The Economics of Land Use at the Intensive and Extensive Margins

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1. BACKGROUND AND INTRODUCTION

There are few economic activities that do not involve land resources in some way. Land is a location for residential, commercial and industrial activities, and an input in the production of private and public goods, including household production of leisure and recreational goods. While many economically relevant market and nonmarket outputs can be produced by natural landscapes, economic effort is frequently required to convert or "develop" natural land into a condition that produces a desired mix of outputs. Because the quantity of land is finite, when undeveloped lands become scarce the opportunity cost of land development becomes apparent. Public goods such as habitat for biologically diverse species, or terrestrial stores of carbon (that would otherwise be released to the atmosphere to contribute to global warming) can be lost when land use or cover is changed. The growing scarcity of natural landscapes throughout much of the world, combined with increased awareness of environmental and resource consequences of land use and land cover change, has renewed and increased research on the economics of land use. This is in large part because influencing land use or land cover is necessary to understand and help solve the resource and environmental problems that face policymakers today.

Although treatment of land use economics as a separate field in applied economics has decreased, several attributes of land differentiate it from other economic goods. For example, land is immobile, so it is necessary to model space and location; it is heterogeneous, so it is necessary to account for quality differences; and land has the property that, because it has the potential to produce multiple outputs and amenities, different attributes of land can be separated through the legal system by an appropriate structuring of property rights. Land or its products/services can be held in the public domain at the same time that it is privately owned. As a result, issues of ownership, takings and rent seeking are important considerations in studies of land use.

In this paper, we focus on economic policy instruments that affect land use or land cover (both referred to after this point as land use). Because land use ultimately is a function of societal preferences for land products and services, and these preferences vary spatially, we begin by examining policy using the von Thünen spatial framework. Lands that have been developed from a natural state into a location for residential, commercial or industrial activity will be referred to as urban. Lands used in agricultural or forestry activities will be referred to as rural. Rural lands are distinct from unused land such as wilderness, or nature. The von Thünen framework can be used to identify intensive and extensive margins of land use (van Kooten and Bulte 2000, Chapter 4). The intensive margin occurs between land in urban uses and rural uses. The extensive margin occurs between land in rural uses and unused land (wilderness/nature).

Approaches to policy and management differ depending on which margin is relevant. Command and control instruments are more frequently used to influence the intensive margin (the urban-rural interface), while other instruments are then brought to bear in response to the adverse social consequences of regulation (including adverse income distributional and political results). At the extensive margin (the rural-nature interface), policymakers appear much more willing to let the market determine land uses, and then rely on a variety of instruments, but most often regulation or subsidies, to correct for undesired consequences. The economics of managing land for multiple benefits are somewhat easier to model at the extensive margin, where there is less overlap of products or services from land uses than at the intensive margin.

We begin in the next section by considering the intensive margin. Because of the close relationship between theory and practice, the two are jointly examined. Economic theories related to the extensive margin are the subject of section 3, while policy instruments that have been, and currently are used, to get landowners to take into account spillover effects are reviewed in section 4. The problem here is to reconcile theory and practice. We conclude with some observations for future research in section 5.

2. THE URBAN-RURAL INTERFACE: THE INTENSIVE MARGIN

The major land use issues at the intensive margin are generated by population increase, the formation of new households, and the associated conversion of land to residential, industrial and commercial use. Quantity of land converted is sometimes the issue, as jurisdictions seek to slow or limit population growth by regulating land use. But more often the concern is about the spatial pattern of development. Government programs are implemented to eliminate sprawl, to preserve farmland and open space, to alleviate spillovers between nearby parcels with different uses (farmland next to residential, residential next to industrial), and to lower the costs to government of providing the infrastructure (roads, schools, water and sewer) necessary to support urban land uses. Because spatial organization of land use is of primary concern, policy is often formulated in conjunction with plans defining desired geographical distributions of permitted land uses. These desired land-use plans are formulated by agencies within government jurisdictions that are often granted the power to withhold approval of land development projects, to validate compliance with existing laws, to administer fees and to negotiate changes in development plans before approval. Because of this, spatial planning plays an important role in the implementation of government policy at the intensive margin.

The conceptual framework for the economic analysis of land use at the intensive margin has developed primarily from Alonso's adaptation of the von Thünen location rent model (with a good introduction provided by Fujita 2001). The "bid rent" model emerging from this theoretical development is a competitive market model with equilibrium established by equality between urban land users' willingness to pay for developed land (their bid rents) and the supply price of the developed land. The addition of a second spatial equilibrium condition locates urban land uses in a compact set around a "Central Business District" (CBD), and produces a von Thünen location rent or price gradient. This addition creates the "urban growth" model that is basic to current applied work by urban economists. While insightful for land value analysis, the second equilibrium condition is not essential to the development of the underlying market model, and it has been abandoned by researchers concerned primarily with the location of land uses within the suburban area surrounding urban centers (Bockstael and Irwin 2002).

Capozza and Helsley (1989) summarize the primary results concerning land value that come from the urban growth model. They derive a land price gradient that originates from the CBD, decreases monotonically to a rural-urban fringe, drops precipitously at this fringe, and then continues to decrease as land is located even further from the urban center. This theory formalizes the idea of active land conversion at the edges of cities when urban population is increasing, and it identifies the basic value components of this process. Land conversion occurs in annular rings in Capozza and Helsley's version of the theory because they use a particularly simple spatial equilibrium condition.[1] Land price inside the rural-urban boundary (defined as a specific distance from the CBD) is:

$$(1)\qquad P^d(t,m) = \frac{A}{r} + D + \frac{1}{r}\frac{T}{\bar{s}}[\bar{m} - m] + \frac{1}{r}\int_t^{\infty} R_\tau(\tau,m)e^{-r(\tau-t)}d\tau\,, \quad m(t) \le \bar{m}(t)\,,$$

while price outside of the boundary is derived as:

$$(2)\qquad P^u(t,m) = \frac{A}{r} + \frac{1}{r}\int_t^{\infty} R_\tau(\tau,m)e^{-r(\tau-t)}d\tau\,, \qquad m(t) > \bar{m}(t)\,.$$

These equations indicate that the equilibrium price (p) of developed land at any time t and distance m from the urban center is the value of undeveloped (agricultural)

[1] This condition is $N(t)\bar{s} = \phi\bar{m}(t)^2$, where $N(t)$ is the number of households at time t, $\bar{s}$ is the (fixed) average lot size and $\bar{m}(t)$ is the distance from the CBD to the urban boundary at time t. The spatial condition can be relaxed or supplanted to obtain more general spatial patterns, such as edge cities (see Henderson and Mitra 1996).

land A plus two additional components – the cost of developing the land D (treated here as a constant) and a location rent created by the distance of the site from the urban center (CBD) relative to the urban boundary $\overline{m}$. The location rent depends on the per-unit distance commuting cost T, the average size of developed lot $\bar{s}$, and the discount rate r. These location rents increase over time for any given site if the city grows and the urban boundary moves farther from the CBD.

The equilibrium price of undeveloped land is the capitalized value of its agricultural rent ($\frac{A}{r}$), plus a development premium. The development premium is the capitalized value of the future increases in rent R of developed land that will occur as the city grows (the subscript indicates a partial derivative with respect to time τ). Thus, the effect of urbanization extends beyond the rural-urban fringe in the urban growth model, and the land market capitalizes the value of future development into the current price of undeveloped land. This premium is generally omitted in the analysis of farmland prices in the agricultural economics literature, which has traditionally defined the price of farmland as the capitalized rent that accrues from farming (Clark et al. 1993; Just and Miranowski 1993).

Two observations of immediate interest emanate from the urban growth model. One is the dominance of urban land use. According to this model, quantity of urban land depends primarily on population growth, and population growth is exogenous to the land market. If additional demanders of urban land services enter the market, their willingness to pay for land is high enough that they can claim however much rural land they desire. Thus land is ensured to remain in agricultural or natural uses only if government sees fit to guarantee that use. While much of government policy affecting land use at the intensive margin has been concerned with the preservation of rural land, this policy emphasis has not been unambiguous. Maintaining rural land within the urban boundary will expand the size of the city and increase the costs of providing schools, roads, sewers and other infrastructure. Policy may be concerned with sprawl as well as with open space.

A second immediate implication of the model is the consequences of the land development premium for farming. As noted by Lopez et al. (1988), land next to the rural-urban boundary takes on the characteristics of an appreciating financial asset that can be held for speculative purposes. Farmers' planning horizons can be shortened by the prospect of selling their land and this can lead to a reluctance to maintain and replace farm machinery, drainage systems and other farm infrastructure. In addition to this "impermanence syndrome," higher land values also result in a change in the character of farming. "Traditional" farms, meaning enterprises constructed similarly to farms in non-metropolitan regions, incur higher costs without increased revenues, while "adaptive" farms, including pick-your-own, Christmas tree, nursery and other specialty agricultural enterprises, obtain per-acre returns of as much as 7.5 times that of traditional farms (Heimlich and Barnard 1992). "Recreational" farms also emerge, with smaller acreages and very little market output per dollar of expense on each acre. Rural land owners become a mixture of farmers, land speculators and lifestyle consumers, with different desires for policies that protect the right to farm, regulate farming, and preserve farmland through subsidies. The amenity value of having open space in an urban area and the spillovers from farming (noise, smell, chemical) also encourage urban land consumers to enter these policy debates. As a consequence, policy development becomes a complex endeavor, and seemingly contradictory policies may be observed in the rural-urban fringe communities (Gardner 1994).

Forcing all land-use change into annular rings imposes obvious limitations on the analysis of spatial distribution of land uses. This suggests removal of the von Thünen spatial equilibrium condition. When this is done, we are left with a supply relationship that Anderson (1993) traces back to Wicksell, a demand function, and a market equilibrium condition. The supply relationship can be expressed as:

$$(3) \qquad P(m,s,t,h;z) = \int_0^t e^{-r\tau} A(\tau,m)d\tau + \frac{e^{-rt}}{s}\left[\int_t^\infty e^{-r(\tau-t)} R(s,\tau,m,h;z)d\tau - D(s,h;z)\right].$$

This is Fujita's (1982) specification, augmented by an exogenous vector *z* of immutable land characteristics (floodplain, wetland, topography) and a vector *h* of "improvements" (house, landscaping, parking areas). Equation (3) is a net present land value obtained from the premise that land located at distance *m* from the CBD will earn agricultural land rents until time t, be instantly developed at cost *D*, and thereafter yield rents *R* from the developed land use. But it also is a land developer's profit maximization problem in which the per-acre land value *P* can be maximized by choosing the optimum time *t* to develop, the optimum lot size *s* to provide, and the optimum level of improvements *h* (Hardie and Nickerson 2002). This supply interpretation assumes all owners are potential producers of developed land (though they may rent to themselves), there is perfect foresight, and housing is durable since there are no costs of replacement. It applies to land at any date, since the choice of *t* is endogenous, and to any distance from the urban center, since *t* may be very far in the future. It also allows for the possibility that land of different quality may develop at different distances at the same date.

If population increases cause bid rents to increase faster than agricultural rents over time, and if landowners maximize land values, then optimization implies that a lot with location *m* and characteristics *z* will be developed whenever the returns just cover the costs of development:

(4) $$R(s,t,h;m,z) = sA(t;m) + rD(s,h;z)\ .$$

This is a consequence of the dominance of the rent for developed land. If, in addition, *R* is consumers' maximum willingness to pay for developed lots (the bid rent function), and if the price of a developed lot (P^L) at time *t* is the present value of future rents, then

(5) $$P^L(t,h;m,z) = \int_t^\infty e^{-r(\tau-t)} R(s,t,h;m,z)d\tau\ .$$

Optimized land development then implies

(6) $$P^L(t,h;m,z) - \frac{sA(t;m)}{r} = D(s,h;z).$$

Perfect foresight is assumed, in the sense that land developers correctly assess consumers' willingness to pay for developed lots and that bid rents are well defined at every location *m* and time *t*. This assumption leads to the competitive market equilibrium condition that the difference in the prices of undeveloped and developed land just equals the cost of development.[2] This equilibrium condition is independent of the spatial equilibrium condition and it describes a well-functioning competitive land market at the

[2] Theoretical results can change if the perfect foresight assumption is relaxed. Titman (1985), Capozza and Helsley (1990), and Batabyal (1996) have shown that uncertainty and irreversibility can combine to delay the timing of development. Capozza and Li (1994) also show that replacement of capital can affect the timing of development. Thus, the durable capital assumption of the bid rent model also may be limiting. Smith et al. (2002) raise the associated question: Can consumers of developed land successfully forecast future land-use patterns, particularly of open space?

intensive margin.

If such a well-functioning market exists, the question underlying policy intervention becomes: “Where is the market failure?” Brueckner’s (2000) answer consists of three parts: (1) the social value of open space is not accounted for in development costs, (2) congestion externalities are not internalized and people live farther away than they would if these costs were incorporated, and (3) the impact of new development on infrastructure is not fully incorporated into the developed land price. Brueckner omits the possible failure of developers to internalize the effect of their developments on the environment, and he takes the assumptions of the developed land market model as given. In particular, these assumptions eliminate the NIMBY (“not in my backyard”) response to land use change, since this response occurs when individuals have forecasted one situation and subsequently encounter another (Dear 1992). One may also question the assumption that households are able to move between houses without cost at any time (as is needed for a well-defined bid rent function) and the assumption that all landowners have the same discount rate. If that were true, farmers nearing retirement age would be no more likely to sell land for development than young farmers just beginning their enterprise.

Although not part of the model, the NIMBY response of suburban homeowners to noise, odor and other spillovers from farming has led to right-to-farm legislation in most states within the United States and in some provinces in Canada. This legislation seeks to supercede the common law of nuisance by granting farmers who employ acceptable farming practices exemptions from litigation that seeks to restrict their farming operations (Lapping and Leutwiler 1986). Its goal is the protection of farming rather than the preservation of farmland, although right-to-farm laws do sometimes provide incentives to keep land in agriculture. The original New Jersey law, for example, states that farmers in an official farmland preservation program are to benefit from an "irrebuttable" presumption that their operation does not constitute a nuisance, while farmers not in a preservation program are to benefit from a "rebuttable" presumption (Lisansky and Clark 1986). Right-to-farm laws are sometimes integrated with laws providing for the formation of agricultural districts. New York's agricultural district law, for example, packages right-to-farm provisions, protection from public regulations that might restrict farming practices, stringent review of eminent domain takings and restrictions on the provision of infrastructure for urban uses with the granting of relief from property tax assessments (Boisvert and Bills 1984; Bills and Boisvert 1986). The objective of this legislation is to keep commercial farming viable in areas near urban centers, to maintain a critical mass of farm supply and farm market facilities, and indirectly to conserve and protect agricultural lands. Protection is indirect because these laws do not regulate the sale or conversion of rural land, and conversion can take place whenever the premium for doing so becomes sufficient. In the context of the market model, the right-to-farm and agricultural district laws delay development by increasing the agricultural rents, $A(t, m)$, which depend on time and development pressure.

Tax incentives designed to give farmers a break from having to pay high property taxes are a widespread policy devel` oped to maintain farming in areas where farmland has a large development premium. These policies can extend to land speculators and recreational farm owners if requirements to be classified as a farmer are not onerous. They are not, by themselves, capable of compensating rural landowners for providing a public good (open space or farmland protection) at private expense, and they generally do not deter landowners from selling out for development when the opportunity arises (Heimlich and Anderson 2001). Indeed, the various tax policies that have been designed to preserve farmland may actually have the opposite effect: they may increase the area affected by lack of investment in agriculture (since they can decrease the costs of land speculation) and provide incentives that encourage urban sprawl (Barichello et al. 1995; Corbett 1990; Ervin et al. 1977).

As evidence has accumulated that preferential tax assessments do more to subsidize farmland owners than to conserve farmland, governments have increasingly initiated programs to purchase development rights and conservation easements (Wiebe et al. 1996). These programs involve separating and purchasing some but not all of an owner's rights to a property: separated rights might include, for example, the right to build residential or commercial buildings, to drain sloughs and/or burn associated uplands, and to remove endangered species of trees. In the United States, most purchases have been in the form of agricultural conservation easements. These are targeted at prime farmland and have the goal of permanent preservation of farmland in urbanizing areas (Heimlich and Anderson 2001).[3] Significant impetus for these programs has come from ballot referendums that show taxpayers are willing to pay for the provision of open space with bond issues. In November 2001, for example, voters passed 85 of 115 state and local open space spending measures, which provided for more than $1.2 billion in public funds for open space protection efforts (Hollis and Fulton 2002). This suggests that Breuckner's identification is correct and that the market for land at the intensive margin is failing to

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[3] By 2002, state and local governments within the U.S. had purchased conservation easements for 1.1 million acres at a cost averaging approximately $1,746 per acre (American Farm Trust, Fact Sheet: Status of State PACE Programs, November 2002).

completely incorporate the social value of open space.

In Europe, where supranational policies are dictating reduced farmland cultivation, emphasis has changed from preserving farmland to preserving countryside (Alterman 1997). This has implications for open space benefits when farmers are concerned about trespass. Then actively farmed land is not likely to provide the same environmental or amenity benefits as, say, a regional park providing recreational access or a greenbelt providing natural habitat. Such limitation on access is more of a concern in the United States, than, say, in Britain where rights to traverse farmland are well established. Perhaps because of this limitation, nonprofit private land trusts, such as the Nature Conservancy, The Conservation Fund and the Trust for Public Land, have become active in the preservation of open space within the United States. These organizations purchase properties or easements on lands that provide environmental benefits and seek to protect land slated for urban development. Purchased land is often turned over to state and local governments. This establishes a means for the governments to provide some of the social values that are not obtained from working farmland with limited access.

An important difference between preferential tax assessments and purchase of development rights is the potential role of planning. Preferential tax assessments typically are extended to all eligible landowners regardless of the location of their property. But purchases can be targeted to sites where the social or environmental benefits are deemed to be particularly high, such as along a wildlife corridor or within a densely populated area. While the potential for targeting exists, it generally is not realized. Hollis and Fulton (2002) find few cases where agencies and organizations concerned with open space coordinate with agencies developing zoning and land-use plans. The agencies concerned with land-use planning are more likely to rely on zoning regulations, impact fees and infrastructure development to obtain their desired landscapes.

Transferable development rights are an exception to this dichotomy (Johnston and Madison 1997). These can constitute a case where separation of development rights is integrated with land-use planning. Zoning-based transferable development right (TDR) programs are initiated with a partial taking of property rights in source areas where development is to be "down-zoned." Landowners in these designated source areas receive the option to sell the separated development rights to land developers in designated development areas (sinks). Purchasers of the transferable rights can use them to gain variances from lot size and per-acre dwelling unit zoning restrictions, and to increase the density of development in the target area. Landowners who lose the property rights consequently are compensated in a development rights market, but at rates driven by the opportunity costs of zoning instead of consumer willingness to pay for their land. Prices of the restricted land also can increase above agricultural use values if the demand for recreational farming sites is sufficient (Nickerson and Lynch 1999). Governments incur the costs of planning and administration of these TDR programs, but can reduce infrastructure costs by providing fewer services in the source areas and more efficient services in the sinks. This appears to be a primary motivation for these programs.

Zoning regulations can be developed to reduce negative externalities that some land uses impose on others, to meet fiscal goals such as increasing a local tax base or lowering infrastructure costs, or to "maintain the homogeneity of exclusive residential districts" (Rolleston 1987). Large lot zoning (minimum lot sizes of 3 acres or more) has been enacted to control growth, but has been found to be ineffective for this purpose

(Coughlin and Keene 1981; Heimlich and Anderson 2002). Exclusive-use zoning and urban growth boundaries have been successful at restricting farmland conversion in Oregon, Hawaii and Quebec, although they have recently been overwhelmed in Israel by increased population and housing pressures (Nelson 1992; Alterman 1997). Such strict controls can affect income distribution and lower social welfare by constraining the demand for low-density development. Some evidence of this demand has been documented by Fuguitt and Brown (1990), who found that 70 percent of Americans would prefer to live in a rural setting within 30 miles of a city of at least 50,000 people. But despite this stated preference, citizens in Oregon and Hawaii have continued to support exclusive-use zoning.

Wallace (1988) and McMillen and McDonald (1991) find that variances and revisions can cause zoning other than exclusive-use zoning to "follow the market."[4] If so, these regulations may serve more to guide development as it takes place ("growth management") than to control the amount of development located in a particular jurisdiction. The initial precept of nonexclusive-use zoning was to separate incompatible land uses and to abate negative externalities. This was expected to raise land values, but verifying this effect empirically has been difficult (Fischel 1990; McMillan and McDonald 1993). The idea that zoning should be used to establish homogeneous use is now under challenge by planners who espouse a "new urbanism" of mixed-use zoning (Grant 2002).

Zoning as a tool for growth management has seen less application in European

[4] The primary counter argument is presented by Hamilton (1978), who argues that zoning applications by competing jurisdictions within a local metropolitan area can lead to situations in which the supply of housing will be below and the price above purely competitive levels. Hamilton's focus is on the ability of local jurisdictions to use zoning to restrict the movement of households within a given market (cf. Tiebout 1956).

countries such as Britain, The Netherlands and France. There planning is substituted for zoning and growth is managed by reviewing development proposals for adherence to government plans. Compensation is not paid when development of rural land is refused, and "takings" are not the issue that they are in the United States. A review by Alterman (1997) finds that the citizens of these countries are more committed to urban containment, higher density living and the preservation of countryside. This makes planning-based control easier to implement and less likely to lower social welfare.

Zoning for fiscal reasons includes the development of industrial and business parks to increase the tax base and the management of residential growth to reduce infrastructure costs (Cameron and Stephenson 2002). Management to reduce infrastructure costs almost always involves the containment of sprawl: In a review of studies of the cost of sprawl, Burchell et al. (1998) found that compact development reduced infrastructure costs by 5 to 25 percent and operating costs of municipalities and schools by 2 to 5 percent. Provision of infrastructure also can be used as an instrument to affect the location of development. Maryland's "Smart Growth" program designates priority-funding areas, usually in-fill sites, for which infrastructure development is targeted. The objective here is to transfer development location by increasing the quality of the site within the priority area.[5] Infrastructure policy can also be used to discourage development at chosen locations: adequate public facilities laws can put moratoriums on development until adequate school or sewer capacity is provided, and developers can be charged impact fees to pay for additional infrastructure that would be required to service new development. Thus, zoning is only one of several policy instruments that can be used

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[5] Irwin and Bockstael (2002) find that this program significantly affects the probability that land will be developed.

to manage growth in a rural-urban area.

Instruments other than zoning, particularly transportation policy and the development of roads, may be the most important tools for growth management, particularly if zoning does follow the market. Breuckner's congestion externalities depend on a failure of commuters to recognize the social costs created by their use of existing roads. But the provision of new roads can direct the location of new development and the development of the transportation network can have an important influence on individuals' housing decisions (Smith et al. 2002). Citizens experiencing congestion effects can also demand new and improved roads (Heimlich and Anderson 2002). Public transportation in the form of trains and buses can serve as a good or poor substitute for automobile travel – a key difference between some of the European countries and the United States. Because several instruments are involved, growth management may incur greater costs of coordination and implementation across government jurisdictions and agencies than will more specific policies aimed at the correction of particular market failures.

The question of whether planning, zoning and infrastructure policy will manage growth better than market forces has not been resolved. Unfettered land use change at the intensive margin is a complicated dynamic process. In addition to changes in the character of farming, spatially discontinuous development will naturally occur as households with different preferences and incomes trade off the cost of commuting against the benefits of living in the country. Large lot housing dependent on wells and septic systems will develop at the outer edges of the metropolitan area. Then as land values increase, more dense development will occur on nearby parcels. Demands for infrastructure will increase and the eventual provision of infrastructure will lead to further development. Businesses will develop to be near customers and labor sources when urban densities become sufficient. Peiser (1989) finds that discontinuous development in a freely functioning land market can lead to higher final housing densities as parcels left undeveloped in the short run increase in value and eventually convert to more intensive use. The rub, however, is in the intermediate period when government intervention can lower the costs of providing infrastructure and provide social benefits by preserving farming and open space. Because of this, change in land use at the intensive margin can be expected to depend both on the functioning of the land market and on public policy.

3. MODELING LAND-USE CONVERSION AND PUBLIC POLICY AT THE EXTENSIVE MARGIN

At the extensive margin, the concern is mainly between land used in forestry or agriculture versus its use in nature. At a specific point in time, there may exist marginal agricultural land that, from the perspective of society, would be better left as nature (e.g., wetlands, natural range), or forest that would be better left unharvested. In practice, the social allocation of land use at the extensive margin relies to a much greater extent on market policies than is the case at the intensive margin. While it is straightforward to model policies for dealing with the divergence between privately optimal and socially optimal land-use decisions when land-use activities are spatially separable, difficulties arise when activities on one parcel of land can affect the optimal decisions to be taken on other parcels, whether these are adjacent or not. Although spatial dependence is also present at the intensive margin, this dependence is frequently taken into consideration through zoning ordinances and land use planning. While zoning may adjust spatial flows of land benefits within the intensive margin, zoning cannot guarantee that a land allocation is economically efficient (see above).

Thinking about land use changes at the extensive margin can be facilitated by developing an economic model of the land use choices for forest and agricultural land available at this margin. The model presented here is similar to the Faustmann model (Faustmann 1995; Samuelson 1976), expanded to consider partial harvests, carbon and other non-timber benefits, the influence of adjacent or separate stands on non-timber production, and potential conversion to non-forest use.6 The Faustmann model was developed to determine optimum harvest cycles (rotations) for optimum timber production in a single stand permanently dedicated to timber production. Among the many changes to the basic model, the extensions that are relevant here include: (1) the influence of non-timber forest amenities whose production increases monotonically with age (convex joint production with respect to stand age) (Hartman 1976); (2) the influence of non-timber forest amenities whose production does not increase monotonically with age (nonconvex joint production) (Swallow, Parks and Wear 1990); (3) the influence of neighboring stands (Swallow and Wear 1993); and (4) the possible conversion of land to non-forest use (McConnell, Daberkow and Hardie 1983; Parks, Barbier and Burgess 1998). A survey of this literature is provided by Newman (2002).

Carbon stored in forestland is treated as an amenity that increases monotonically with stand age, and is addressed using a method developed by van Kooten, Binkley and Delcourt (1995). The influence of neighboring stands is addressed through a non-timber environmental benefits function. A forest is presumed to comprise several stands, and

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6 Faustmann's original 1849 paper is translated from German and appears in the first issue of the *Journal of Forest Economics*, 1995. This issue also includes Samuelson's 1976 paper and two other classic papers on forest rotation age.

aggregate environmental benefits are a non-separable function of activities chosen on each of the component stands. Stands can be adjacent (Krcmar and van Kooten 2002; Koskela and Ollikainen, 1999, 2002; Swallow and Wear 1993; Swallow, Talukdar and Wear 1997), or separated by distance (Bogdanski, van Kooten and Binkley 2002). When economic benefits are a linear function of the amount harvested, clear felling at an optimum finite rotation length maximizes net benefits. Introducing non-separable forest-level environmental amenity benefits presents an opportunity cost of stand-level harvest that can make partial harvests a part of an optimum solution. Conversion to non-forest use (e.g., agriculture) occurs when the present value of continued forest benefits no longer exceeds the opportunity cost of agricultural use (McConnell, Daberkow and Hardie 1983). Corner solutions for zero or infinite length optimum rotations motivate immediate conversion or permanent preservation for non-timber amenity production. Addition of distance and quality considerations allow for a rural landscape that includes noncontiguous areas of different land uses (Parks, Barbier and Burgess 1998).

The objective is to choose harvest dates and amounts to maximize the net discounted social benefits from two forest stands, with different owners, that may or may not be adjacent to one another. Benefits from forest use are derived from timber harvest, carbon storage and other environmental benefits. To maintain focus on forest use and provision of nature, forest and nature benefits are assumed to exceed those of other uses such as agriculture. This is a simplification of convenience that amounts to emphasizing a forest solution to the rural land allocation problem. For each parcel, the economic decision is how much volume, if any, to harvest from the stand. Harvest choices are constrained to the interval between zero (no harvest, only nature benefits) and all volume in the stand (clear felling). Time can be considered as a decision variable, since a time is implied whenever harvest is optimally greater than zero.

By choosing the level and timing of timber harvest on a stand, the decision maker also chooses the level of inventory (volume) left on the stand. By delaying harvest, the remaining timber grows and permits a larger future harvest (unless the stand is mature and additional growth is effectively offset by decay). More importantly, standing timber has non-market (nature) value while growth removes CO_2 from the atmosphere, which can be valued. When non-market and carbon values are appropriately taken into account, it still may not pay to grow trees for timber production. It is possible that the land has little or no value in agriculture or in commercial timber production, and is best suited to produce only non-market (e.g., biodiversity, water storage) and carbon storage outputs. The model captures all these possibilities.

Denote the two stands 1 and 2, and assume that the decision maker's choice is unaffected by other consumption and investment decisions; income and benefits derived from forest activities are separable from other activities. We express annual total net benefits at any given time as:

$$(7) \qquad B(h_1(t), h_2(t), v_1(t), v_2(t), \dot{v}(t))$$

$$= F_1(h_1(t)) + F_2(h_2(t)) + C(\dot{v}_1(t), h_1(t)) + C(\dot{v}_2(t), h_2(t)) + E(v_1(t), v_2(t)).$$

In expression (7), $v_i(t)$ refers to the volume of timber in stand i growing at time t, with $\dot{v}(t) = \partial v(t)/\partial t = \dot{v}_1(t) + \dot{v}_2(t) \geq 0$, $\dot{v}_i(t) \geq 0$ (i=1,2). The $h_1(t)$ and $h_2(t)$ refer to harvests from each stand, which are also functions of time. (To minimize notation, time arguments for volume and harvest functions will not be shown.)

Total value is the sum of timber, carbon and environmental values. Timber value,

$F_i(h_i)$, $i = 1,2$, is a function of harvest, and may vary with the quality of the timber grown on the stand. Carbon value, $C(\dot{v}_i, h_i)$ is the change in carbon stored in stand type $i = 1,2$. Increases in standing timber volume increase stored carbon ($\partial C/\partial \dot{v}_i > 0$ since $\dot{v}_i \geq 0$) and harvests of timber volume release carbon ($\partial C/\partial h_i < 0$). Environmental value, $E(v_1, v_2)$ includes non-carbon environmental amenities. These depend on timber volume in each of the two stands. Under this specification, spatial interaction occurs through the environmental benefit function, where it is assumed that $\partial E/\partial v_i > 0$, $\partial^2 E/\partial v_i^2 < 0$, and $\partial^2 E/\partial v_1 \partial v_2 \neq 0$. Commercial timber benefits are given by $F_i(h_i) = (p - c)h_i - R$, where p is the price received for logs (in \$ per m^3), c is the harvest cost (in \$ per m^3), and R is a fixed cost associated with harvest (and may include a legislative requirement to regenerate harvested sites). For convenience, p and c are assumed not to vary with log size and fixed costs R are assumed to be incorporated in the harvest cost c. Note that, under these conditions, timber benefit is linear in harvest, so that optimal harvest $h_i^*(t)$ would be to clear fell $v_i(t)$ or zero harvest. Optimal partial harvests, $0 < h_i^*(t) < v_i(t)$, require that opportunity costs, such as $\partial^2 E/\partial v_1 \partial v_2$, be considered.

Assume that the growth function, $g_i(v_i)$, is known and has the properties that $g_i' \geq 0$ and $g_i'' < 0$, $\forall v_i$, and that growth differs between stands. This enables us to consider the difference between growing hybrid poplar on marginal agricultural land (or on denuded forest) versus growing native species, for example. It also enables us to model different non-carbon environmental benefits on each stand, and different interaction effects between the stands. This is discussed further below.

The objectives of the landowners and the authority diverge. Each landowner's objective is to

(8) $$\underset{h_i}{Maximize}\int_0^T F_i(h_i)\, e^{-rt}\, dt\ ,$$

where T is the length of the planning horizon, with T possibly being infinite. Each owner solves what amounts to a Faustmann rotation problem, given the linearity in $F_i(h_i)=(p-c-R)h_i$ (Samuelson 1976). In contrast, the objective of an authority responsible for all benefits from both stands is to

(9) $$\underset{h_1 h_2}{Maximize}\int_0^T \{F_1(h_1) + F_2(h_2) + C(\dot{v}_1, h_1) + C(\dot{v}_2, h_2) + E(v_1, v_2)\}\, e^{-rt}\, dt,$$

perhaps subject to a constraint on the public expenditure required to bring about convergence between private and social objectives. The rate r used to discount benefits need not be the same for the private landowners and the authority, but, for simplicity, we assume they are the same. Adding annual flows of non-timber benefits such as $C(\dot{v}_i, h_i)$ converts the owners' Faustmann problem into the equivalent of a Hartman rotation problem (Hartman 1976). Adding non-carbon environmental benefits, $E(v_1, v_2)$, which are not separable into $E(v_1)$, and $E(v_2)$, gives spatial interdependence among stands, and provides an analytical basis for optimal partial harvests not present in Faustmann- and Hartman-type problems.

The constraints for problems (8) and (9) are:

(10) $h_i(t) \leq v_i(t),\ i=1,2$

(11) $\dot{v}_i(t) = g_i(v_i(t)) - h_i,\ i=1,2.$

The following additional constraints are required on the optimal solutions to problems (8) and (9) to ensure that land is optimally in forest use and not in its next best alternative, agriculture:

$$(12) \quad \int_0^T \mathrm{F_i}(h_i{**})\, e^{-rt}\, dt \geq \frac{A_i}{r}(1 - e^{-rT}) - M_i,\ i=1,2$$

$$(13) \quad \int_0^T \{F_1(h_1^*) + F_2(h_2^*) + C(\dot{v}_1, h_1^*) + C(\dot{v}_2, h_2^*) + E(v_1^*, v_2^*)\}\, e^{-rt}\, dt$$

$$\geq \frac{A_1 + A_2}{r}(1 - e^{-rT}) - M_1 - M_2$$

where A_i refers to the (constant-over-time) annual returns to agriculture for stand i, M_i denotes the cost of converting stand i to agriculture, and superscripts * and ** denote optimal social and private choices, respectively.[7]

It is reasonable to expect that $E(v_1, v_2)>0$ and that $C(\dot{v}_i, h_i)>0$, especially if storage of carbon in wood product sinks or biomass burning in place of fossil fuels are taken into account. This means that society (the authority above) might optimally prefer to keep land in forestry rather than agriculture, even though the landowner might wish to optimally convert forestland to agriculture. One means to prevent conversion of forest into agriculture is to decrease the net benefits of conversion, $\frac{A_i}{r}(1-e^{-rt}) - M_i - \int_0^T \mathrm{F_i}(h_i{**})\, e^{-rt}\, dt$. This can be accomplished, for example, by providing a subsidy to landowners who retain land in forestry, by taxing those who convert land, or by removing incentives, such as subsidized loans or special tax breaks, related to agricultural land "improvements." Alternatively, the authority can lower A_i by discontinuing output or input subsidies (including farm credit subsidies that reduce r), or by taxing agricultural commodities. We

[7] Since the planning horizon is T, the infinite stream of agricultural benefits on the RHS of equations (12) and (13) is converted to a finite horizon of T via the term $(1-e^{-rT})$.

discuss some programs that aim to do this in the next section.

Landowners control only the amount they harvest in each period, including possible clear felling with or without conversion to agriculture. Under these circumstances, the problem facing the authority is to design appropriate incentives that motivate landowners to take into account the external effects of their harvesting decisions. These incentives should motivate landowners to make optimal land use choices by solving (9) rather than (8). An intermediate step between (8) and (9) is to consider carbon only, ignoring non-carbon environmental amenities (and possible stand interdependencies).

Internalizing Carbon Fluxes from Land Use

The problem of carbon fluxes can be addressed by incorporating into the decision calculus a price for carbon. That is, landowners can be compensated for carbon uptake and taxed for carbon released at time of harvest (see van Kooten, Binkley and Delcourt 1995). If a market for carbon credits from sinks can be established, and this is not without problems (see Marland, Fruit and Sedjo 2001), such a market could take the place of carbon taxes and subsidies. Whether taxes or credits are used, the decision maker would face a price of p_c (\$ per tonne carbon, tC) for any carbon sequestered or $-p_c$ for any carbon released as a result of harvest. Suppose that the forestland owner chooses to harvest trees at the time that leads to the maximum financial benefit. Suppose that the time horizon is infinite ($T \to \infty$) and that the optimal harvest strategy is to clear fell a site at equal periodic intervals corresponding to t^*, so that $h_i^* = v_i(t^*)$. If carbon uptake benefits are taken into account, the net benefit at time of harvest equals $[(p-c) - p_c\alpha(1 - \beta)]v_i\,(t^*)$, where p is the price of timber and c harvesting cost (as discussed above), α is a parameter that converts timber into carbon, and β is pickling factor or proportion of carbon stored in products or landfills after harvest (van Kooten et al. 1999). Then, assuming an interior solution exists to problem (9) when $E(v_1, v_2)$ is excluded, so that each site can be considered independent of the other, the optimum rotation length t^* can be found by solving (van Kooten, Binkley and Delcourt 1995):

$$(14) \qquad \frac{\dfrac{\dot{v}(t^*)}{v(t^*)} + \dfrac{r}{\beta}}{1 + \dfrac{r}{\beta}\dfrac{\int_0^{t^*} v(\tau) e^{-r\tau} d\tau}{v(t^*)}} = \frac{r}{1 - e^{-rt^*}}.$$

Setting p_c=0 gives the Faustmann or financial rotation age, while setting p=0 gives the formula for calculating the non-timber only rotation age t' (assuming also that β≠0):

$$(15) \qquad \frac{v(t')}{\int_0^{t'} v(\tau) e^{-r\tau} d\tau} = \frac{r}{1 - e^{-rt'}}.$$

As a particular case, if the pickling rate also equals zero (i.e., β=0) in (14), then we obtain the Hartman rotation age, which depends only on non-commercial timber benefits. As shown by van Kooten, Binkley and Delcourt (1995), by increasing p_c, the authority can delay private harvesting decisions. Indeed, in their examples, harvests might even be delayed infinitely if carbon prices were sufficiently high and β low.

Including Environmental Amenities: Land-use Interdependencies

Until now we have not considered non-carbon environmental amenities and the possibility that activities on one site affect environmental amenities, and thus the socially optimal harvest strategy, on other sites. For example, the amenity value of planting native trees and encouraging wetlands will depend, to a large degree, on the surrounding landscape. Wetlands have much more value in a region characterized by fence-row-to-fence-row cultivation than in an area already containing similar habitat; tree plantations with native species have greater amenity value in areas planted to hybrid poplar than they do in regions where native species are abundant.

The spatial problem in forestry is that many non-timber values (e.g., wilderness preservation, provision of forage for wild ungulates, wildlife habitat) vary in different ways with forest age, with some even unrelated to forest age (see Calish, Fight and Teeguarden 1978; Bowes and Krutilla 1989). Examples of the relationship between a forest stand's age and non-timber amenities are provided in Figure 1. For example, amenity flows might represent the value of wildlife species (e.g., herbivores) adapted to young forests with plentiful forage (I), wildlife values that are independent of forest age (II), and the value of species reliant on more mature forests, such as trout and spotted owls. Benefit stream IV represents the sum of these amenity flows (Swallow, Parks and Wear 1990).

When non-timber values are combined with commercial timber benefits in the objective function, solving for the rotation length that maximizes total net (timber plus non-timber) benefits is more complicated. Rather than finding a global maximum, one often discovers local minima or local maxima upon solving the first-order conditions for an optimal solution. For example, for total benefit stream (IV) in Figure 1, the same marginal conditions that define a local maximum also apply to a local minimum. Neither of these are a global maximum. Typical policies are derived to reconcile external benefits or costs present in first order conditions. In Figure 1, where total benefits (IV) are not convex with respect to time, policies based on first order conditions could lead to either a local maximum or local minimum, and not to the global maximum.

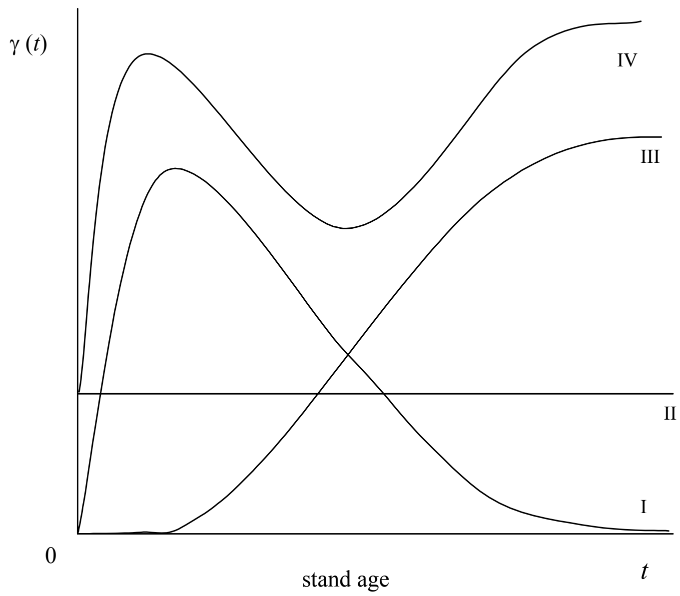

Figure 1: Relationship between Stand Age and Amenity Value, Various Amenities

This policy-relevant nonconvexity can prevent a tax or subsidy policy from achieving the socially desirable harvest levels or rotation age. The reason can also be illustrated using marginal benefits and costs associated with rotation length (Figure 2). It is well known that the condition for a socially optimal (internal) solution for a finite timber harvest occurs when the marginal opportunity cost of delaying harvest (MOC) equals the discounted marginal benefit of delay (MBD).

Suppose that the private, financial rotation age is given by t^*. Points 1 and 2, with accompanying rotation ages t_1 and t_2, represent cases where MBD=MOC is satisfied. Because MOC intersects MBD from above, a non-convexity occurs at 1 but not at 2 – the point 1 is an equilibrium that is not optimal, but 2 is. Providing the forest manager with a myopic subsidy equal to the value of the non-timber benefits will result in a rotation age, t_1, that is shorter than the financial rotation age t^*. That is, a subsidy to get the manager to take into account environmental spillovers results in a too-soon harvest – one that reduces nonmarket values compared to a later harvest at t^*. However, a policy that rewards the forest owner or manager with an appropriate subsidy only over the period $t_1 \leq t \leq t^*$ will achieve the desired solution at 2.

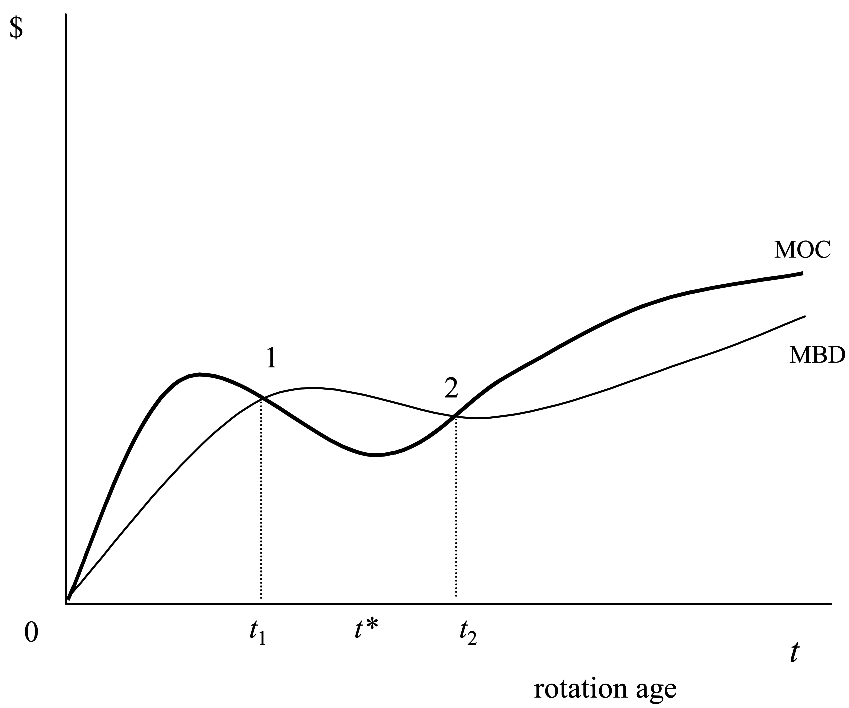

Figure 2: Non-convexities and Optimal Hartman-Faustmann Rotation Age

For some standing forests the external amenity benefits might be so great that it would not be economically optimal to harvest the forest at any time in the future. This would be the case if equilibrium points existed at ages beyond those indicated in Figure 2 (e.g., MOC and MBD may intersect again, with MOC upward and MBD downward sloping). If this is the case and society inherits "ancient" forests, it may be worthwhile delaying harvests, perhaps indefinitely.

Finally, consider our problem (9), where environmental amenities at one site are affected by harvest decisions at another site. For convenience, we ignore carbon flux benefits. Assume that trees on a site grow according to the following function: $v_i(t) = a_i v_i - b_i v_i^2$, $i = 1,2$. Non-carbon environmental amenities are assumed to be a function ofgrowth on both stands and assumed to take a Cobb-Douglas form: $E(v_1, v_2) = \gamma v_1^{\alpha} v_2^{\beta}$, with $\gamma, \alpha, \beta \geq 0$ and $\alpha+\beta<1$. Then problem (9) can be written as:

(16) $$\underset{h_1 h_2}{Maximize} \int_0^T \{(p-c)(h_1 + h_2) + \gamma v_1^{\alpha} v_2^{\beta}\} e^{-rt} dt,$$

with constraints

(17) $h_i(t) \leq v_i(t)$, $i = 1,2$, and

(18) $\dot{v}_i(t) = a_i v_i - b_i v_i^2 - h_i$, $i = 1,2$.

For the problem defined by equations (16), (17) and (18), the current-value Hamiltonian is given as (with time notation on control and state variables assumed only implicitly):

(19) $$H(v_1, v_2, h_1, h_2, \theta_1, \theta_2) = (p-c)(h_1 + h_2) + \gamma v_1^{\alpha} v_2^{\beta} + \theta_1[a_1 v_1 - b_1 v_1^2 - h_1] + \theta_2[a_2 v_2 - b_2 v_2^2 - h_2]$$

The set of admissible controls must satisfy conditions (17), which require that the complementary slackness conditions must also be satisfied (Leonard and Van Long 1992, p.199):

(20) $\lambda_i[v_i - h_i] = 0$, $[v_i - h_i] \geq 0$, $\lambda_i \geq 0$, $i = 1,2$,

where λ_i are the lagrangian multipliers. This problem involves two state variables and two controls, and the need to satisfy inequality constraints. This makes it much more difficult to solve analytically than the one-state, one-control problem (Leonard and Van Long 1992). Hence, numerical mathematical programming techniques are generally employed. Since our objective here is only to illustrate the problem when activities on one site affect those on other sites, we only report theoretical solutions obtained by other researchers using a variety of techniques.

Swallow and Wear (1993) and Swallow, Talukdar and Wear (1997) consider multiple use across forest stands. Consider two sites, one publicly owned and the other private. Suppose that harvest of the private forest stand affects the flow of amenity benefits from the public stand, thus shifting both the MOC and MBD functions at the public site (see Figure 2). While it may be optimal to harvest the public stand, the public manager may wish to delay harvest in anticipation of felling of the private site, thus extending the public rotation age beyond that which would be socially optimal in the single-stand case. When both sites are managed together for their joint commercial timber and amenity values, the sequence of harvest schedules can take rather odd forms. For example, even though two forest stands may be nearly similar in all respects, it might be socially optimal to permit one site to mature to beyond 100 years before harvesting it, while the other site is harvested several times during this period. This caused Vincent and Binkley (1993) to recommend the use of zoning rather than subsidies as a public policy for increasing social well being. When both sites are privately owned, the authority needs to design incentives that cause each of the owners (or the single owner of the two stands) to take into account the effect on the amenity values of one stand of decisions taken on the other. Truly spatial problems occur when more than two stands and two amenities are considered, with socially optimal solutions diverging from those derived from two-stand analyses.

Bogdanski, van Kooten and Binkley (2002) consider the case of three stands, two of which are adjacent, with values derived from timber harvesting, domestic forage use, wildlife production and passive use. They solve their non-linear mathematical program in GAMS. When there are only two stands, the results are similar to those obtained by Swallow, Talukdar and Wear (1997). Depending on parameter values, non-timber outputs, and the distribution of values across the forest landscape, introducing a third stand can affect the degree of specialization in outputs for each stand. As long as the joint environmental benefits are not separable with respect to stand volumes, harvests and inventories can differ across stands, even if the stands are identical and not adjacent.

When there are one or two stands, nonconvexities can lead to specialization as an optimal solution. This solution can be implemented using regulation (zoning). However, nonconvexities need not be main policy drivers, because as Bogdanski, van Kooten and Binkley (2002) demonstrate, many factors besides nonconvexities determine how closely or differently stands are managed. Management that ignores the explicit location of stands, spatial scale of habitats, and/or interdependence among stands can result in lower social well being. Indeed, if we look across jurisdictions, research indicates that different management strategies can arise in different forest regions even when the technical production relationships and objectives are identical. But the converse may also be true: It is possible that similar management strategies should optimally be followed in different jurisdictions even if the physical forest, prices and discount rates are different. Forest regulations and taxes used to promote or protect non-timber amenities need to be sensitive to the spatial location of stands, the natural physical differences of stands, and stand interdependencies. Therefore, forest policy tools and initiatives that promote or support the principle of socially optimal use of forest resources, such as codes of forest practices and land-use zoning, need to vary from one forest region to another to account for spatial considerations. The conclusion of theoretical economics research using a model such as that described above is that there is no one dominant land management paradigm.

In many jurisdictions, governments have introduced various laws to regulate timber-harvesting practices on public and private land as a means to promote multiple-use forest management and achieve efficient forest resource use. In some cases, strict laws apply on all forest sites (Cook 1998), but such an approach fails to account for linkages and interdependencies between forest areas, regional differences in marginal values, or differences in forest ecosystems. Other jurisdictions (e.g. Sweden) recognize the need for forest management to be flexible (Wilson et al. 1998). Initiatives that do not account for spatial differences and that are inflexible over time will fail to achieve efficient resource use. As asserted by Brown, Brown and Binkley (1993), policy rigidities must be avoided; laws of forest practices and management programs need to adapt over time as more information becomes available so as to better account for the spatial and temporal aspects of forestry, and achieve better social outcomes. If forest practice laws fail to do so, they will fail to achieve economically efficient resource use.

What policies have been implemented to address spillovers at the extensive margin? In the next section, we examine these in greater detail. In some cases, we describe policies in place; in others, we point to policies that are being considered or in the process of being implemented.

4. POLICIES TO ADDRESS LAND-USE SPILLOVERS AT THE EXTENSIVE MARGIN

While we have already suggested some policy instruments for dealing with the divergence between privately and socially optimal land-use activities at the extensive margin, reality is often less straightforward. A challenging task facing policymakers is, therefore, that of developing appropriate policy instruments for addressing environmental spillovers. Different instrument choices that governments can use include command-and-control regulations (such as zoning, which is the instrument of choice at the intensive margin as we have seen), and market-based incentives that promote flexibility in achieving environmental objectives (Stavins 2002). Market incentives include tax-subsidy and cap-and-trade schemes. However, whether regulations or incentives are employed, state involvement is generally required, if only to determine the cap level and enforce and monitor the subsequent trading mechanism. Reliance on private transactions to resolve environmental spillovers, in the Coasian sense, is generally eschewed because empirical evidence of its success is lacking. The usual conclusion is that transaction costs of reaching agreements are onerous, so some form of state involvement is required. Even where firms (landowners in our case) have voluntarily agreed to address environmental spillovers, the explicit threat of state intervention is generally a prerequisite (Segerson and Miceli 1998).

There is now increasing evidence of the emergence of non-state, market-driven governance structures for addressing environmental spillovers (Kolk, van Tulder and

Welters 1999; Bernstein 2001; Khanna 2001). Unilateral action may be undertaken because it leads to a reduction in production costs (e.g., energy savings); examples are 3M Company's "Pollution Prevention Pays" and Dow Corporation's "Waste Reduction Always Pays" programs, which have reduced production or operating costs (Stavins 2002). Of such governance structures, private certification of sustainable forest management practices is possibly one of the more comprehensive examples (Kiker and Putz 1997; Swallow and Sedjo 2002), and it is examined further below. Before doing so, however, we examine agricultural programs that encourage farmers to produce more nature. We then consider forest-sector policies and more general policies affecting land-use at the extensive margin.

Protecting Nature in Farming Areas

Conservation Programs: Contracts to Protect Land

Governments have increasingly adopted direct "performance" contracts as a way to protect the environment. The state enters into long-term contracts with agricultural producers to idle specified parcels of land or to restrict land use in environmentally sensitive areas. The U.S. Conservation Reserve Program employs this approach for taking marginal, environmentally sensitive land out of production. Lands in the lowest soil capability classes, those with a soil-loss tolerance rate of 3 tons per acre or less, and those with a high potential for degradation are eligible. At the beginning of the program, eligible lands were identified in each region and competitive bids (to enroll lands) were employed to keep program costs down. However, when the U.S. Department of Agriculture established an upper limit on accepted bids, subsequent bids converged on the cap, thereby undermining the cost-saving potential of the bid system. In addition, the

CRP affected enrolment in other conservation programs.

Similarly, the Province of Saskatchewan's Permanent Cover Program provided financial incentives to farmers to take cropland out of production, planting it to trees or forages. The purpose of the Program was to reduce soil deterioration on high-risk lands that were under cultivation. Producers entered into ten- or twenty-year agreements to "seed" land to permanent cover and maintain it, receiving $20/ac to offset the costs of establishing permanent cover in addition to an annual payment. Initially, a bidding procedure was employed, but, subsequently, payments were fixed. Given low program payments, economists criticized the program for encouraging enrolment of land that might not have been cropped in any case. If that is the case, then this program is simply another mechanism for transferring income to farmers.

Cross Compliance

Unlike the aforementioned policies, cross (conservation) compliance explicitly recognizes that government subsidies are needed to enable farmers to keep pace with the standard of living enjoyed by the rest of society. It also recognizes that, in many cases, environmental programs simply offset incentives provided under other farm programs. There are two alternative approaches to cross compliance (Batie and Sappington 1986): (1) program payments are provided only if certain conservation standards are attained (the "red ticket approach"), or (2) program benefits increase as farmers meet or exceed specified (and increasingly higher) conservation thresholds (the "green ticket approach"). In essence, farmers are required to implement certain conservation practices in order to be eligible for subsidies from applicable present or future government agricultural programs.

The U.S. is the only country that has implemented cross compliance using a number of different approaches (in addition to the CRP). Under the "Swampbuster" and "Sodbuster" provisions of the U.S. Farm Bill, farmers become ineligible for agricultural program subsidies if they destroy wetlands (including swamps) or cultivate land that has not previously been producing annual crops. It does not aim to prevent land degradation by producers not eligible for farm subsidies. The Acreage Reduction Program (ARP) requires that farmers retire or "set-aside" land (and seed it with grasses to prevent erosion) each year in order to remain eligible for price supports and deficiency payments. The amount set aside each year depends upon the perceived over-supply of various crops. The main objectives of the ARP have been to reduce supplies and, thereby, program payments rather than to reduce land deterioration. However, the ARP has had little impact on supply due to "slippage" – the potential supply effects are dampened by farmers idling their least-productive but not necessarily most-erosive lands. Thus, the main effect of the set-aside program has been budget reduction for the United States government.

Finally, some conservation compliance provisions that require those farming highly erodible lands to implement acceptable farm conservation plans in order to remain eligible for agricultural subsidies. The emphasis of conservation compliance is enhanced management. Examples of conservation plans include retaining a certain level of trash on fields during the winter months to retard soil erosion, contour plowing, grassed waterways to reduce water erosion, planting trees to mitigate wind erosion, and flexcropping to reduce tillage fallow or to include conservation practices (viz., green manure) in management strategies that maximize returns and minimize risk. Conservation plans differ among regions and crop types. However, many problems with conservation compliance have already been identified. Examples of problems include: enforcement of trash levels may give rise to conflicts because local committees of farmers determine whether or not other farmers (their neighbors) are complying with the conservation plan; implementation of flexcropping requires knowledgeable management personnel; and certain aspects of conservation compliance could lead to adverse income-distributional consequences.

The major difficulties of cross compliance are those of identifying appropriate conservation strategies and enforcement. Canada has no conservation compliance provisions in its farm subsidy programs, although there is information about erosion rates on some lands (however, it has a physical bias and is incomplete). In Canada, unless economic information is incorporated, it will be difficult to identify and implement cross compliance strategies that are not doomed to fail. In particular, it is necessary to identify lands that are subject to the most serious degradation problems (provide information on erosion rates for each parcel of land), determine the on-farm costs of erosion (i.e., estimate damage functions), and calculate the off-farm costs of erosion. Otherwise, the benefits of cross compliance could turn out to be lower than the costs.

Forest-Sector and General Policies to Protect Nature at the Extensive Margin

In the past decade or so, there has been a spate of public policies designed to protect nature in forest ecosystems. The main characteristic of these programs is their reliance on regulation, or command-and-control, as opposed to market instruments. We discuss these policies in the remainder of this section.

Zoning of Protected Areas

Zoning is increasingly used in countries' conservation programs to protect representative wildlife habitats. In 1991, some 5% of the earth's land surface was protected, while some 9% of the globe's land surface is protected today (Green and Paine 1997). The Brundtland Commission (WCED 1987) suggests that 20% of tropical forestlands be protected (p. 152), and that there be a three-fold increase in the amount of land set aside for species and ecosystem preservation (pp. 165-66). As a result, there appears to be international consensus that, as a rule of thumb, nations should commit 12% of their land base to protect biological resources. Therefore, many countries have either formulated or are in the course of designing plans to move towards this target. For example, British Columbia's Protected Areas Strategy is designed to protect more than 12% of the Province's land area as wilderness reserves.

The creation of conservation reserves raises at least two questions: Is 12% an adequate level of protection? Can such a level of protection be sustained?

Protected areas constitute *in situ* protection of biodiversity and other environmental values. Along with *ex situ* facilities, they help sustain many species, including some in serious danger of extinction. But the establishment of protected areas was not originally oriented towards the conservation of biological diversity. Many parks and wilderness areas are considered too small effectively to conserve intact ecosystems or provide for their inhabitants. At the end of the 20th Century, there were 30,350 protected areas covering 13.2 million km^2, but 59% of these were less than 1,000 ha in size and six large protected areas accounted for 18.5% of total protected area (Green and Paine 1997). The largest protected areas are thinly populated and contain very little in the way of biodiversity. Further, rates of protection vary greatly by biomes, with protected areas accounting for 16.3% of mixed island systems, 10.3% of subtropical and temperate rain forests, and 9.1% of mixed mountain systems, but less than 1% of temperate grassland

and 1.1% of lake systems (Green and Paine 1997). It is little wonder that biologists argue that greater areas need to be protected, although they do recognize that this needs to be done in an economically wise (efficient) manner (Pressey 2000; Sinclair 2000).

The more relevant question might be whether significant conservation reserves can be sustained indefinitely. First off, creation of protected areas has not gone unopposed, particularly in developing countries where local people were often evicted from newly-established reserves without compensation. Benefits from protected areas frequently extend beyond the sites to society at large in the form of existence values, or hunting benefits for an international elite, while costs are borne locally. Unless local citizens have a stake in a protected area, they are just as likely as not to undermine efforts to preserve the ecosystem. Ineffective management and insufficient funding to maintain protected areas, both in developing and developed countries, have led to the conclusion that "all reserves in the world are presently in a state of decline as a result of attrition from human interference" (Sinclair 2000, p.43). Ironically, in many countries where parks are major sources of tourist revenue, very little is reinvested in conservation. Poaching is a particular problem in many developing countries because the values of products from some endangered and threatened species, such as rhinoceros, elephants, tigers and bears, are high compared to the incomes of people living in the regions where animals are found. It is also a problem in developed countries, where poaching of bears and other wildlife, as well as timber (e.g., cedar shakes), also appears difficult to stop. As in the rural-urban interface, zoning may not by itself be adequate.

TRIADs

Zoning has also been recommended in Canada, which has perhaps the highest degree of public ownership of forestland in the world (Wilson et al. 1998). In order to address environmental concerns surrounding use of public forestlands, some Canadian provinces are looking to zone forestland into three components – non-commercial use (no logging whatsoever), multiple use (a mix of forestry operations and other activities), and intensive forestry use. The acronym TRIAD derives from the need to create three zones of use. The idea is that, by investing heavily in silviculture in the intensively managed zone, enough timber will be produced to cover loss of harvests from the other zones. As such, it is based on (albeit incomplete) research from models similar to those presented in the previous section.

There are problems with this zoning approach to protect nature. First, Triad zoning does not necessarily lead to an economically efficient outcome from society's point of view. As we have seen, when there are interdependencies among spatially separated stands, which is the case here, whatever is done on one stand will affect how other stands are managed. It does not follow, therefore, that permanently setting aside one particular area never to be harvested is efficient. Indeed, periodic harvests, perhaps even more than a hundred years apart, may result in a "better" outcome. Second, with risks of fire, disease and climate change, it is possible that amenity values on the permanently set aside area can be lost for a long period of time. Salvage logging on the no-logging area along with reduced logging in intensively managed areas may be appropriate. Of course, some of these observations apply to conservation reserves as well, although Triad zoning is over and above biological reservation.

Triad zoning on the scale of a Province (with some 50 or more million ha of working forest) may simply be asking too much, because zoning will reduce overall flexibility. It seems to us that adaptive management with appropriate economic incentives may better protect non-timber amenities. For example, wood engineering has made it possible to use fiber from hybrid poplar plantations to produce solid wood products that are comparable in terms of their properties (strength, flexibility, etc.) with products from traditional plantations and original forests (Stennes 2002). However, in areas such as temperate British Columbia where hybrid poplar grows faster than in other regions of Canada, there is a lack of private land for plantations, while Provincial regulations on public land often preclude planting hybrid poplar on a large scale, even on land zoned for intensive forest management. Unless environmental amenities are sufficiently relaxed on the intensively managed, timber-only zone, it may not be possible to offset losses in timber output from increased set asides by designating special zones for single use (see Krcmar, Vertinsky and van Kooten 2003).

Endangered Species Legislation

Endangered species legislation is another example of regulation over land use in order to protect nature at the extensive margin. To our knowledge, the United States is the only country to have enacted legislation to protect endangered species that affects how private landowners can use their land. While Canada also has endangered species legislation, it only applies to federal lands and not to private lands or land under the ownership of a Provincial government (the most common form of public ownership). In the U.S., Congress passed the Endangered Species Act (ESA) in 1973 and re-authorized it in 1988. ESA was interpreted by the Courts to mean that species were to be saved *at all costs*, which established a duty to preserve all species, but the duty itself was impracticable. Therefore, shortly after ESA was enacted, the Congress established the

Endangered Species Committee, comprised of relevant agency heads and other representatives, to resolve conflicts between federal government projects and ESA – an attempt in other words to get around ESA. Environmentalists dubbed the Committee the "God Squad," but it has rarely met since it was established and even less often taken action to over-turn Court decisions.

Endangered species legislation affects land use because endangered species' habitat is found on land, or, in the case of fish, land use (e.g., removal of water for irrigation, clearing trees too close to streams) affects habitat. ESA can lead to less than socially optimal land use for several reasons. First, because private landowners often incur the costs of protecting the habitat of endangered species, they have an incentive to destroy wildlife habitat on their land before it is identified as harboring an endangered species or before an identified species is listed under ESA. Thus, more habitat may potentially be destroyed than is socially optimal. Second, the legislation could prevent certain land use activities that generate high net social benefits that would exceed the benefits from protecting a specific species. Perhaps the species has little value to society or better habitat exists elsewhere, or preventing the land use activity will not succeed in preventing the species from going extinct in any case. This is typical of most land use regulations: they are not designed to achieve a socially optimal allocation of land.

Protection of species can be modeled in ways described in the previous section, but only if species numbers are somehow related to land use activities. If that is not the case, then other approaches for analyzing optimal land use will need to be applied.

Codes of Forest Practice and Forest Certification

Beginning in the early 1990s, many forest jurisdictions began to introduce codes of forest practice in order to address environmental spillovers associated with forest operations and to ensure sustainable forest management (Wilson et al. 1998). Sweden's code was embodied in the 1993 Forestry Act. The Act itself consisted of only a few pages, with on-the-ground application left to local state foresters. In contradistinction, the Province of British Columbia's 1995 Forest Practices Code consisted of thousands of pages of detailed requirements that placed on onerous burden not only on firms but also on the state foresters responsible for enforcing it (van Kooten 1999). In B.C., there were delays in getting forest management plans approved (recall that logging companies harvest timber from public lands), harvesting costs increased dramatically, and flexibility in regeneration was reduced. Forest practices code are, perhaps, an unneeded regulatory burden (over and above any zoning regulations), because of the development of non-state, market driven schemes for the certification of forest management practices.

Failure to sign a global convention on forestry at the Earth Summit in Rio de Janeiro in 1992 led environmental, non-governmental organizations to develop a private, non-mandatory regulatory scheme for sustainable forest management. In 1993, a coalition of environmental groups (led by the World Wide Fund for Nature, or WWF), foresters and timber companies formed the Forest Stewardship Council (FSC) to develop standards for SFM and certify companies practicing sustainable forestry. In response, competing domestic certification schemes developed primarily in Canada, the United States and Europe. These were initiated by the forest industry in North America and by forest landowners in Europe. As of June 2002, 122 million ha of forests had been certified globally (Figure 3), but this constitutes only about 3% of the world's forests or double the area in 2001. Nearly 9 percent of forests in North America are certified and nearly 6 percent of those in Europe, but only about 0.5 percent of forests elsewhere. Only 8 percent of all certified forests are in Asia, Africa and Latin America. Most of the certified forestland is certified under a domestic scheme as opposed to the FSC.

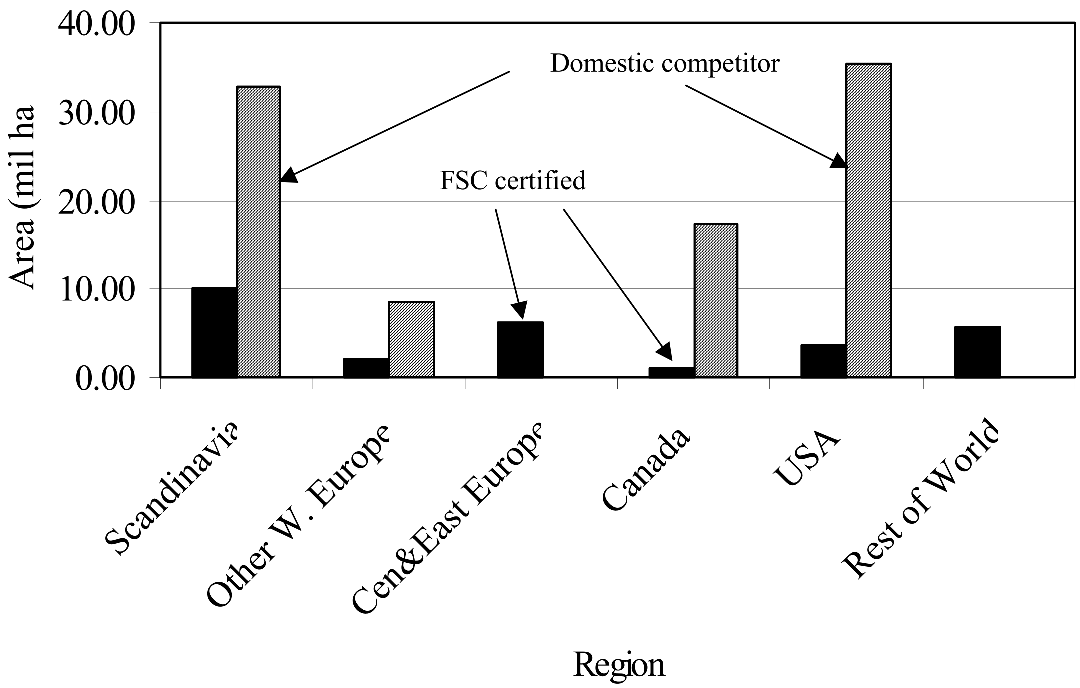

Figure 3: FSC Certified Area versus Area Certified under a Competitor Program

The FSC provides both SFM certification and chain-of-custody certification, although the latter presupposes the former. Our focus is on certification of forest management practices, since this concerns the land base. As a result, we ignore ISO 14001 certification as it is process based – processing of wood products and not forest practices are certified. As of January 2002, the FSC had issued only 86 certificates for forest holdings larger than 50,000 ha, but these accounted for more than 90% of the FSC certified area. The FSC had only certified 284 forest holdings smaller than 50,000 ha by

2002 (Eba'a Atyi and Simula, 2002).

In Canada, the Canadian Pulp and Paper Association (now the Forest Products Association of Canada) asked the Canadian Standards Association (CSA) to develop a forest certification program based on a systems approach to SFM. To become certified, companies would have to establish environmental management forestry systems that include auditing requirements. CSA certification has built in flexibility to encourage on-going improvements in forest management. Although CSA certification was initiated by industry, its requirements are quite stringent; costs of obtaining and complying with CSA certification are now comparable with those of FSC certification, although it currently lacks the same global recognition as FSC.

In the U.S., the American Forest and Paper Association's Sustainable Forestry Initiative (SFI) requires firms to file reports with SFI regarding their SFM plans. Like CSA certification, no attempt is made to follow wood fiber through its various stages to the final consumer (chain-of-custody certification), although labeling of products is emerging (Meridian Institute 2001). Because the U.S. is the most important market for Canadian wood products, about half of certified forestlands in Canada are SFI certified.

In Europe, it was landowners who developed their own certification program, because they felt that their needs and opinions were ignored by FSC. The various national forest landowner associations began the Pan-European Forest Certification (PEFC) scheme in 1999. PEFC endorses national schemes that then rely on third party certification.

The main certification schemes operating in the tropics are the FSC and a national scheme in Malaysia, although some forests have been issued a Keurhout declaration signifying they are certified. Areas certified under these programs are insignificant.

Compared to FSC certification, PEFC and SFI have certified significantly more smallholdings and community forests (Eba'a Atyi and Simula 2002). There have been meetings aimed at reaching agreement on mutual recognition, but these have focused mainly on the FSC and PEFC, and the tropical countries. The International Tropical Timber Organization (ITTO) has been involved in these discussions, but, despite the fact that SFI has been widely adopted in Canada, ITTO only recognizes two international certification programs, FSC and PEFC (Eba'a Atyi and Simula 2002). Unfortunately, such an attitude pits North America against Europe in the marketing of wood products.

While the intention of legislated codes of forest practice was to foster joint production of commercial timber and nature, that is, multiple use, forest certification has perhaps eliminated the need to have state regulations. Indeed, to the extent that local codes governing forest practices are inflexible and yet must be retained by some certification scheme (which is the case for FSC certification), these could become an obstacle to firms seeking to become certified. Regardless of the situation, forest certification is a non-state, market driven governance structure that addresses environmental spillovers related to land use in forestry. Could such an approach extent to other land uses as well? This is unclear, but certification could conceivably extend to terrestrial carbon sinks, where it could be used to facilitate a CO_2-emissions trading market that also including carbon offset credits. Further, the potential for other land uses to become certified is something that governments need to consider in the development of future land-use policy.

5. DISCUSSION

Scarcity of undeveloped rural or natural land has focused society's attention on urban and rural land uses, and on land in its natural state. A range of analytical techniques have been developed to study land use at the intensive margin (between urban and rural uses) and at the extensive margin (between rural uses and nature). The opportunity cost of developing either rural or natural land may include lost benefits that are not valued in markets. Economic policy issues frequently involve the (external) opportunity cost of developing rural land for residential purposes, or developing natural land for agricultural or forestry purposes. Policy approaches such as regulation and market-based incentives have been developed to incorporate these (external) opportunity costs into the land development process, and to reconcile private land use decisions with public preferences for multiple benefits from the landscape.

One common perspective used to analyze land use at the intensive margin is based on the bid rent framework of von Thünen, as presented in Alonso. In this basic model, land is optimally allocated in a competitive land market to the use that provides the greatest net benefit. Net benefit from a particular land-use option depends on benefits and costs associated with that option, and on a land parcel's location relative to a central business district. Innovations to this perspective by Capozza and Helsley (1990) give rise to the widely-used urban growth model, in which the value of rural land includes a premium for potential development (in addition to rural land-use benefits and costs). Introducing land quality into land benefit functions (in addition to location) results in a more realistic landscape that includes noncontiguous land uses. When external benefits are associated with rural use, policies are needed to influence the allocation of land between urban and rural uses.

Specific policy issues at the intensive margin include the opportunity cost of lost open space, congestion externalities associated with development, and other external costs of development infrastructure (e.g., schools, sewer, public services). Policy approaches to help sustain agriculture in a changing landscape include right-to-farm legislation and preferential property tax valuation. When development premiums for rural land are substantial, incentives for continued rural use may be provided through conservation easements or purchase of development rights programs. Regulatory approaches such as land use zoning and large minimum developed lot sizes have also been used to influence the intensive margin and the developed landscape.

A common perspective used to analyze land use at the extensive margin is based on the optimum timber harvest model developed by Faustmann (1995). The Faustmann model has been extended in numerous directions including the influence of (1) non-timber benefits, (2) neighboring stands, and (3) non-forest land use (see Newman 2002). Including non-timber benefits can lead to an important optimum in which a forest might be permanently preserved for non-timber production. Whether the joint production of timber and non-timber benefits is convex with respect to time is crucial in determining optimum forest management policies. Including neighboring stands (or other nonlinear harvest effects) is crucial in distinguishing optimum partial harvests from optimum clear felling. Considering non-forest land use is essential to represent accurately any landscape that consists of more than a single forest use.

Specific policy issues at the extensive margin include the opportunity cost of developing natural lands for agriculture, and competing joint production of timber and non-timber benefits in forested landscapes. Policy approaches used to sustain environmental benefits in agricultural landscapes include conservation payment programs, and, in the U.S., linking agricultural subsidies to environmental performance standards (i.e., land use). Regulatory approaches used to obtain optimum joint timber and non-timber production include forest zoning, TRIAD zoning (in Canada), and Endangered Species habitat protection (in the U.S.). Forest practice-related performance standards are also used in forest landscapes throughout the world, frequently taking the form of forest practice certification.

New research opportunities are emerging throughout land economics, particularly in areas of models, methods and policy analysis. For example, new conceptual models are integrating urban, rural and natural land uses. There is increasing recognition of rural use in urban models, nonagricultural use in agricultural models, and non-forest (non-timber) use in forest (timber) models.

Statistical methods have evolved to harness increased computing power and abundant remotely-sensed spatial data. Statistical biases from omitting uses have been quantified. At the intensive margin, optimal land-use choice models and optimum development timing models now include spatially independent variables (neighborhood variables) or incorporate spatial correlation in the covariance matrix. At the extensive margin, optimal land-use choice or Faustmann models now include neighborhood variables as independent variables, or include neighboring stand characteristics in non-timber benefit production function. This affects decisions regarding when to harvest stands, if ever.

The relevance of land to current policy problems is the engine that drives recent innovation in both conceptual and analytical areas. The role of the landscape in environmental public goods, such as carbon storage, species habitat and water quality, is receiving increased attention by policy researchers. Most of the policy analyst's traditional instruments (command and control, charges and subsidies, and transferable property rights) have been applied or proposed for solving land-related policy problems. The conclusion is that there currently appears to be a growing enthusiasm for market-based approaches at both the intensive and extensive margins. However, implementation of some of these market incentive approaches (such as CO_2-emissions trading that includes terrestrial carbon offsets) offers areas for further research.

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