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FORESTS AND CLIMATE CHANGE

Economic perspectives

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Abstract

This chapter examines economic analysis of climate change impacts in the forest sector. It begins with a discussion of the potential effects of climate change on ecosystem and then discusses how those impacts can be introduced into an economic model. One critical issue in economic modeling identified in the paper is that the way in which ecosystem impacts are introduced into the economic model could have important implications for the results. Thus, models that incorporate dieback directly will estimate different impacts than those that incorporate dieback through changes in growth and yield. Given the importance of potential dieback in climate change impacts, this difference in modeling can have implications for measuring climate change adaptation and damages. To illustrate how these modeling choices can affect results, the chapter presents a simple numerical example of climate change impacts. The study then presents a literature review discussing the results of climate change impact studies to date. It concludes with a discussion about potential research topics that could and should be addressed with future research.

Keywords

Climate change, dynamic optimization, dieback, disturbance, ecosystems

Introduction

The world's forest ecosystems are amazingly diverse, ranging from dense tropical rainforests along the equatorial belt to boreal forests covering the northern tier of the world. Without humans, forests would cover over 6 billion hectares (FAO, 2012). Conversion of land to agriculture in the past several centuries, however, has reduced this to less than 4 billion hectares today. In recent decades, the rate of converting forests to agriculture has stabilized in temperate regions, while conversion of forests to agriculture continues in the tropics (Houghton, 1999, 2003; FAO, 2010). Although most expansion of agriculture has occurred in the tropics in recent decades, forest cover loss occurs in virtually all continents for a number of reasons (Hansen, Stehman and Potapov, 2010), including harvesting, forest fires or other disturbances, or urbanization.

There is substantial concern that climate change could have large impacts on forests globally. The impacts projected by many ecosystem models include larger and more intense disturbance events, such as forest fires or bug infestations, changes in the distribution of different types of trees and shifts in the rates of growth of species (IPCC, 2007). Such changes would clearly have large-scale ecological and economic implications, from changes in ecosystem service flows to losses in economic value. As a consequence, there has been substantial research in the past two decades to try to determine how large these ecological and economic impacts may be.

The impacts, of course, will vary depending on location and type of forests. As a rule, timber harvesting has become more sustainable in the past century, shifting from primarily old-growth extraction to a larger share of plantation forestry (Daigneault, Sohngen and Sedjo, 2008). The economic implications of climate change on highly managed plantations will be substantially different than the implications of climate change on old-growth forests. As more and more timber output is derived from plantations, a larger share of forests is left in a natural state with very little management. This trend has important implications for measuring the impacts of climate change in forests and for assessing the scope of adaptation. For example, there are many more opportunities for adaptation in forests that are heavily managed than in regions that are not managed. Regions that are relatively unmanaged may experience large-scale ecosystem changes, with little economic impact.

This chapter examines the implications of climate change and forests. It begins with a discussion of the impacts of climate change on ecosystems. The results of ecosystem models dictate what we know about the potential economic impacts of climate change in the forestry sector. The chapter then turns to discuss how these ecological impacts are integrated into economic models. A formal economic model is presented and examples are shown illustrating how ecosystem impacts can be linked into the economic model. The results of the economic model change substantially depending on how the ecosystem results are linked into the economic model, illustrating the importance of conducting integrated research. The final section examines the existing literature to discuss the potential impacts of climate change in markets.

Modeling the impacts of climate change in timber markets

Modeling climate change impacts on timberland use and management is substantially more complex than modeling climate change impacts in most other sectors. The impacts in many other sectors often can be modeled econometrically, with reduced form models that link average temperature and precipitation to output (e.g. Mendelsohn, Nordhaus and Shaw, 1994). Forestry, however, is inherently dynamic, and as a result, efforts to model impacts in the forestry sector require a different approach.

The typical approach taken by most analyses thus far involves linking climate models to ecosystem models to economic models (Figure 15.1). The data sets do not currently exist to go straight from climate to economic models, so it is necessary to use biological models to first measure the impacts on ecosystems. The outputs from ecosystem models typically cannot be used directly in most economic models, however. For example, many economic models aggregate inventories across space, and these aggregations occur at different scales than those used by the ecosystem models. Alternatively, many ecosystem models operate at different time scales than economic models. Economic modelers must take additional steps, often in conjunction with ecosystem modelers, to utilize the appropriate results from the ecological models within the economic models.

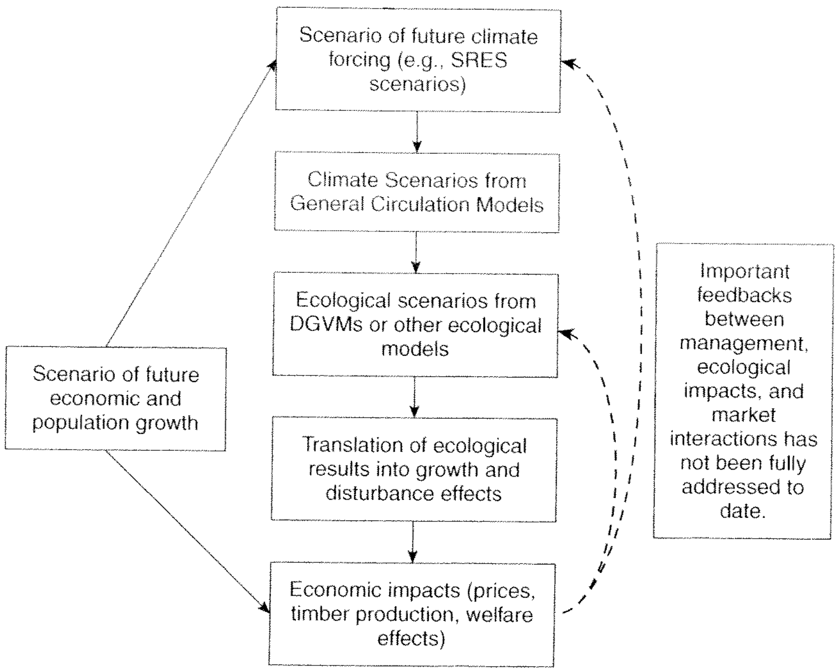

Figure 15.1 Integrated climate-forest modeling systems (from Balgis et al., 2009).

Potential climate change impacts on forested ecosystems

Ecological models suggest a wide range of potential impacts of climate change in forests, including shifts in the rate of forest growth, shifts in the disturbance regimes and changes in the distribution of different species (Balgis et al., 2009). Given that climate change is likely to strengthen over time, these changes will continue to affect forests over long periods of time. This section examines these impacts in more detail.

Growth changes

Tree growth is heavily dependent on both temperature and precipitation, and as climate influences these variables in any given location, trees could start to grow more quickly or more slowly depending on the impact of climate change. Additional precipitation will increase the growth rate of trees in locations where growth is limited by moisture, while higher temperatures or longer growing seasons could enhance growth if accompanied by adequate precipitation. The critical question with climate change will be whether higher temperatures are accompanied by adequate precipitation.

Additional carbon dioxide in the atmosphere should also increase plant growth. Because trees convert carbon dioxide (CO_2) from the atmosphere into woody biomass, higher concentrations of CO_2 are expected to help trees grow. Estimates suggest that a doubling of CO_2 from preindustrial times should increase tree growth by around 20%–25% (Norby et al., 2005). Indeed, some evidence exists now suggesting that forest growth is already accelerating as a result of higher CO_2 concentrations (Boisvenue and Running, 2006). Modeling studies suggest that over the past century, the combined impact of climate change and higher CO_2 concentrations have resulted in increased forest growth of 0.3% to 0.6% per year (Scholze, Knorr, Arnell and Prentice, 2006).

Although climate change and CO_2 fertilization could increase tree growth, that increase may not automatically convert into ecosystems with more live biomass. The effects on the landscape will be complicated by numerous additional factors. For instance, if plant growth is not limited by temperature or precipitation, it is likely to be limited by other nutrients, such as nitrogen. If these other nutrients are not available in adequate amounts in a given location, the effects of climate change will be reduced. Furthermore, one of the most important influences on forests is disturbance. If disturbance regimes change, then even if gross growth is projected to increase, net growth may not increase at all. If disturbances increase enough, then net growth may in fact be negative.

Dieback

As climate changes in a given location, tree species and forested ecosystems will end up in climatic conditions that differ from their optimum. For instance, if temperatures rise, but there is not enough additional precipitation, ecosystems could be susceptible to increases in forest fire activity. As a consequence, dieback from forest fires, windthrow, ice storms or insect infestations represents a bigger concern than climate-induced changes in forest growth (Adams et al., 2009).

Some studies suggest that current observed increases in forest fires may be caused by climate change (Westerling, Hidalgo, Cayan, and Swetnam, 2006). More recently, portions of western Canada have been devastated by large-scale insect infestations, and there is concern that the scales of impacts of recent widespread insect infestations are related to climate change (Kurz et al., 2008). Ecosystem models imply that climate change may cause more and more damage in the future by causing conditions that lead to increases in forest fires and other disturbances (Bachelet, Lenihan, Drapek and Neilson, 2008).

Dieback is one of the most important ecological effects to consider when modeling climate change because it can have substantial impacts if modeled in economic models (Sohngen and Mendelsohn, 1998). It also will have different impacts in different regions depending on the management regime. If climate change increases potential dieback in areas where forests are heavily managed, land owners and managers are more likely to adapt by changing their management strategy, e.g. by salvaging or by changing the date of harvest. If dieback increases in regions where management is sparse or does not occur (e.g. boreal zones), then the dieback may have large ecological consequences but little direct economic impact. Either way, changes in disturbance regimes can have long-term consequences for forest ecosystems by altering the age class distribution of forests for years to come.

Species shift

Individual tree species can live within a wide range of temperature and precipitation levels, but they also have a limited range of temperature and precipitation where they gain competitive advantage over other trees or plants. Thus, the optimal tree types in any given location will be a function of temperature and precipitation. As climate changes, one would expect the optimal ecological mix of tree species to adjust. Most trees will move further north and upslope in mountainous regions. Maps of potential changes in the United States are available from Iverson and Prasad (1998) and Iverson, Prasad, Matthews and Peters (2008). These maps illustrate potentially large changes in tree locations under climate scenarios proposed today.

With climate change, species are generally expected to move northward and upslope. The rate of movement of trees, if left to natural forces alone, such as the spread of seeds by birds or wind, could take long periods of time to occur. If humans assist in the movement of tree species, as they are widely expected to do with our long history of moving trees, the movement of species northward is expected to occur much more rapidly. It is useful to use economic models in addition to ecological models to measure the movement of species, given the important influence humans can have on the process.

Economic modeling

In order to assess the economics of these ecosystem impacts, one must develop economic models that account for several key features. First, the models must be dynamic. Dynamics in economics means not just capturing changes over time, but also modeling economic decision making in a dynamic sense. When humans manage forests, they must do so with one eye on the future. For instance, the harvesting decision is often based not only on the current stock of timber available to harvest, but also on an understanding about the growth of the trees and the likely change in timber prices over the coming year. Landowners will make different decisions depending on whether their trees are currently growing quickly or slowly, and whether they anticipate prices to increase, stay the same or fall over the coming year.

Beyond the harvesting decision, which may require looking forward for only a short time horizon, most planting decisions require very long time horizons. Many species will not mature for 20, 30 or more than 50 years. Any decision to spend resources planting or managing forests that cannot be harvested for such long time horizons require some information or assumptions about what future market conditions will be. When we think of dynamics in economics, models must be developed to account for these long-term considerations of landowners and managers.

Second, models must be clear about whether they assume prices are exogenous or endogenous. On the one hand, climate change is such a widespread phenomenon, which will affect growth and productivity in ecosystems throughout the world, that prices will certainly be affected as climate change occurs. Even regions that do not experience large ecological changes could be affected by climate change if timber prices or land prices change. Although this suggests that it is important to measure the price effects associated with climate change, economic analyses need not focus on global changes to provide insights. For instance, if modelers are interested primarily in understanding how stand management changes when forests are perturbed by climate change, then they may choose to use stand level models with prices fixed. Furthermore, if analysts are interested in conducting stochastic analysis of the effects of changes in forest fires (e.g. Stainback and Alavalapati, 2004; Amacher, Malik and Haight, 2005; Daigneault, Miranda and Sohngen, 2010), they likely will need to assume that prices are exogenous in order to solve the models. The key issue is that modelers should be clear about their assumptions when developing their models.

Third, modelers must be careful when integrating ecosystem impacts into their economic models. The way in which ecological impacts are actually used in economic models can make a large difference to the impacts. For example, suppose climate change causes more disturbance in a given region, and hence a slowdown in the net growth of timber over time. Modelers could directly model the disturbance, or they could simply alter their yield functions to account for the implied changes in net growth. This difference in modeling the same phenomenon would alter the results substantially, as shown subsequently. It is consequently very important for economic modelers to understand the results proposed by ecological models and carefully integrate those results into their models.

Illustrative example of a dynamic forestry model of climate impacts

To illustrate the importance of these features in modeling climate change impacts, this section develops a simple model of climate change and applies it to forestry analysis. The model follows that laid out originally in Sohngen and Sedjo (1998). It is a simplified dynamic timber model that assumes only a single timber type but also assumes that timber prices are endogenous. The economic model is first presented. Then, two of the climate change impacts described previously, changes in growth and dieback, are integrated into the model. Finally, the results of the model are compared assuming different methods of integrating the ecological phenomenon.

The forestry model is assumed to maximize the net present value of consumer's plus producer's surplus in forestry. To develop the model, it is useful to start with the inverse demand function, given as

$$P_t = \alpha_t - \beta(\Sigma_a H_{a,t} V_a) \qquad (1)$$

where P_t is timber price, α_t and β are demand function parameters, $H_{a,t}$ is the area of forest harvested in age class a and time period t and V_a is the volume of timber in the age class a. Total annual harvest is $\Sigma_a H_{a,t} V_a$. Given this demand function, annual welfare in timber markets is

$$W_t = \alpha\left(\sum_a H_{a,t}V_a\right) - \left(\tfrac{1}{2}\right)\beta\left(\sum_a H_{a,t}V_a\right)^2 - c\left(\sum_a H_{a,t}V_a\right) - mG_t \qquad (2)$$

where c is the constant marginal cost of harvesting timber, m is the cost of replanting trees and G_t is the area of land replanted each year. The objective of the model is to choose $H_{a,t}$ and G_t so as to maximize the present value of welfare:

$$\sum_{t=1}^{\infty} \rho^t W_t \qquad (3)$$

The term ρ^t is discount factor. The function in equation (3) is maximized subject to the following constraints, where $X_{a,t}$ is the area of land in forest in age class a at time period t:

$$X_{a+1,t+1} = X_{a,t} - H_{a,t} \qquad (4)$$

$$X_{1,t+1} = G_t \qquad (5)$$

$$H_{a,t} \leq X_{a,t} \qquad (6)$$

$$H_{a,t}, X_{a,t}, G_t \geq 0 \qquad (7)$$

This model is well defined, and the baseline case is one in which there are no climate perturbations. Demand shifts out (i.e. α_t increases over time) as income and population increase, driving demand up. Alternatively, of course, recycling and environmental concerns could slow the rate of growth of timber harvesting. The base case can be solved in a fairly straightforward way, determining the optimal timber price, rotation age and forest stock. One would need to impose terminal conditions on the model, but as long as those terminal conditions are imposed sufficiently far into the future, they will not affect the solution over the period of interest (say the first 50 to 100 years).

The climate change impacts described previously will change various features of this model. The first impact of climate change is a change in timber growth, which alters forest yield, V_a, over time. These changes will not occur all at once, and in fact, they are likely to occur slowly over time. Furthermore, changes in forest growth affect only future growth, not the standing stock of timber. This is a critical distinction to make and requires modelers to take care when introducing the impact of climate change into their model.

For example, suppose tree growth increases by 5% from one period to the next. One cannot simply multiply the yield function by 1.05 to determine the new yield for standing trees. The stock of trees that is already standing is the result of historical growth, which will not be affected by this future change. Modelers must be careful to link changes in tree growth caused by climate change only to annual increments in tree growth, and specifically only to future growth.

The yield function for trees is typically given as the sum of historical annual growth,

$$V_a = \sum_0^a AG_a \tag{8}$$

where AG_a is the annual growth of trees. The volume in any year is the sum of the growth up to time period a. If the impacts of climate change on annual growth are γ_a, then the climate adjusted yield function becomes:

$$V_a^C = \sum_0^a \gamma_a AG_a \tag{9}$$

The effect of climate change on the forest in this model is captured by γ_a. This parameter must be obtained from ecosystem models.

To see how changes in forest growth are incorporated into economic models, consider a southern pine stand that is 20 years old when climate change starts affecting tree growth. If climate change causes the stand to grow 2% more quickly each year, then Figure 15.2 shows the change that should be modeled. The increase in tree growth does not lead instantly to a bigger tree in time period 20. Instead, in time period 20, the annual growth in year 20 is increased by 2%, so the volume in year 21 will be modestly larger than it would have been without climate change. Subsequent annual growth is increased as well, so that the effect of climate change accumulates over time. Faster growth due to climate change does ultimately lead to more tree volume, but only after many years. Of course, if the timber manager harvests the stand and starts over, the new stand will be growing at a significantly faster rate than the original stand.

The dieback effect described previously can be modeled similarly to the yield changes, by modeling net effects, or it can be modeled directly as a dieback effect. The method of actually implementing the ecological change will have important implications for the economic results. One way modelers have accounted for dieback is through net yield effects. Most estimated yield functions used in forestry models are 'net' yield functions, meaning that they model timber volume net of all growth and dieback processes. As a consequence, many economic modelers have simply aggregated the impact of dieback with the growth effects described previously to determine net yield impacts (Joyce et al., 1995; Perez-Garcia, Joyce, McGuire and Xiao, 2002). Modelers using this approach capture the net effects of changes in tree growth and changes in dieback together. If tree growth increases but dieback also increases, the net effect of climate change on biomass on site may actually be negative. That is, dieback may be large enough and strong enough to reduce overall biomass on forested sites.

Alternatively, one can directly incorporate dieback in the previous model through equation (4), as has been done in Sohngen and Mendelsohn (1998) and Sohngen, Mendelsohn and Sedjo

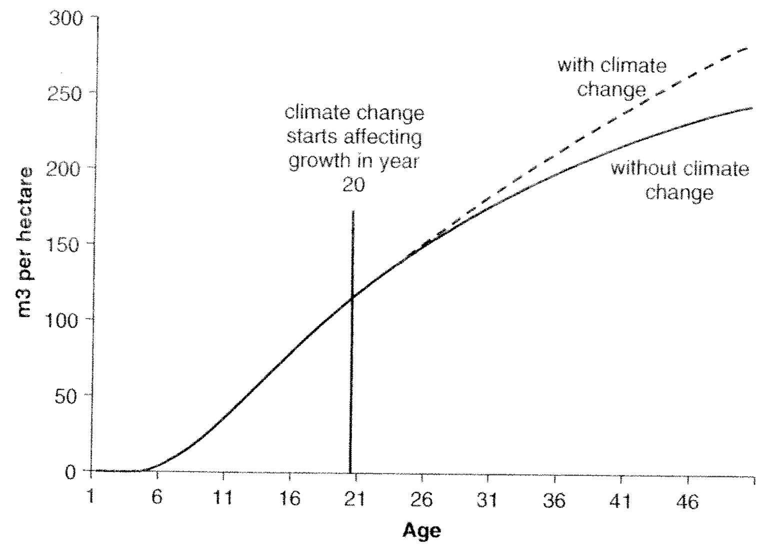

Figure 15.2 Volume of a southern pine stand with and without climate change effects on tree growth. The impact of climate change is an increase in stand growth by 2% per year starting in year 20.

(2001). If the proportion of stock that dies back each year is given as δ_t, then equation (4) can be adjusted to incorporate dieback directly as:

$$X_{a+1,t+1} = X_{a,t} - H_{a,t} - \delta_t X_{a,t} \tag{10}$$

The adjustment in equation (10) is fairly simple in that it assumes that all age classes of trees will be affected similarly by climate change. Ecosystem models may provide data that suggests differing impacts depending on the age of the trees. This could be incorporated into the model in a fairly straightforward way by modeling δ_t also as a function of a.

Modeling dieback via equation (10) rather than as a net effect in the yield adjustment shown in equation (9), even if the net effects from the ecosystem model are the same, will lead to far different estimates of the economic impacts. The perturbation in equation (10) will induce dynamic stock adjustments in a dynamic forestry model, such as incentives to harvest forests before dieback occurs. Modelers who attempt to model the same ecological phenomenon using only net yield changes will not be able to capture these types of adaptations. As a consequence, they likely will show fairly modest impacts of climate change on timber markets, at least initially. Modelers who use equation (10) combined with equation (9) likely will show larger impacts, be they negative or positive, in markets.

Beyond yield changes and dieback, it is important also to account for changes in area, or the effect of climate change on the distribution of tree species. Many species are likely to move northward or upslope with climate change. For commercially important species, the change most likely will be driven by humans who shift the species across space. In natural areas, the changes are likely to occur much more slowly.

A shift in species distribution can be modeled via a change in constraints in the previous model. For example, the total area of the timber type in the model can be constrained to be less than a given amount. The model described previously provides the area planted as a decision variable; therefore, the area of forests can be expanded or reduced over time through replanting decisions. These replanting decisions will be a function of the allowable area for the forest type and the economic efficiency of planting (i.e. whether the present value of replanting at a given time exceeds the marginal costs). The efficient replanting decision can be shown by taking first order conditions on the model with respect to G_t.

Numerical simulation

To illustrate the potential implications of climate change on markets, the model described through previous equations is programmed and simulated for a simple single region forestry sector. The model uses parameters developed originally by Sohngen and Sedjo (1998). The demand function is given as:

$$P_t = 40A_t - 0.084(\Sigma_a H_{a,t} V_a) \tag{11}$$

and the timber yield function is given as

$$V_a = \exp(7.82 - 52.9/a) \tag{12}$$

The term A_t accounts for growth in timber demand over time due to population and income growth in the economy. The forest in this model initially has 500,000 ha in each of 32 age classes. For the purposes of this analysis, $X_{a,t}$ is given in millions of hectares, so each of the timber age classes has 0.5 million ha of trees. The age of 32 years is approximately the Faustmann rotation for the forest if $A_t = 1$, so the forest starts out roughly in steady state if demand is constant. For the purposes of this example, it is assumed that timber demand increases 1% per year, but that the rate of growth in demand slows over time.

For this analysis, the area of timberland is assumed to remain constant. This simplifying assumption means that we impose another constraint on the dynamic model shown previously, namely that the area of timberland replanted each year equals the area of timberland harvested last year:

$$X_{1,t+1} = \Sigma_a H_{a,t} \tag{13}$$

As a result of this simplifying assumption, in the climate analysis it is not possible to consider the effects of changes in forestland area; however, this simplification allows us to focus on the effects of the yield changes and the implications of different methods of modeling forest dieback. The model is programmed and run in GAMS for 200 years. A terminal condition is imposed at that time, but because only the first 100 years of results are shown, this terminal condition has little effect on the results examined.

The base scenario assumes no climate change, and demand grows. Demand increases 1% per year initially, but the rate of increase slows over time so that eventually it is stable. Timber prices rise over time, but the rate of growth slows (Figure 15.3). An interesting dynamic adjustment occurs with the rising demand for timber. The total forest area is fixed, so timberland cannot be expanded to satisfy the rising demand; however, the model can still accommodate additional timber output in the long run by increasing the rotation age. As a result of the increasing demand, the model will shift the rotation age from about 32 years initially to between 33 and 34 years of age during the transition period. In a dynamic model, increasing the rotation age leads initially to lower timber harvests. The only way to increase rotations is to withhold timber from the market initially. Over time, with higher rotation ages, supply will expand and slow the

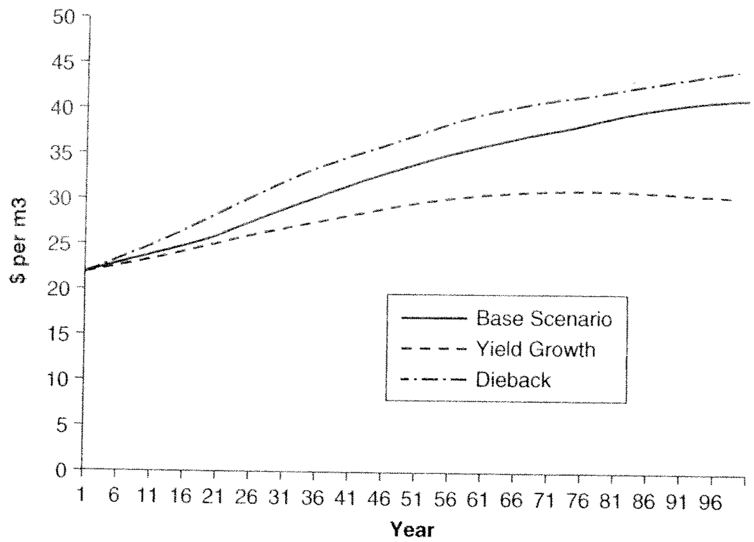

Figure 15.3 Representative price paths in the forestry model for the base scenario, the yield growth scenario, and the dieback scenario.

growth in prices. Thus, in this example, timber supply initially falls to accommodate a rise in rotation age, and this adjustment ultimately expands timber supply and reduces the impact of future demand increases on timber prices.

The first climate scenario assumes a net yield increase of 0.5% per year for 100 years. After 100 years, timber yields are assumed to stabilize at the higher level. Timber prices rise more slowly under this scenario because higher yields offset the demand increases (Figure 15.3). Timber prices do not change very much in the first couple of decades; in fact, the price change is less than half the yield change. For example, in year 10 yields have increased 5%, but prices fall only 1.6% relative to the base. The reason for this is fairly straightforward; although growth has increased substantially, all timber harvested in the first 10 years was already at least 20 years old at the beginning of the simulation period, so the total effect of the yield increase on the volume of timber available for harvest is limited. Ultimately prices begin to fall as the cumulative effects of the yield increases outpace demand growth (recall, demand growth is slowing and ultimately demand is stable).

The second climate scenario assumes that 1% of the forest dies back each year due to forest fires. This proportion of dieback is assumed to remain constant over time. This differs from the way the yield increase discussed previously is modeled (where it is assumed that the yield increase grows over time). It is also assumed that 30% of the forest material that dies back can be salvaged. In the first assessment of this scenario shown in Figure 15.3, it is assumed that there is no yield increase in this scenario, i.e. yields remain at their baseline level. This allows us to examine the implications of the increased disturbance effects in isolation.

With an increase in disturbance, prices fall modestly in the first few years. There are two reasons for this. First, the model incorporates salvage, and salvaged timber enters the market and lowers prices. Second, the economic incentives when disturbance occurs suggest that rotation ages should fall (Reed, 1984). With additional disturbance, landowners would prefer to harvest trees sooner rather than lose a large portion of the stock (70% that is not salvaged) to dieback. In order to reduce rotation ages, more timber has to be harvested initially, so this increases supply in initial periods. By shifting to shorter rotation ages, however, long-term timber supply falls. Thus, the dynamic adjustment to dieback entails at first a reduction in timber prices and then an increase relative to the base.

Thus far, changes in forest yields and dieback are modeled separately. The most likely climate scenario, however, will include some change in yields and some change in the area of land that dies back every year due to an increase in forest fires or other natural disturbances. As discussed previously, economists may choose to model the yield and dieback effects directly, or they may choose to model the net effects of both processes on aggregate timber yields. Whether one models the effects of these two climate impacts as a net effect or as separate impacts will have critical implications for estimating the resulting economic impact.

With the simple model developed previously, it is possible to compare how these alternative methods of modeling climate effects would influence the resulting estimates of the economic impacts. The analysis in Sohngen and Mendelsohn (1998) and Sohngen et al. (2001) used an approach that accounts for the two effects separately, such that they modeled the gross effects of the yield changes (+0.5% per year) and the gross effects of the dieback (1.0% of the stock dies back each year) as separate perturbations in the same model. Alternatively, one could model the net effect of both dieback and yield changes on total carbon stocks. The change in total carbon stocks implied by these two effects would then be used to adjust forestry yield functions used in the economic model. This is the approach used by Joyce et al. (1995) and Perez-Garcia et al. (2002). For our previous analysis, when dieback increases to a 1.0% loss each year, and the yield is increasing at 0.5% per year, total forest carbon will fall at first. Total forest carbon falls because the increase in dieback initially is greater than the yield increases, particularly for existing stocks. Over the long run, total forest carbon will rise at nearly 0.5% per year as the steady annual increases in forest yields ultimately overtake the losses due to dieback.

The results of both of these approaches are presented in Figure 15.4. The first approach is titled 'Yield + Dieback' and the second approach is titled 'Net Effects'. When dieback and yield changes are modeled directly, prices fall initially because additional timber makes its way onto markets through salvage, and harvests increase as foresters reduce the optimal rotation age of their forest. As noted previously, this avoids losing 70% of the stock that dies back near the optimal rotation age. Although dieback reduces the stock modestly, continued increases in yields ultimately overtake the losses due to dieback and there is substantially more stock in forests and greater supply. Hence, prices are lower in the long run when dieback and yield changes are modeled separately.

Under the net effects model, the market takes more time to adapt the forest to climate change (Figure 15.4). As a result of the dieback, net forest yields are projected to fall initially. By year 25, net yields have risen above the baseline and remain greater than in the baseline for the remainder of the scenario. Although dieback is actually occurring in the forest, the market model does not account for it directly; thus, the model has no way to respond to it directly. What the model sees is a reduction in forest growth in the initial periods. It responds to this reduction in forest growth with lower harvests and higher prices, which is exactly the opposite response of the model that incorporates dieback directly. Over the long run, prices fall relative to the baseline, but not as much as in the model that accounts for dieback directly, because it takes longer to adjust the forest to climate change with this approach to economic modeling.

The two different models lead to very different welfare effects as well. To measure welfare, the net present value of consumer's plus producer's surplus is calculated for each of the scenarios (baseline and two climate scenarios). This calculation is given in equation (3). The with and without (baseline) scenarios are then compared to determine the welfare effects of climate change. Under the yield + dieback scenario, welfare declines by $1.4 million, while in the net

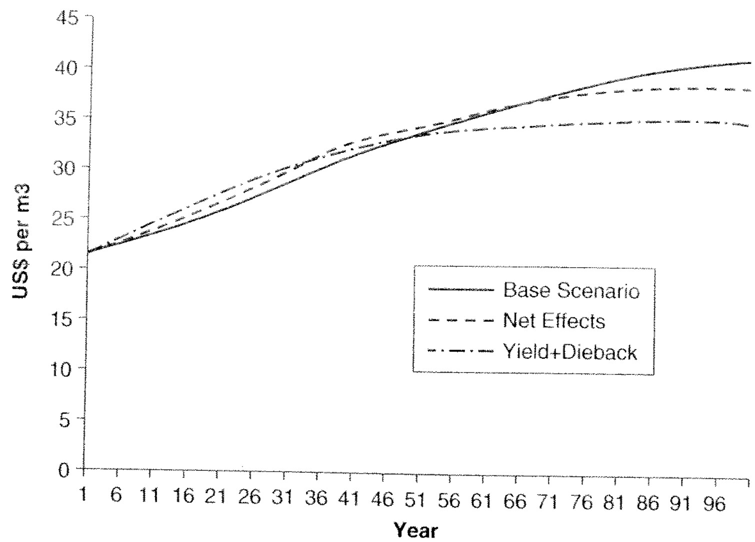

Figure 15.4 Representative price paths in the forestry model for the base scenario, the "yield + dieback" scenario, and the "net effects" scenario.

effects scenario, welfare declines by $2.7 million. Modeling the net effects without directly modeling disturbance potentially leads to a large over-statement of the welfare effects. The reason for this is that the model allows many fewer options for adaptation when only the net effects are modeled.

These results illustrate that the method of introducing climate change into the economic model has as much of an impact on the measurement of the impacts as the scale of the impacts themselves. In both cases, climate change is projected to decrease welfare, but when the effects of climate change are modeled directly (i.e. through the yield + dieback model), more adaptive responses are measured, and the welfare effect is estimated to be smaller. In economic analysis that is reliant on ecological modeling, it is thus critical to attempt to measure the ecosystem effects properly and to incorporate them into the economic model appropriately.

Review of economic estimates in the literature

Compared to agricultural systems, economic impacts and adaptation in forest systems are much more difficult to assess. One reason is that the data sets are not as widely available to assess economic outcomes from climate variation, such as in the Ricardian or hedonic studies (Mendelsohn et al., 1994; Dechenes and Greenstone, 2007). Another reason for this is that forests involve dynamic resources and investments which take many years to provide benefits. One needs dynamic models to assess impacts in forests (Sohngen and Mendelsohn, 1998).

Despite the complexities, there have been a number of economic analyses of climate change impacts in forests to date. The earlier economic analyses focused on the United States and suggested that climate change would increase timber supply and reduce timber prices (Joyce et al., 1995; Sohngen and Mendelsohn, 1998). The largest impacts in the United States occurred in the South and Pacific Northwest, which makes sense given that these regions also have the largest timber sectors. Sohngen and Mendelsohn (1998) directly account for changes in dieback and disturbance in addition to changes in timber yield. They also allow species to shift from one region to another. Joyce et al. (1995) focus on net yield changes and assume that forest types remain in the same location over time.

One problem with the earlier studies is that they were national in scope. Climate change is likely to have global impacts, and the effects of climate change in markets in any given region is a function not only of the underlying ecological impacts, but also of the changes that occur in other regions. For example, if timber supply expands dramatically across the world, adaptations that would otherwise be efficient in the United States when evaluated by a model of only the United States may not be efficient if evaluated with a global model. Sohngen et al. (2001) and Perez-Garcia et al. (2002) both develop dynamic models to address this issue. Sohngen et al. (2001) use similar methods to those in Sohngen and Mendelsohn (1998) to model climate change impacts. They find that climate change in general is likely to increase global timber supply, although subtropical and tropical regions gain more. With shorter rotation periods, subtropical and tropical regions are able to adapt fairly rapidly to climate change.

Temperate and boreal regions, in fact, may experience losses in some climate scenarios because prices fall enough to make many adaptation options inefficient. Furthermore, temperate and boreal regions experience significantly greater dieback with climate change, further adding to economic losses. Over the long run, the global studies suggest that output in northern regions does expand significantly relative to the baseline. Thus, places like Canada, northern Europe and Russia appear to be vulnerable in the short run due to dieback, but they appear to benefit in the long run.

Emerging issues

There are a number of important emerging issues in the adaptation of forests to climate change. Most studies have focused on adaptation in managed forests, and a growing proportion of timber is derived from managed plantation forests. Daigneault et al. (2008) suggest that the amount of timber supplied from managed plantations will continue to increase in the future. Sohngen et al. (2001) illustrate how climate change likely will strengthen this trend by enhancing subtropical forests relative to boreal and temperate regions. Shorter-rotation plantation species can be adapted across space and time more readily than many of the longer-rotation species and unmanaged forests currently used for a large share of the world's timber supply.

Although the results of climate analyses have important implications for adaptation in the timber sector, they have equally important implications for adaptation in unmanaged forested regions. As the share of plantation forests grows, a larger share of forests around the world is being left unmanaged each year due to economic circumstances. Higher productivity in plantation forests is driving down timber prices, and these lower prices are reducing the efficiency of extracting timber in regions that are not managed. Practically, this means that as climate change affects the world's ecosystems, managers may or may not be available to help adaptation along. If there is little economic incentive to manage forests without climate change, the effects of climate change are unlikely to make management more efficient.

Forests are not only being reserved for economic reasons; they are also being reserved for ecological reasons. Many parks and reserves have been established over the past 100 years to protect places with unique features or ecosystem attributes. These locations may have high biodiversity, an abundance of plant and animal life or some other features that provide incentives for government to protect them. With climate change, however, many of these forests may be imperiled. This chapter has not addressed how adaptation may occur in these reserved forests.

It is beyond the scope of this chapter to detail adaptation plans for public forests and preserves, but it is worthwhile noting that it is likely that adaptation in these areas, especially those with high ecosystem value, will be substantially more difficult than adaptation in private forestlands. Many private forestlands are managed with a fairly simple set of objectives, such as maximizing the value of the land in timber, or providing income with enhancing recreational opportunities. Public forests, and particularly those with substantial ecosystem value, are often managed with many objectives. They also have many stakeholders. Developing adaptation plans will be exceedingly difficult for these forests, given the many individuals who will have a say in the plan. Carrying out the plans likely will be even harder.

One potential response to climate change is to sequester carbon in forests by expanding the area of forests, changing forestland management or reducing deforestation. Estimates indicate that forestry could efficiently provide up to 30% of the total reduction in CO_2 this century (Sohngen and Mendelsohn, 2003). None of the studies that have examined carbon sequestration in forests, however, have fully considered the effects of climate change. Climate change will undoubtedly have large implications for carbon sequestration given the potential shifts in dieback, species range and forest growth. Future studies of carbon sequestration should more carefully account for potential climate change impacts.

A final emerging issue to consider relates to the growth in biofuels as an energy source. With higher energy prices in recent years, there has been a re-emergence of forests as a potential source of energy, both for electricity and as a source for biofuels through cellulosic ethanol. To some extent, the use of forests as an input into energy production is promoted by government policy, largely renewable energy laws. These trends, if they continue, could dramatically increase the demand for all forests.

Conclusion

This chapter examines the implications of climate change on forested ecosystems. The chapter begins with a discussion about the potential ecological effects of climate change in forests. These include changes in the rate of growth of trees, changes in disturbance patterns and shifts in the distribution of tree species. The paper then describes how these results can be integrated into economic models. Several different approaches have been discussed in the literature and there is some debate about the best way to approach important issues like the modeling of forest dieback.

To illustrate how climate change impacts can be integrated into an economic model of forestry, a simple model of the forest sector is shown. The differences in the economic effects associated with different methods of perturbing the economic model with the impacts of climate change are then examined. The results show that directly modeling dieback leads to far different estimates of the potential for adaptation and to far different estimates of welfare effects of climate change. These results suggest that modelers need to carefully consider how best to integrate ecology into their economic models. The chapter concludes with a discussion about results in economic analyses to date.

Although a number of studies on climate change impacts in forests have been conducted to date, research in this area is actually fairly limited, and there are a number of areas where additional work could be very useful. First, there is fairly little research examining potential adaptation strategies for individual landowners. The changes described in the chapter suggest that landowners will need to adapt to new disturbance regimes, shifts in the types of species that will grow in their location and changes in timber prices. It would be useful to conduct additional research on the costs and benefits of making different harvesting or planting decisions, given both the ecological and economic uncertainties involved.

Second, beyond adaptation on private lands, a vitally important issue of global concern will be adaptation on common property forestlands or public forestlands. Adaptation in these regions actually will be much more difficult to accomplish given the much more complicated incentive arrangements at play. Common property forests are often managed by groups most effectively when the institutions have had a long period of stable ecological conditions in which to evolve. If ecological conditions are changing and important forest outputs are declining due to exogenous climate-related factors, it may be very difficult for these institutions with long histories to adapt. Understanding adaptation in these regions is another important area for research, given that common property forests do provide a large share of the world's non-timber forest products and fuelwood. Beyond common property lands, many protected zones will be undergoing important climate-related changes, and society will have to decide whether to actively manage the change or let adaptation occur naturally.

Third, policy responses to climate change could have important consequences for forested ecosystems. Carbon sequestration would change the area of forests and the amount of harvesting that occurs in different regions. Understanding how climate change potentially affects forests preserved or planted for carbon sequestration will be important for preserving carbon in the biosphere in the long run. For instance, regions with increasing forest fire potential due to climate change may not be the best places to increase forest area for carbon sequestration. Biofuels also could dramatically affect the landscape by altering timber harvests. Understanding whether biofuels are a net carbon source or sink is actually still an important research question that needs to be addressed with additional work.

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