropical regions reduces soil moisture, thereby inducing shorter growing seasons. This is indicated by climate-induced decreases in LC 6 in the Southeast Asia and rest-of-world regions (Table 10). Decreases in LC 6 result in forest land losses in moist tropical areas ranging from 18.7 to 51.6 percent (Table 12). Note that losses of forest land on LC 6 are greater than total losses of LC 6 land. The latter range from 18.4 to 51.0 percent (Fig. 7). Also note that LC 6 cropland losses (ranging from 18.3 to 49.3 percent) are smaller than LC 6 total losses. These results indicate that, under global climate change, competition from crop production is likely to exacerbate direct climate-induced losses of forest land in moist tropical areas. These climate-induced losses of forest land mean severe reductions in the area covered by tropical forest ecosystems.

Timber harvest rates and per-hectare timber inventories in moist tropical areas increase in three of the four climate change scenarios (Table 12). Increases in per-hectare timber inventories are larger than increases in harvest rates, which indicates decreases in the economic depletion of remaining tropical forests. The health and integrity of the remaining natural ecosystems in those forests, however, would probably decline. In the scenario where both timber harvest rates and per-hectare timber inventories decrease, economic depletion of remaining tropical forests increases while the health and integrity of the remaining natural ecosystems in those forests would probably increase.

Overall, these results imply that global climate change threatens the health and integrity of tropical forest ecosystems and the biodiversity that they maintain. Any ecosystem gains obtained in the scenario where timber harvest rates and per-hectare timber inventories are reduced would be more than

Table 12

Changes in forest land, timber harvest rates, and per-hectare timber inventories in moist tropical areas due to various potential global changes

<table>
<thead>
<tr>
<th>Global change</th>
<th>Forest land</th>
<th>Timber harvest rate</th>
<th>Per-hectare timber inventory</th>
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</thead>
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</table>

<sup>a</sup> Moist tropical areas occur in Latin America, Africa, and Asia (excluding China and Japan) where growing seasons are longer than 300 days per year. Timber harvest rate is the amount of timber harvested per unit land area per year.

<sup>b</sup> Climate changes based on doubled atmospheric carbon dioxide levels and generated by the general circulation models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU).

<sup>c</sup> Scenarios based on 5-year estimates of population and labor force growth derived from data on the 1985–1990 period (see WRI, 1992).

<sup>d</sup> Based on 30 percent across-the-board cuts in agricultural subsidies, duties, and tariffs worldwide.
offset by forest land losses. Also, because losses of tropical forest ecosystems represent a significant source of atmospheric carbon dioxide, these results indicate that a positive feedback loop between global warming and tropical deforestation may exist.

4.1.2. Effects of world population growth

Forest land in moist tropical areas increases slightly (0.10 to 0.26 percent) in our population growth scenarios (Table 12). These increases are associated with a shift of land from the manufacturing and services sectors (the capital- and labor-intensive sectors) to the land-intensive sectors (i.e., crop, livestock, and forestry). The shift occurs for two reasons: (a) the quantity of land is fixed, and (b) it is harder to substitute labor, capital, and water for land in the land-intensive sectors than in the other sectors of the economy. Timber harvest rates and per-hectare timber inventories also increase in the population growth scenarios. When capital growth is set equal to labor growth, per-hectare timber inventories grow faster than timber harvest rates, implying that economic depletion of tropical forests is slowed. When capital growth is set equal to zero, however, economic depletion of tropical forests increases.

These results indicate that world population growth might slightly stimulate reforestation in moist tropical areas of Latin America, Africa, and Asia. Given the increases in per-hectare timber inventories, reforestation would probably mean greater reliance on tree plantations. Investments in timber inventories must be relatively large, however, to avoid economic depletion of tropical forests. At the same time, increases in timber harvest rates and per-hectare timber inventories suggest that population growth probably has an adverse effect on natural forest ecosystems in the tropics.

4.1.3. Effects of revised agricultural trade policy

In this scenario, lower producer subsidies in the United States and European Community reduce the supply of agricultural products from these regions
Table 13
Changes in forest land, timber harvest rates, per-hectare timber inventories, forestry export prices, crop export prices, per capita income, total debt service, relative debt service, real exchange rate, cereal self-sufficiency ratio, and arable land ratio in Southeast Asia due to various potential global changes

<table>
<thead>
<tr>
<th>Global change</th>
<th>Forest land change</th>
<th>Harvest rate change</th>
<th>Timber inventory change</th>
<th>Export prices change</th>
<th>Per capita income change</th>
<th>Total debt service change</th>
<th>Relative debt service change</th>
<th>Real exchange rate change</th>
<th>Cereal self-sufficiency change</th>
<th>Arable land ratio change</th>
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</thead>
<tbody>
<tr>
<td>Climate change</td>
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<tr>
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<td>1.62</td>
<td>-0.90</td>
<td>-3.94</td>
<td>-2.96</td>
<td>0.085</td>
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<td>-0.19</td>
</tr>
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<td>2.92</td>
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<td>-3.48</td>
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<td>0.94</td>
<td>0.41</td>
<td>0.303</td>
<td>0.14</td>
</tr>
</tbody>
</table>

* Southeast Asia is composed of Thailand, Indonesia, Philippines, Malaysia, and Singapore. Harvest rate is the amount of timber harvested per unit land area per year. Per capita income is per capita gross domestic product. Total debt service is saving minus investment. Relative debt service is the ratio of total debt service to total export earnings. Devaluation is measured by the price ratio of non-tradeable goods to tradeable goods. Cereal self-sufficiency is the proportion of domestically produced cereal out of total cereal consumption. Arable land ratio is the ratio of arable land to rural population. (We approximate changes in rural population by changes in farm labor.)

* Scenarios based on 5-year estimates of population and labor force growth derived from data on the 1985-1990 period (see WRI, 1992).

* Based on 30 percent across-the-board cuts in agricultural subsidies, duties, and tariffs worldwide.

while lower tariffs in United States, European Community, and Japan simultaneously increase the demand for other regions’ agricultural products. This induces greater crop and livestock production in Southeast Asia and other tropical areas. As more land is converted to agricultural purposes, forest land in moist tropical regions declines slightly (0.21 percent) as is shown in Table 12. Timber harvest rates and per-hectare timber inventories in these areas increase, respectively, by 0.18 and 0.27 percent. These results indicate that deregulating agricultural trade poses a relatively small economic threat to forestry sectors in moist tropical areas. The economic losses incurred when some forest land is converted to other uses are partially offset by a reduction in economic depletion: i.e., the increase in per-hectare timber inventories is larger than the increase in harvest rates. The threat to forest ecosystems in moist tropical regions posed by deregulating agricultural trade is slightly larger. All results—the decrease in forest land and the increases in both timber harvest rates and per-hectare inventories—portend negative ecological effects.

4.2. Effects on all forests in Southeast Asia

In this section we show that a framework that utilizes land use and cover as an integrating element in ecological economics can relate forest depletion to various economic variables. The economic variables considered were selected because they have been found to be significantly correlated with depletion of tropical forests in previous studies (Capistrano and Kiker, 1995; Kahn and McDonald, 1995). They,

18 We do not explain the results of Capistrano and Kiker (1995) or Kahn and McDonald (1995) in this paper. The major shocks and responses that coincided with their analyses’s time frame were related to exchange rate policies in the 1960s and food and energy shortages in the 1970s. Only our population growth scenarios are relevant to that period.
like the forest measures, are endogenously calculated by FARM's CGE model. The forest measures presented in this section are the same as those presented in the previous section. The measures presented in this section, however, pertain to all forests (not just those on LC 6), but in Southeast Asia only.

The forest effects in Southeast Asia (Table 13) are similar to those in moist tropical regions (Table 12). The only exception is that Southeast Asian timber harvest rates and per-hectare timber inventories increase in all four climate change scenarios, and, because the increase in per-hectare timber inventories is larger than the increase in harvest rates, economic depletion of remaining tropical forests decreases. All scenarios, therefore, are correlated with adverse effects in natural forest ecosystems in Southeast Asia.

We can also relate our forest measures to forest depletion (i.e., the area of closed broadleaf forest logged per year), the dependent variable in previous econometric studies (Capistrano and Kiker, 1995; Kahn and McDonald, 1995). Forest depletion is indicated either by decreases in forest land or by increases in timber harvest rates. The former recognizes that deforestation encompasses forest depletion. The latter recognizes that forest depletion can occur even though land use doesn't change. Old growth tropical forest can be logged, for example, and left to regenerate naturally. The latter also recognizes that increased harvest rates imply forest depletion at least in the short or intermediate run even when they may be more than offset by increases in per-hectare timber inventories in the long run.

Because forest land decreases and timber harvest rates increase in our global climate change and agricultural trade scenarios, we conclude that these global change scenarios are positively correlated with increased forest depletion in Southeast Asia. In the population growth scenarios, timber harvest rates increase, but so too does forest land. Whether the latter offsets the former is uncertain. We believe the case for increasing forest depletion is stronger, primarily because afforestation in Southeast Asia is likely to be associated with monocultural tree plantations rather than forests per se. Also, in the population growth scenario where capital growth is zero, the timber harvest rate increases more than the increase in per-hectare timber inventories: i.e., economic depletion occurs. When investment in timber inventories is low, then increased harvest rates are likely to depend on old-growth timber more than on new forest inventory.

The economic variables are as follows. The forestry export price is a real price index of all exported forestry products. The crop export price is a real price index of all exported crops. Per capita income is per capita real gross domestic product. Total debt service is the difference between domestic saving and domestic investment. Relative debt service is the ratio of total debt service to total export earnings. Our measure of the real exchange rate is the ratio of a real price index of tradeable commodities to a real price index of nontradeable commodities (i.e., primary factors). A real devaluation occurs when tradeable commodities become relatively more expensive. This measure is comparable to Capistrano and Kiker (1995)'s real devaluation rate (i.e., the annual percent rate of change of the real bilateral exchange rate between the domestic currency and the U.S. dollar). Cereal self-sufficiency is measured by the ratio of domestically produced cereal to total domestic cereal consumption. The arable land ratio is the ratio of arable land to labor in the crops sector.

Capistrano and Kiker (1995) found positive correlations between forest depletion and (1) per capita income, (2) crop export price, (3) real exchange rate, (4) cereal self-sufficiency ratio, (5) population, and (6) arable land ratio. They found a negative correlation between forest depletion and relative debt service and both negative and positive correlations between forest depletion and forestry export prices. Kahn and McDonald (1995) found positive correlations between forest depletion and (1) total debt service and (2) relative debt service.

In our global climate change scenarios, forest depletion is positively correlated with forestry export

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19 Capistrano and Kiker (1995) found positive correlations between forest depletion and (1) per capita income, (2) crop export price, (3) real exchange rate, (4) cereal self-sufficiency ratio, (5) population, and (6) arable land ratio. They found a negative correlation between forest depletion and relative debt service and both negative and positive correlations between forest depletion and forestry export prices. Kahn and McDonald (1995) found positive correlations between forest depletion and (1) total debt service and (2) relative debt service.

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19 In Capistrano and Kiker (1995), the arable land ratio is the ratio of arable land to rural population. We assume that labor in the crop sectors is highly and positively correlated with the rural population.

20 Kahn and McDonald's (1995) positive correlation between forest depletion and relative debt service was estimated on data pertaining to the 1981–1985 period. Capistrano and Kiker's (1995) negative correlation was estimated on data pertaining to 1972–1975; they found no correlation from 1981–1985 data.
prices, crop export prices, and arable land ratios, and negatively correlated with per capita income, total and relative debt service, and cereal self-sufficiency. Correlation with real exchange rates is mixed, though generally positive (Table 13). In the trade policy scenario, forest depletion is positively correlated with all economic variables except the arable land ratio. The positive sign on real per-capita income also indicates a positive correlation of deregulated trade with throughput.

If one assumes that forest depletion occurs in our population growth scenarios, then it is positively correlated with total and relative debt service, and is negatively correlated with crop export prices, per-capita income, the real exchange rate, and the arable land ratio. The correlation of forest depletion with forestry export prices and cereal self-sufficiency in the population growth scenarios is mixed—positive when capital growth equals labor growth and negative when capital growth equal zero. The overall implication of all the results is that the nature of correlation (i.e., positive or negative) between forest depletion in Southeast Asia and a particular economic variable depends on the type of global change occurring. These results are in line with previous econometric research as well.

5. Conclusions

Because land is a basic source of mass and energy throughput in all terrestrial ecosystems, land use and cover represents an integrating element in ecological economics. The usefulness of this concept was illustrated with scenarios of global climate change, population growth, and deregulation of agricultural trade. Results from our scenarios indicate that such changes are likely to have adverse effects on the health and integrity of tropical forest ecosystems. Results from our scenarios also indicate that forest depletion in Southeast Asia can be correlated with numerous economic indicators. Whether the correlation with a particular economic variable is positive or negative depends on the global change scenario. This merely reflects the fact that interactions between economic and ecological phenomena are complex. Other changes (or the same changes in different regions) could yield a different set of relationships between forest depletion and the economic variables considered here.

Modeling capabilities can be expanded by adding economic and ecological detail, including more material on throughput, and developing methods for simulating dynamic analyses. Economic detail, for example, can be added by increasing the number of regions and sectors in the modeling framework. This can be done with the revised GTAP database (Hertel, 1994). Improved throughput analyses require better tracking of resource stocks (soil, water, forests, fossil fuels, etc.) coupled with waste emission coefficients for various economic sectors. Methods for simulating inter- and intraregional labor migration, investment in human and physical capital, and technological change are needed to conduct dynamic analyses. And as these new data and methods become available, models that fully simulate economic-ecological integration will become more and more of a reality.

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References


Schlesinger, M.E. and Zhao, A.C., 1989. Seasonal Climatic Changes Induced by Doubled CO2 as Simulated by the OSU Atmospheric GCM/Mixed-Layer Ocean Model. Report No. 70, Climate Research Institute, Oregon State University, Corvallis, OR.


