Economics and the Land Use-Environment Link

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INTRODUCTION

The use of land as an economic activity has long been a central theme in economics. From issues of land as a productive input and scarce resource to property rights and the role of institutions, the question of land use has spawned a vast and diverse portfolio of research and economic thought. In analyzing the connections between land use and the environment, this chapter takes a different approach from much of this literature. The focus is not land use, *per se*, but how economists have thought about land use *change*, specifically in the context of the link between land use and the environment.

A narrow interpretation of the land use–environment link would consider only the question of how the amount and pattern of land use affects ecological systems. We take a broader perspective by also including a discussion of the characteristics of land use pattern that are directly valued by individuals, such as open space and other landscape amenities. While consideration of such landscape amenities does not necessarily have an ecological basis, the two perspectives are so intimately intertwined in policy motivation and modeling as to be effectively inseparable. The breadth of our discussion on land use change is quite limited in other ways, however. The literature that relates to land use is voluminous, as is the list of policies that affect land use decisions either purposefully or unintentionally. Here we restrict our attention to the land use–environment literature relevant to the U.S. and Europe, with obvious weight given to the former. We focus on what we see to be the most pressing current problems, and limit our discussions to the policies and the literature of the last 10 or 15 years. Our treatment of the problem is tailored to highlight a few themes that have emerged from the recent literature. These are themes that we believe will likely influence land use research over the next several years.

Land Use and Ecological Systems

Land use/land cover change is generally considered to be the single most important factor affecting ecosystem health (Hunsacker and Levine, 1995). Changes in land cover alter the fluxes of mass and energy in the ecological system, which has consequences for ecological structure, functioning, and the flow of ecological goods and services. The existing scientific literature on the connections between the amount and pattern of land use and the functioning of ecosystems is extensive. Here we briefly summarize the principal links and refer to some general sources that can provide greater depth.

Before proceeding, we draw an important distinction between land use and land cover. The former denotes humans' employment of the land, e.g. crop production, grazing, logging, urban development, while the latter denotes the physical and biotic characteristics of the surface, e.g. forest, homogenous or heterogeneous vegetation, asphalt, ice (Meyer and Turner, 1992). Land *cover* is considered the essential determinant of ecological structure and function,[1] but land *use* determines land cover to a large extent. In addition, land use is important in assessing ecological impacts because it signals the nature of the human interaction with the environment. Even the very act of land use change can have systematic effects. Examples include biomass burning, which generates air pollution and greenhouse gas emissions, and clearing and excavation, which contribute to soil erosion and sedimentation.

One of the primary connections between land use and ecological impacts is the discharge of nutrients, toxics, or other substances that are generated by a specific use of the land. Agricultural land, at least in developed countries, is often associated with discharges into surface and ground waters of pesticides and herbicides, high levels of nutrients from fertilizers and manure, and fecal coliforms, as well as discharges of methane and N_2O into the air. Frequent cultivation of agricultural land provides a natural transport of chemicals and nutrients through soil erosion and sediment transport. This process leads to sedimentation of streams and changing hydrology. Where agriculture is fed by irrigation systems, salinization can result in serious soil degradation. Agricultural irrigation represents the principle source of water loss from the natural system and can

[1] Climate affects land cover change and vice versa, but it is often argued that land cover rather than climate has the most effect on the ecology of the planet (Dale, 1997).

lead to arid conditions downstream as well as groundwater depletion (Riebsame, Meyer, and Turner, 1994).

Likewise, urban land is associated with discharges of nutrients and fecal coliforms from sewage, and of toxics and heavy metals from industry and transportation infrastructure. Urban systems are characterized by impervious surfaces that prevent precipitation from infiltrating soils and collect such contaminants as petroleum products from vehicles and chemicals used in winter road treatment for direct deposition into surface waters. Also, irrespective of the contaminant flows, extensive paved surfaces alter the hydrological regime, increasing the variance in stream flow. The latter leads to soil bank erosion and to alterations in the aquatic habitat.

Both urban and agricultural systems have obvious impacts on the abundance and diversity of flora and fauna. Both landscapes are notably inhospitable to a broad range of wildlife and vegetation. Where vegetation exists, it is often monoculture or non-native, placing high water and nutrient demands on the system. Where human engineered landscapes exist, natural ones do not. Intensive urban and agricultural land uses come at the expense of forest, grasslands, and wetlands, and each of these provides functions of value to the broader ecosystem. Forests play an important role in carbon cycling and nutrient removal. Wetlands and other riparian areas have been identified as some of the most productive areas of the planet. Riparian areas support an unusually diverse array of species and environmental processes. Small scale variations in topology and soils are exacerbated by the natural variation in water levels and stream flows, making these areas extremely heterogeneous and complex over small geographical extents. Riparian and wetlands areas serve as sediment traps and, in doing so, can reduce contaminant discharges into streams and coastal areas. Natural riparian areas help maintain stream flows and stabilize shorelines, providing storm and flood protection. Human interventions through damming and drainage or direct elimination have simplified these systems and reduced their ability to perform these functions (Naiman, DeCamps, and Pollock, 1993).

It is not just the land use or land cover *per se* that determines ecological impacts. The ecological consequences of human activities are also determined by the pattern, and not just the amount, of land use/land cover. The field of landscape ecology, which studies the relationship between landscape *pattern* and ecological *processes*, treats landscapes as spatially heterogeneous, environmental mosaics (Turner, 1989). The ecological processes of a system are in part determined by its landscape pattern, e.g. the flow of matter and nutrients across the landscape is a function of its spatial pattern. For example, consider the interaction of natural and agricultural landscapes. Since natural vegetation can remove nutrients from a system, the spatial coupling of natural and agricultural landscapes within a watershed can significantly reduce the adverse effects of the latter.

Spatial pattern also affects regional abundance, movement, and distribution of species. Patch size and shape, as well as habitat connectivity, dictate which species will survive in a region. Interconnections are undisturbed corridors through which species can and will move. They can be supplied by something as simple as a hedgerow and destroyed by a pipeline or road. Habitat connectivity determines the ability of many species to move between desirable habitat patches and, as a consequence, has an effect on the survival of some populations. Different species are differentially dependent on these corridors and thrive in different types of habitat mosaics, depending on such factors as amount of contiguous natural habitat and edge-to-interior ratios.

Likewise, the relative magnitudes of the various problems caused by urban development depend on the pattern of development. For example, low density sprawl may not involve substantial increases in impervious surfaces, but will generally be serviced by septic fields rather than sewage treatment, increasing per capita nutrient loadings and fecal coliform discharges. Because it generally occurs in areas well outside urban centers, low density sprawl implies long commuting distances, a high number of vehicle miles, and consequently air quality degradation. In addition, low density sprawl fragments the landscape in ways that will be detrimental to some species and beneficial to others, but those that benefit are rarely among the endangered or threatened.

Landscape Amenities

The ecological services and functions that are affected by land use/land cover have obvious if not always direct impacts on humans. These effects include climate change, air and water quality, water quantity, storm and flood protection, soil productivity, biodiversity, and wildlife abundance. These are not the only ways in which land use/land cover affects humans, however, and they are not the only motivations for the policy interventions that will be discussed in the next section. The spatial arrangement of people relative to each other, to sites of human activity, and to natural landscape features has enormous effects on the quality of life in a region. Different landscapes afford different recreational experiences – both in type and in quality. They also embody different levels of aesthetic value and reflect, in differing amounts, a people's cultural heritage. Lastly, urban settlement patterns can generate a host of positive and negative spillover effects themselves that may influence an area's quality of life. Some spatial configurations of urban development generate positive spillover effects by fostering a sense of community while others degrade the character of the community or produce congestion.

The fact that people might be willing to pay for increases in landscape amenities and pay to avoid increases in disamenities makes these landscape features of importance to economists. The fact that landscape amenities and disamenities are often interrelated with environmental factors make them important for this chapter. In the remainder of this section we review some of the economics literature that provides evidence of people's willingness-to-pay for different landscapes. We give special attention to those studies designed to measure the value of landscape amenities in the context of agricultural land, for reasons that will become clear in our policy discussion.

The literature that links locally undesirable land uses with depressed property values is extensive (for a recent review, see Farber, 1998). While the fact that the effect on housing prices can be documented empirically is certainly important to our argument, the types of land uses addressed in this literature are specific facilities such as landfills or chemical plants. For a number of reasons it will not be these "point sources" of environmental and amenity effects that will be of most interest to us in this chapter, but rather the pattern of land use and the interaction of that pattern with the environment. Far fewer studies have tested whether the *pattern* of land use in the neighborhood of a house affects its property value, although a growing number address this question (e.g. Bell and Bockstael, 1999; Bockstael and Bell, 1998; Garrod and Willis, 1992a; Garrod and Willis, 1992b; Geoghegan, Wainger, and Bockstael, 1997; Leggett and Bockstael, 1999). The evidence from these papers is inconclusive. Garrod and Willis test whether different types of forests affect neighboring housing prices and find evidence that this is so. The study is limited for our purposes, since it does not reveal whether woodlands relative to other land uses are valuable as neighbors. The remaining papers investigate the determinants of housing prices for different purposes, but in the process explore whether, in the immediate vicinity of a housing parcel, the proportions of surrounding land in each of different land use categories (agriculture, forest, low density residential, high density residential, commercial/industrial) affect price. The results are mixed and depend on whether the houses are in predominantly urban, suburban or rural areas, since marginal additions to surrounding open space may be valued highly in suburban areas, but not in rural areas. The hedonic model is problematic for determining the value of different surrounding densities of development because of an inherent endogeneity problem. Even if open space is a desired amenity, open space will be rare in areas where development values are high because in these areas open space will have a high opportunity cost.

Landscape amenities do not accrue solely to immediate neighbors. City and suburban residents may have high values for agriculture or wooded land in their region. To test for this, several authors have investigated, in a more direct way, whether individuals value features of the landscape. In a series of papers, Kline and Wichelns (1994, 1996a, 1996b) examine agricultural preservation programs in the northeast U.S. Citizens were found to be willing to support these preservation programs for several reasons, including (in order of importance): protecting groundwater, wildlife habitat, and natural places; providing local fresh produce; preserving rural character and scenic beauty; slowing development: and providing public access. The authors found that support for farmland preservation programs was greatest in those counties experiencing the largest increases in population and in housing and property values.

This result is borne out by contingent valuation studies used to estimate the amount people would be willing to pay to preserve land in agriculture. Halstead (1984) and Beasley, Workman and Williams (1986) estimated significant bids that rose to about $150 per household from about $50 when the replacement for agriculture was hypothesized to be high density rather than low density development. Two other studies report considerably lower values for farmland protection. Bergstrom, Dillman, and Stoll (1985) estimate an average willingness to pay per household of only $5 for protecting half the prime agricultural land in a county in South Carolina, and Ready, Berger, and Blomquist (1997) an average per household per farm preservation bid of less than 50 cents for horse farms in Kentucky. In both these cases, the current development levels were not as high as in the northeast and the density of the hypothetical new development was not specified in the contingent instrument.

A few studies in Europe have explored preferences for preserved agricultural land, but here the alternative is either an alternative agricultural method or abandonment and re-growth in natural vegetation. Pruckner (1991) found that tourists in the mountainous areas of Austria visited the areas for "environmental and countryside" reasons, but their bids per day of travel to preserve the farmland landscapes rather than have these farms abandoned were quite small. In contrast, Drake estimated average bids of 541 SEK ($70) per person to prevent half of all Sweden's agricultural land from returning to dense spruce forest. Faced with a choice among agricultural methods, individuals valued the traditional sparsely wooded pasture of Sweden more highly than cultivated pasture and the latter more than cropland. Motives for support included (in order of importance): nature conservation, aesthetics, recreation, and cultural-historic values.

As an indication of the importance of this question in Europe, the Commission of the European Community sponsored a workshop in 1993 focusing on the economic valuation of benefits from "countryside stewardship." Included in these proceedings is a paper by Watkins (1994) that attempts to define the illusive concept of "landscape amenities" with reference to the interplay between natural characteristics and historical human activity that generates the regional variability of the European landscape. Merlo and Della Puppa (1994) and Riera (1994) review studies, in Italy and Spain respectively, that have attempted to value traditional agricultural or forest landscapes; Willis (1994) and Dubgaard (1994) report contingent valuation results for farmed landscapes in the Yorkshire Dales of England and Mols Bjerge in Denmark, respectively. This collection of studies documents the rising importance of landscape amenities to the European populace as per capita income and leisure time increase, and identifies preferences for wild or more natural agricultural landscapes over planned or intensively cultivated ones.

While the willingness to pay estimates would not all bear close scrutiny, the results do suggest that landscape amenities are commodities with value for humans. Exactly what people are seeking to gain when they support programs to protect rural landscapes, and whether these are bids for agricultural landscapes or just open space, is still unclear. A few general results emerge that are expected, but significant: (1) bids for landscape amenities are found to be highly responsive to income and education,[2] and (2) preferences for landscape depend on location and alternative land use.

THE POLICY ENVIRONMENT OF LAND USE CHANGE

To Americans, the most striking feature of European landscapes is the relative absence of residential sprawl. While the historical roots of these landscape differences may be quite complex, primary reasons include Europe's earlier recognition of the costs of unregulated land use decisions and the relative strength of constitutionally protected property rights in the U.S. In addition, the relatively low population to land ratio in the

[2] Not all the studies reviewed tested this hypothesis, but the result is robust for those studies that did .

U.S. has delayed the onset of serious externalities and encouraged dependence on the automobile and accompanying spatially extensive activities. Where the existence of externalities has become an issue, the 5th amendment of the U.S. Constitution has often served to discourage public entities from wresting control of property rights from individuals.[3] Despite such differences, the two continents share a considerable commonality in land use concerns – and even policy.

The network of policies designed to affect the amount and pattern of land use in both the U.S. and Europe is complex, often indirect, and dependent on perceived property rights. Types of activities for which spillover effects are sufficiently large are constrained in their location possibilities. An extreme example is the siting of noxious facilities.[4] But even in the U.S., more benign industrial operations are restricted to specifically zoned locations and cannot be undertaken at the owner's discretion. Similarly, government programs on both continents have succeeded in protecting some lands from substantive human impacts by designating them as environmentally sensitive areas. In locations where human activities are perceived to generate excessive environmental damage, public policies have tended toward withdrawing specific property rights from the private sector and granting these activities only by some form of permitting, as with wetlands. More often, public policies aimed at affecting land use do so by providing incentives or disincentives to individual landowners. Land use decisions are also affected by policies designed to address completely different social concerns whose unintended consequences for land use change can be severe.

An attempt at a succinct discussion of the policies that affect land use in the U.S. and Europe is doomed to failure. Almost every conceivable public policy has some effect, however indirect, on land use decisions. In addition, many of the policies that are designed to affect land use decisions directly are specific to localities. In the U.S., most

[3] See Miceli and Segerson (1997) for a thorough discussion of the "takings" issue.
[4] In this chapter we do not attempt to cover the siting of noxious facilities literature. A recent review of the locally undesirable land use literature can be found in Farber (1998). In addition, a series of papers published in the Journal of Environmental Economics and Management address the issues of efficiency and fairness (see, for example, Ingberman (1995); Kunreuther, Kleindorfer, Knez, and Yaksick (1987); O'Sullivan (1993); Opaluch, Swallow, Weaver, Wessells, and Wichelns (1993)).

land use authority rests with the local governments, although increasingly states are taking a role in planning and policy implementation. Likewise in Europe, EU directives may encourage member states to implement certain types of policies, especially those made more effective by inter-nation cooperation, but land use planning is largely left to the individual member states. On both continents, however, policies that affect land use indirectly often originate at "federal" levels of government. These include many wildlife and environmental initiatives. But it is probably through agricultural policy that the "federal" levels of government exercise the most influence on land use pattern and change.

The diversity of programs over states and countries is so great as to make discussion of the details impractical. In outlining the policies that influence land use decisions, we indulge in considerable generalization. In addition, we restrict discussion to those policies that affect the conversion of land from one use to another and omit those that affect practices *given* the particular land use. For example, we will be interested in policies that encourage or discourage urban development of agricultural land, but will not be interested in best management practices designed to alter the amount of run-off generated by agricultural operations.

This distinction is easier made in theory than in practice. To the extent that policies may encourage a different type of agriculture or a different density of residential use, it is important for ecological reasons to distinguish among these. Broad categories of land use do not map perfectly into land cover, and it is often land cover that ultimately determines ecological impacts. Low intensity grazing land can behave, in an ecological sense, more like grasslands than agricultural cropland; and very low density residential or hobby farms may behave more like forest or pasture than like higher densities of residential use. Given the breadth of policies that could conceivably alter land use decisions, we proceed with some trepidation, focusing on those that have received the most attention in the literature.

Containing Urban Development

Compared to the U.S., land use is heavily regulated in Europe. In most European countries landowners must obtain permission from local authorities to change land use. Extensive comprehensive planning frameworks exist that are integrated over levels of government from the national and provincial to the local. One notable result of this process is the protection of rural lands from urban development.

The Town and Country Planning Act of the U.K. is an example of landscape protection legislation in Europe. Since the 1940's the rights of land development outside urban areas have been nationalized. Rural land, synonymous in Europe with agricultural land, generally can not be developed without permission from local planning commissions, following the directives embodied in national policy. Controls on development are especially restrictive in greenbelts around urban areas. Policies of urban containment that involve more or less extensive layers of bureaucracy can also be found, among others, in the Scandinavian countries, Germany, France, and The Netherlands (Bramsnaes, 1992).

The public sector's ability to control development in the U.S., especially for residential use, has historically been limited. Land use regulation is largely in the hands of local governments. As a result, land use control, to the extent that it has been practiced at all in the U.S., has been fragmented and idiosyncratic in nature. States are slowly assuming more authority in the land use control arena, but, consistent with the diverse character of states, the pattern of state intervention is uneven. Examples range from Oregon, widely viewed as aggressive in forcing localities to comply with a more uniform and restrictive land use regulation philosophy, to Texas, which discourages its localities from interfering in private property rights at all.

Substantive interest in growth control in the U.S. dates back to the 1970's. This "first wave" of activism had as its motivation the environmental consequences of land use change, where this change endangered specific environmental resources viewed as either valuable or fragile or both. Concerns over traffic congestion, and more recent concerns over the loss of open space and rising costs of public infrastructure. have spawned a new wave in growth control legislation. Currently, more than a dozen states mandate local comprehensive plans statewide (Burby and May, 1997).

This second wave, which has gained an unprecedented amount of attention, is motivated as much by the *pattern* as the *amount* of growth. In 1998, a record number of political elections turned on growth control issues and some 15 state governors advanced "Smart Growth" legislation. The term "Smart Growth" has become synonymous with policies that reduce incentives for sprawl development (incentives such as transportation subsidies and public utility extensions) and attempt to redirect both the location and density of new development. According to "Smart Growth" proponents, preferred development patterns are those that preserve large contiguous greenspaces and concentrate residential uses in areas where public services can be provided most efficiently. The "Smart Growth" vision has been embraced at the federal level as well; the Environmental Protection Agency has instituted a "Smart Growth" website[5] and supports growth management strategy workshops. A $10 billion federal bond program has been announced to help communities preserve green space, reduce traffic congestion, protect water quality, and clean up abandoned industrial sites (brownfields). Land use regulation, once a topic avoided by U.S. politicians and relegated to isolated local debates, has emerged as a key political issue at all levels of government in the U.S.[6]

Despite growing concerns, there are relatively few direct means for localities to constrain growth and direct its pattern. In the U.S., instruments that directly affect the development pattern include zoning and rationing or delaying the issuance of housing permits. The latter include capping the number of new permits issued per year or placing a temporary moratorium on new permits based on the capacity of the public infrastructure through adequate public facilities legislation.

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[5] This website can be found at http://www.smartgrowth.org/index.html

[6] See "The New Politics of Urban Sprawl," New York Times, November 15, 1998; "On 2 Coasts, a Search for Limits to the Sprawl that Appalls", Washington Post, March 5, 1995; "Urban Sprawl Strains Western States", New York Times, December 29, 1996; "Green, More or Less", Washington Post, March 25, 1997

Local governments have attempted to discourage development in rural areas by increasing minimum lot sizes, charging impact fees, and/or withholding public utility provision, thus lowering the net returns to residential development in these areas. Where increases in minimum lot sizes are not sufficient to make development unprofitable, however, large minimum lot sizes merely exacerbate the trend towards low density sprawl and fragmentation.[7] Withholding the provision of public utilities is a related mechanism aimed at discouraging development beyond some urban boundary. However, because public health regulations generally limit the density of development when dependent on private wells and septic fields, the pattern of low density development is again reinforced.

Where zoning ordinances have been sufficiently restrictive to preclude profitable development, they have faced legal challenges. The famous "takings clause" of the 5th Amendment to the U.S. Constitution specifies that the government shall not take private property for public use without just compensation. Public actions that significantly affect the value of property can be challenged on this basis. For the most part, courts have upheld governments' rights to impose zoning (Miceli and Segerson, 1996), but dramatic "down-zoning" that imposes huge losses on landowners by increasing the minimum lot size for residential development has been challenged.

Transferable development rights (TDR) programs seek to mitigate these losses by granting to landowners a given number of development rights per acre in conjunction with "down-zoning." These development rights can not be used to develop their own property but can be sold in TDR markets to developers who need to obtain these rights if they wish to develop at a higher than allowable density in other, predetermined "receiving" areas targeted for development. While appealing in principle, TDR markets have proven difficult to establish. Administrators encounter problems ensuring that the development rights have sufficient value to compensate for the losses imposed by down-

[7] In part to counter this, some localities have required clustered development, which limits the number of dwelling units on a large parcel and requires that all units be clustered in one section of the parcel. The results are reduced fragmentation and increased open space amenities within the parcel, but the development may still be a noncontiguous "island" within a rural landscape.

zoning. Finding receiving zones where developing at higher densities is both valuable and acceptable to existing residences has been problematic. Both the strength and the weakness of TDR's stem from the localized nature of the development externalities and the resulting distributional implications.

Targeting Ecologically Sensitive Lands

In addition to the long history of federal acquisition of public lands, a number of protection policies at the state and federal levels now target land viewed as ecologically valuable. Intervention in these cases often involves a stringent permitting process or outright removal of these environmentally sensitive lands from the private development market. Many protect the coastal zone where pressures for development are especially keen and healthy ecosystems especially productive. Examples of protected areas within which development is severely restricted include the Maryland's Critical Areas Zone along the Chesapeake Bay and the Pinelands in south central New Jersey.

The most obvious example of direct federal intervention into land use regulation is wetlands permitting. Section 404 of the Clean Water Act precludes discharges of dredge or fill into wetlands without permits. Drainage is not explicitly covered in the Act and some categories of wetland disturbance receive statutory exemptions, including "normal farming activities." Permit requests are allowed or denied based on the social importance of the project, its dependence on the water, and the degree to which the project would impose impacts on the physical, chemical, and biological characteristics of the aquatic ecosystem. The effects on human use must also be assessed, including the impacts on water supplies, recreational and commercial fisheries, recreation, and aesthetics. Those projects that are permitted are required to minimize wetland impacts. Where impacts remain, wetlands mitigation is required. Once again, denial of permits has occasionally been challenged as a "takings without just compensation," since denial is equivalent to the confiscation of potentially valuable development rights.

Considerable discussion has centered on "wetlands mitigation," defined as the creation or restoration of wetlands as compensation in kind for their destruction elsewhere. While in principle meeting the "no net loss" of wetlands[8] mandate, mitigation has been criticized for failing to provide equal wetlands services to those that are destroyed. Since location is of central concern in ecological systems, creation or restoration of wetlands may be least costly where they are already in abundance, and wetlands of low functional quality may be the easiest to produce. Mitigation success rates have been questioned and post-construction monitoring has been infrequent, bringing this process into further dispute.

Wetlands mitigation banking is a means of solving some of these problems. Under this new policy, large sites for the creation, restoration, or enhancement of wetlands are identified in watersheds where development is expected. In order to obtain permission to develop a wetlands site, a developer must have already acquired credits from investment in a completed rehabilitation site in the same watershed. The number of credits earned depends not only on the number of acres of wetland restored or created but also on the success of the project and the resulting quality of the wetland, measured in number of species and/or functions (Fernandez and Karp, 1998). A fair amount of evidence exists that wetlands diversity and resilience increase with size. Since wetlands creation is probably characterized by decreasing average costs at least over relevant ranges, it is more efficient to mitigate for wetlands loss by pooling investments of many firms in one large project. Mitigation banking involves uncompensated costs for the public sector, in terms of planning, designing and assessing these projects. Nonetheless, it may be a much more reliable and cost efficient means of meeting a "no net loss" wetlands goal.

The Pivotal Role of Agriculture in the Landscape

From the perspective of land use change, agriculture plays a pivotal and seemingly schizophrenic role. In both the U.S. and Europe, a host of policies are implemented to keep land in farming, many justified explicitly on the basis of the positive externalities generated by agriculture. At the same time, a vast array of

[8] A "no-net loss" wetlands policy goal has been embraced at the national level in recent years. The goal is to create new wetlands whenever existing wetlands are destroyed through development.

programs are in place to encourage the movement of land out of active or intensive agriculture, justified explicitly on the basis of agriculture's deleterious environmental impacts.

These apparent, and often real, inconsistencies in policies arise because agriculture is indeed the generator of both positive and negative externalities. The net effect of these activities on society depends on how agriculture is practiced, as well as the alternative land use that would arise should agriculture disappear. Where land markets operate relatively freely, the externalities of land use are not internalized. In this case, and particularly if pressures for development are great, alternative land uses to agriculture are often perceived as imposing greater net non-market costs on society than farming itself. Where land markets are extensively circumscribed or development pressures low, the residual claimant of the land may be natural vegetation. In these cases, the negative environmental impacts of agriculture stand in sharp contrast to their alternative.

Urban development in many parts of the U.S. is perceived to be occurring at the expense of agriculture. In part, this is because some of the same physical characteristics (e.g. permeability, slope, and geological structure) that makes land particularly productive in agricultural also makes it desirable for residential use. It is also cheaper to develop a farm than a forest, since the latter often involves large clearing costs. Many state and local governments have implemented programs to discourage farmland conversion. These policies are motivated by a desire to preserve the local farming sector, occasionally justified by a desire for regional self sufficiency, but more often to protect the landscape amenities that farms are perceived to provide. Legislation exists in all fifty U.S. states allowing localities to grant property tax relief to agricultural lands (where these include forested lands in some states). By enrolling in a preferential tax policy plan, agricultural property can be assessed at use value rather than at its "highest and best use."[9] Tax relief programs have typically been viewed as a distortionary policy[10] and are

[9] Once enrolled, farmland that is subsequently sold for development is sometimes subject to a complete or partial rollback penalty.

generally believed to have had little success in retarding development of agricultural lands (Buist, Fischer. Michos, and Tegene. 1995).

Because of this, state and local governments have sought more direct means of preserving farmland. In approximately 15 states (mostly in the northeast and mid-Atlantic regions), voluntary "purchase of development rights" (PDR) programs exist through which farmers can sell their development rights to the public sector. Once again, initial justifications for these programs focused on maintaining the viability of a local farming industry, but, as we discussed in the introduction, current programs probably gain their support because they are perceived as containing urban sprawl and providing open space, scenic values, and wildlife habitat.

The provisions of these programs vary dramatically, but programs usually preserve land permanently and forbid non-agricultural activities. In most cases, only the development rights are sold and no public access is conveyed. The maximum price paid for the easement is linked to the market price of the land, net of its assessed value in agriculture. Limited budgets often force agencies to choose among landowners' offers. Criteria include quality of agricultural land, amount of preserved land in the surrounding area, environmental benefits, and bid discounts offered by farmers.

In some areas the value of the development rights of a farm will be substantial. It often represents the farmer's retirement package, his major and sometimes only asset. Long before the optimal time for development (even from a private rather than a social perspective), the speculative component of the value of farmland can be considerable. Because of this substantive component, the death of a landowner can lead to the premature conversion of farmland if heirs cannot pay the inheritance tax. Likewise, entry

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[10] Some recent studies have cast this preferential tax policy in a more favorable light. A number of "costs of sprawl" studies have found that the cost of providing public services relative to every dollar of revenues is higher for residential use than agriculture or industrial uses (American Farmland Trust, 1992 and 1994; Vance and Larson, 1988; Carroll County Bureau of Planning, 1996; Cecil County Office of Economic Development, 1994). However, these studies have been called into question by a number of economists, who point out that these estimates do not take into account the indirect fiscal benefits of new residential development to a community.

into farming in such an area can be foreclosed because of the high initial investment costs of land acquisition. These considerations contribute to the complex market forces that surround land use conversion in rapidly growing areas. They also complicate the tax implications of PDR programs, which tend to reduce ultimate estate or inheritance taxes, but increase current capital gains taxes, unless payouts are extended over several years.

In contrast to these programs which seek to keep land in agriculture, many policies in both the U.S. and Europe focus on containing the negative effects of intensive agricultural practices on ecosystem functioning and landscape amenities.[11] In the mid 1980's, governments in the U.S. and Europe began concerted efforts to encourage farmers to practice less environmentally damaging practices. Our discussion is limited to those policies aimed at affecting the land use/land cover of rural lands, i.e. those that discourage the extension of farming into previously uncultivated areas and those that encourage the reversion of arable land to traditional farming practices or to natural vegetative cover.

The Swampbuster provision of the 1985 Farm Bill and the 1986 Tax Reform Act are examples of such policies in the U.S. The first denies agricultural program benefits to farmers who drain wetlands; the latter prohibits capital cost tax deductions for drainage activities. The 1985 Farm Bill also established an incentive scheme for conserving environmentally sensitive land. Aimed initially at highly erodible land, the Conservation Reserve Program is a voluntary, long-term (10-15 years) land diversion program that includes secondary objectives of improving water quality, reducing off-site sedimentation, creating wildlife habitat, and curbing surplus production. Most recent authorizations have given greater weight to the secondary objectives. Farmers receive a rental payment plus half the cost of establishing permanent vegetative cover on the land. Similarly, the Wetlands Reserve Program, established by the 1990 Farm Bill, pays for restoration of wetlands previously converted to agricultural uses.

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[11] As we will see in the next section, agricultural support policies can exacerbate these negative externalities by encouraging intensification of production activities and extension of cultivation into marginal and fragile lands.

Concern over water pollution and the destruction of habitat by agriculture led to similar initiatives in Europe at around the same time. Although individual member countries implemented earlier programs, two European Community Directives (797/85 and 2328/91) have led to the establishment of Environmentally Sensitive Areas (ESA's) in several European countries. These directives encouraged (but did not require) member states to establish ESA's within which farmers could be subsidized to practice "traditional" farming methods. The U.K., with over 2.2 million hectares in ESA's by the mid-1990's, has made the most use of this subsidization scheme. Participation in the UK program is open on a voluntary basis to farmers who farm in designated ESA's. Within any designated area, all farmers receive the same flat payment per hectare for adopting prescribed farming practices directed towards the preservation goals of the region. These might include preservation of rare flora and fauna, protection of geological features, enhancement of natural beauty, and protection of historical landscape features. ESA's are designated on the basis of ecosystems such as the moorlands of Dartmoor and the Peaks District, the grasslands of the Suffolk Valleys, or the lowland heath of East Anglia (Whitby and Lowe, 1994).

The Agri-Environmental Directive (2078/92) of 1992 is, in contrast, compulsory for member states and requires members to implement programs to aid farmers in undertaking activities with environmental and rural amenity value. Likewise, an afforestation directive (2080/92) authorizes payments made to farmers to convert marginal lands to forest. These agri-environmental programs have arisen from a perception that intensive agriculture is environmentally detrimental, due to ground and surface water pollution, reduction of ecological services (e.g. storm protection), and destruction of habitats. But more than this, a strong sense exists that intensification of agriculture is simplifying the landscape of Europe and eliminating its diversity. While the programs are aimed at preserving or restoring natural woodlands, wetlands, grasslands, and heath, they also promote traditional farm landscapes that are "semi-natural," such as terracing and hedgerows (Beaufoy, 1994). Diversity in landscape is important to biodiversity of plants and wildlife, but it is also deemed important to people and rural cultures. These programs appear to seek not only environmentally more benign activities but also preservation of rural amenities and cultural landscapes as well.

The agri-environmental programs are long term (20 years), voluntary land diversion schemes in which farmers receive rental payments to set land aside for environmental purposes. Recently, cross-compliance features have been added that tie agricultural supports to participation. In addition, these land diversions can now be used to fulfill set-aside requirements aimed at supply control (Colman, 1984). The EU shares support of these subsidies, but allows programs to be designed to respond to local conditions. In some parts of France, for example, the emphasis is on water quality; several German programs focus on riverbanks and meadowlands; and Luxembourg targets habitat protection (OECD, 1997). The UK's emphasis on the aesthetics of the landscape has led some to characterize these programs as new agricultural commodity supports, where the commodity being produced is now "countryside amenities."

Not all conservation is achieved through government purchase or incentive programs. About 900 non-profit land trusts exist in the U.S. that own or hold development easements on about 1 million acres of land. This represents considerably more protection than is provided by state and local farmland preservation programs. Similar conservation trusts, often referred to as CART's (Conservation, Amenity and Recreation Trusts), exist in Europe. Land is acquired through direct donation or purchased through private monetary contributions, although some public support is often provided. The goal of these non-profit organizations is environmental improvement, as we have broadly defined it, and includes nature conservancy, the provision of landscape and recreational amenities, and the conservation of "landscape and cultural heritage" (Hodge, 1995).

ECONOMIC POLICY ANALYSIS

In this section we review the economics literature that bears on the policies discussed above. To structure a coherent story, we limit our focus to a few major themes in the literature. The first is the assessment of the impact of urban containment policies in the context of the classic bid rent model. The second is broader and addresses the effects of a variety of land-related policies – including differential taxes, farmland preservation and conservation programs, and flood control policies – on the micro-level decisions of landowners. We conclude by considering the importance of heterogeneity of land in the optimal land allocation problem.

Growth Control Literature in the Context of a Bid-Rent Model

Two principle questions are asked in the growth control literature: Do growth controls matter? Are growth controls efficient? The answer to the first question is generally considered to be "yes." The empirical literature has provided sufficient evidence that where growth controls are present, housing prices in that jurisdiction are higher (Katz and Rosen (1987), Schwartz, Zorn and Hanesen (1986), Pollakowski and Wachter (1990), Segal and Srinivasan (1985)). Similar studies conducted by authors investigating the consequences of development restrictions in areas targeted for special protection come to the same conclusion. Parsons (1990) and Beaton and Pollock (1992) consider the question with respect to the Critical Areas of Maryland; Beaton (1991) does so for the New Jersey Pinelands. The majority of this literature implicitly or explicitly attributes the higher prices to supply restrictions. Growth controls either increase marginal costs (shift upwards the supply curve) of housing or truncate that supply curve at some maximum number of new permits per period. If one assumes that this is the only effect of growth controls, then the conclusion that controls are inefficient is inescapable. They represent a dead weight loss.

Fischel (1990), Navarro and Carson (1991), and Engle, Navarro, and Carson (1992) presented the competing argument that higher prices are not necessarily evidence of inefficiency. For one thing, growth controls are more likely to be instituted in areas where growth pressures are already intense, such as areas with considerable excess demand for housing. These are areas where prices will be increasing rapidly even without growth controls. As a consequence, analyses that compare areas with and without controls and treat the presence of controls as exogenous will suffer sample selection bias.

More importantly, if growth controls are instituted through a political process, presumably they are expected to achieve some beneficial outcome - specifically an increase in some set of amenities or at least a forestalling of the anticipated disamenities of future growth. By correcting a negative externality, they shift out the demand curve for housing. As a result, these amenities or reductions in disamenities will be capitalized into housing prices. In this case, higher prices are not evidence of inefficiency but evidence that the growth controls are working to mitigate a negative externality.

The prevailing economics model of land development is the bid rent model of Alonso (1964), Muth (1969) and Mills (1967). The model is based on the usual monocentric city formulation, in which individuals obtain utility from a numeraire good and consumption of one homogeneous housing unit at distance x from the city. The individual spends his income on commuting costs, kx, the rent for his housing, r, and the numeraire good. The equilibrium rent gradient that emerges from this model is a function of distance and total population. Given that housing takes up one unit per household, population at any time, t, will equal $\pi\bar{x}_t^{\,2}$, where $\bar{x}_t$ is the radius of a circle describing the edge of the developed area around the city center at time t. The price of a developed parcel at time $t=0$ will be given by:

$$\int_{t=0}^{\infty} r(t, x, \pi\bar{x}_t^{\,2}) e^{-it} dt$$

where i is the discount rate and the price of an undeveloped parcel at time $t=0$ will be

$$\int_{t=0}^{T} r_a e^{-it} dt + \int_{t=T}^{\infty} r(t, x, \pi\bar{x}_t^{\,2}) e^{-it} dt - De^{-iT}.$$

In the above, r_a is the rental value of agricultural land, D is conversion costs, and T is the optimal time of conversion from agriculture to developed use.

In the growth control literature (e.g. Brueckner, 1990; Ding, Knaap, and Hopkins, 1999) a negative externality is added to the utility function, such that for any level of the numeraire good, utility falls with increasing population in the jurisdiction. Growth controls themselves are represented simply as a restriction on the edge of the city.[12] In the closed city model, but with exogenous increases in population, individuals are not free to move. No amenity effect can arise since population, the explicit cause of the disamenity, continues to increase.[13] The rise in prices resulting from growth controls is purely a scarcity effect under this assumption.

When an open city is assumed, the jurisdiction imposing growth controls is small relative to the market and individuals can move costlessly between cities. Growth control restrictions impose a time path of $\bar{x}_c(t) < \bar{x}(t)$ on the outer edge of the city and deflect population growth elsewhere. "Consumers'" of housing initially enjoy an increase in utility relative to other localities due to the amenity effect, but rents increase to equilibrate utility across cities. Brueckner (1990) shows that the value of already developed land will rise, but the effect on the value of undeveloped land is ambiguous. The amenity value of the controls is capitalized into housing prices and thus the measure of the welfare effect is simply the net windfall gain to landowners. Because there is a market failure – an assumed negative externality due to increasing population in the jurisdiction – then it is possible for the growth controls in this situation to be welfare enhancing if they are set optimally. Ding, Knaap, and Hopkins (1999) follow up on this idea and show that relaxing the urban boundary at distinct points in time can increase social welfare when urban infrastructure is fixed.

Engle, Navarro, and Carson also assume an open city and consider several types of negative externalities, including traffic congestion (which raises the commuting costs),

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[12] Urban boundaries, adopted by cities such as Portland, Oregon and Boulder, Colorado are similar to this stylization of growth control, but most growth control measures operate quite differently, usually by implicitly or explicitly raising the costs of development.

[13] A restriction on the physical size of the city implies that with continually increasing population , either households must increase in size or density must increase. In the simpler models density is held constant at one land unit per household.

air pollution, and rising marginal costs in supplying of public goods. They show with a similar model that, irrespective of the nature of the externality, growth controls can be welfare enhancing.

In most jurisdictions, growth controls are likely to involve both amenity and supply restriction effects. As long as amenity effects are possible, enhancement of social welfare is not ruled out. The distribution of welfare effects is likely to be such that landowners of developed land (and homeowners) will benefit, renters may be indifferent, and owners of undeveloped land will tend to lose.[14] Brueckner has suggested an empirical test to determine whether a particular growth control strategy is welfare enhancing – a comparison of the sum of land prices over all parcels (developed and undeveloped) with and without the controls in place. Such an analysis requires answering the more fundamental question: What would land use patterns have looked like in the absence of controls? None of the empirical literature adequately addresses this question.

Although it forms the basis of much of this literature, the bid-rent model is less than satisfactory for assessing growth controls. For one thing, growth control measures are rarely as simple as are portrayed in this modeling context. In addition, they tend to be applied differentially in different zoning areas within a jurisdiction and, more important, within a housing market. They may restrict the growth of new housing in one area where public infrastructure has little capacity and they may raise the costs of construction in another area where rural amenities are targeted for protection.

Additionally, the nature of the amenity/disamenity is often difficult to define and measure. In some cases the gain may be less school crowding, where the geographical extent of the externality includes the school district; in another case it might be lower commuting costs, where those affected reside along a similar radial from the city center.

[14] The distributional results of these analyses suggest that communities will tend to vote for growth controls when homeowners can outvote vacant landowners, with renters often being the swing vote. Several papers investigate communities' decisions to institute growth controls, e.g. Baldassare and Wilson (1996), Gin and Sand (1994), and Gatzlaff and Smith (1993).

In another case, protection of large tracts of open space may benefit anyone who likes taking trips to the country – even individuals from other jurisdictions. Very few growth-related externalities impact the *entire* population, and *only* the population, of the jurisdiction imposing them.

In all of this, the role of population growth is important, but difficult to sort out. Will population continue to increase despite controls? Or will controls deflect population growth to other areas? If so, does an interdependence arise among local jurisdictions setting growth controls? Using data for 164 Connecticut townships, Lenon, Chattopadhyay, and Heffley (1996) find empirical evidence that minimum lot zoning, property tax rates, and government spending levels of neighboring towns are positively correlated.[15] Likewise, Brueckner (1998) finds empirical evidence that a city is likely to impose stringent growth controls when its neighbors' controls are stringent and mild controls when the surrounding cities' controls are mild. Using data on California cities provided by the Lincoln Land Institute, the author tests for interdependence by estimating a spatially lagged dependent variable model where the dependent variable is an index that counts the number of growth control measures in place in a municipality. Brueckner chooses to interpret his results as evidence of "strategic interaction" among these California cities, following the long theoretical literature on this topic.[16] However, as he admits himself, there are alternative competing hypotheses with regard to the motivation that can not be rejected. For example, similar growth controls can reflect spatially correlated constituency preferences or municipalities could be "naïve followers of localized policy fads" (Brueckner, p 465

The Optimal Timing of Development Models

The bid-rent model can be solved for a spatial equilibrium only when the underlying constrained utility maximization problem is simple and little variation is allowed over market participants. A complex network of externalities and interventions

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[15] However, their empirical model does not account for the likely spatial autocorrelation of the error term and therefore, the empirical estimates of the policy interaction term could be biased in a positive direction.

cannot easily be characterized in this context. An alternative means of assessing policies aimed at altering land use is to do so in the context of an individual agent's optimal land use decision. Micro-level modeling of this sort precludes the solution of a market equilibrium, but allows the characterization of the representative landowner's decision in the face of a variety of policy instruments.

Following Arnott and Lewis (1979), Anderson (1986, 1993a, 1993b) and others who have set out the optimal timing decision for the developer, define *f(t)* as the per period net returns from a parcel in agriculture at time *t* and *h(t)* as the per period rents from a developed use of the land. The value of the parcel at time *t=0* will be given by

$$V(D) = \int_{t=0}^{D} f(t)e^{-rt}\,dt + \int_{t=D}^{\infty} h(t)e^{-rt}\,dt - Ke^{-rD}$$

where r is the interest rate, K is the cost of conversion, and D is the optimal time of development. The first order condition for the optimal development time will be given by $f(D) - h(D) + rK = 0$. Defining $H(D)$ as

$$H(D) = \int_{t=D}^{\infty} h(t)e^{-r(t-D)}\,dt\,,$$

the value of the parcel at time D (after conversion costs have been paid), the first order conditions[17] can be rewritten as:

$$-H'(D) + rH(D) = rK + f(D).$$

The developer will develop at the point when the foregone rent from waiting one period (the terms on the left) just equals the interest saved by postponing conversion costs plus the agricultural returns earned in that period (the terms on the right). Given fairly stable agricultural returns over time, this is the optimal point as long as the second order condition is met – that the rental rate is increasing at a decreasing rate.

[16] Oates and Schwab (1988) is perhaps the best known of these papers in the environmental economics literature.
[17] This is true since $H'(D) = -h(D) + r\int h(t)e^{-r(t-D)}$.

Anderson uses this model to show the effects of preferential tax treatment given to farmers. His (1986) comparative statics results show that if pre- and post-development tax rates are different, then a decline in the pre-development tax rate does indeed slow the pace of development (i.e. causes D to increase). Parenthetically, if pre- and post-tax rates are identical and rental rates, $h(t)$, are rising, then higher uniform tax rates speed up development. In a later paper, Anderson (1993b) demonstrates that in the presence of a positive open space externality associated with farmland relative to development, the socially optimal solution can be obtained by driving a wedge between the pre- and post-development property tax rate, where the wedge is equal to the annual value of the positive externality divided by $H(D)$.

A different problem arises when instead of a differential tax rate, a locality chooses to charge the same tax rate on a different assessed value. The concept of use-value assessment implies that the common tax rate is applied to the value of the land assuming it is kept in its current use in perpetuity rather than to the market value of the land (which includes the capitalized expectations on future development value of the land). From the comparative statics it can be shown that for the same tax rate, use value assessment will also slow the pace of development relative to full value assessment. The pace of development will be slower, the greater the divergence between farmland value and full assessed value and the greater the tax rate (Anderson, 1993a).

There are other forces that might speed or slow the pace of development. One could argue that development is irreversible and generates uncertain returns. Capozza and Helsley's (1989) analysis suggests that these features bestow an option value on farming which acts to slow development. However, if there is uncertainty with regard to future regulations on development, then this sort of uncertainty has the reverse effect. Innes (1997) explores the broader question of optimal compensation structures, given that undeveloped land is "taken" by the public sector before developed land.

The model above, appropriately extended to reflect capital gains and estate taxes, could also be a useful framework in which to evaluate agricultural preservation programs.

A few researchers have attempted to model and empirically explain voluntary participation in these programs, but not in the above framework. Based on individual survey data, these studies support the hypothesis that a significant amount of the variation is due to idiosyncratic characteristics of the farmers themselves (Phipps, 1983; Pitt, Phipps and Lessley, 1988). This is not surprising, given the importance of development rights as a chief asset in the farmer's portfolio. Age and family composition matter because they interact with retirement and estate planning considerations. Attitudes towards risk also play an important role in the decision, since future development values relative to current easement payments are highly uncertain.

Some studies have found empirical evidence that participation rates seem to decline with increases in market value of the land (Phipps, 1983; Bockstael and Bell, 1998; Boisvert et al, 1988). However, most have found little relationship between participation and profitability in agricultural use. This latter finding may be due to the relatively little variation in agricultural use values across parcels in any given region. Whether the preservation decision should be modeled as a function of the difference between development and agricultural value is an interesting question in its own right. Preservation programs are generally designed to pay the difference between the full market value of the property at time of sale and the agricultural value of the land in perpetuity, so that the easement payment would be calculated as:

$$E = -\int_{t=D}^{\infty} f(t)e^{-rt}\,dt + \int_{t=D}^{\infty} h(t)e^{-rt}\,dt - Ke^{-rD},$$

With perfect information, perfectly functioning capital markets, and no taxes, such an easement payment should make farmers indifferent between selling their development rights and holding them. The absence of any of these caveats could change incentives, however. For example, if farmers have liquidity problems or if they are uncertain about future returns from development, they may be more inclined to sell development rights when the optimal development time is very far into the future.

Other Micro-Level Models of Land Use Conversion

A somewhat different micro-level decision model is appropriate when the relevant land use decision is a choice between farming and forestry (or some other land conservation use). To answer these sorts of questions, consider the following decision problem in which the farmer decides for every parcel of land under his control whether to place it in agriculture or forest land, conditioned on its current state. We draw on, but simplify, the model of Stavins and Jaffe (1990), by denoting the optimization problem of the farmer as:

$$\max_{g_t, v_t} \int_{t=0}^{\infty} \{F_t(q_t)[g_t - v_t] - C_t + L_t\} e^{-rt} dt$$

where $F_t(q_t)$ is the present value of returns per acre to a parcel of land of quality q at time t, g_t is the number of acres of land converted from forest to farming at time t, and v_t is the number of acres of agricultural land abandoned to re-growth in forest at time t. C_t is the cost of conversion at time t, net of the windfall profits from a one time clear cutting of the forest, and L_t is the net forestry annual revenue from whatever acres are producing timber during time period t. Placing appropriate restrictions on the relationships between land in agriculture and land in timber producing activities, the authors derive the solution to the problem, which implies that:

a) if a parcel is in forest, it will be converted to agriculture if
$F_t(q_t) - C_t - L_t > 0$;

b) if a parcel is in agriculture, it will be abandoned if $\widetilde{L}_t - F_t(q_t) > 0$.

In the above L_t and $\widetilde{L}_t$ are the present discounted value at time t of an infinite stream of forest revenue, where $\widetilde{L}_t$ is adjusted for the delay in re-growth of the forest. Given both the explicit and implicit costs of converting from one use to another, there will be a range of net returns over which land will remain in its current use even when the alternative use is strictly more profitable.

One of the most creative aspects of the Stavins and Jaffe paper is its method for aggregating the micro decision to the county level, presuming land quality is heterogeneous but unobservable. The probability that the quality is high enough to make agricultural production feasible is a function of the percent of land in the county that is naturally protected from flooding and the percent that has been artificially protected by Army Corps of Engineers and Soil Conservation Service (SCS) drainage projects. The model of conversion between the two uses is estimated using data for 36 counties in the lower Mississippi Valley alluvial plain over the period from 1935-1984.

The simulations provided by Stavins and Jaffe suggest that some 32% less land would have been converted from wetland hardwoods to agriculture without the flood-control and drainage projects undertaken by the Corps and the SCS between the 1930's and the 1980's. In contrast, only about .5% less land is predicted to have been converted in the absence of agricultural price supports. In a follow-up study, Stavins (1990) uses the same estimated model to determine what the non-market value of the wetlands in this area would have to have been to justify a "no-net loss" wetlands scenario over these 50 years. With federal flood control projects, annual payments of approximately $150/acre for wetlands protection would have been necessary to obtain a "no-net loss" result, but without these projects the necessary incentive would have been half that figure.

While Stavins and Stavins and Jaffe look at the consequences of drainage projects on wetlands, other researchers have used a similar, although somewhat less complex model, to investigate incentives provided by new conservation legislation. As mentioned earlier, the Farm Bill of 1985 and the Tax Reform Act of 1986 included features that reduce the incentives for wetlands conversion. To assess the effects of these reforms, Kramer and Shabman (1993) simulated the mean net present value of agricultural returns per acre in three counties with different cropping patterns in the hardwood bottomlands of the Mississippi Valley, assuming stochastic prices and yields. They did so for four scenarios compared to a base period simulation which incorporated 1985 agriculture prices and drainage incentives. The four scenarios included: 1987 prices but no reforms, 1987 prices and the Swampbuster provision only, 1987 prices and the tax reform provision only, and 1987 prices and both reforms. The three counties considered are illustrative of the degree of underlying variation in returns. For all counties, the reforms reduced the mean net present value of returns.

Some analysts have feared that current reductions in price supports would remove the disincentive provided through the Swampbuster program for converting wetlands to farmland. Kramer and Shabman find that for two of the three counties simulated. trends in prices were already depressing the likelihood of further conversion of wetlands to farmland - even without policy reforms. The authors use these results together with the strength of the tax reform impact alone to argue that pressures to convert wetlands to agriculture will continue to decline.

More recent agricultural policy has switched from removing drainage project incentives to providing incentives for wetlands restoration. The 1989 renewal of the Conservation Reserve Program (CRP) and the Wetlands Reserve Program of the 1990 Farm Bill offer cost-sharing to farmers for expenses incurred in restoring wetlands and provide a mechanism through which the farmer can receive rental payments for land removed from production and restored to wetlands. Parks and Kramer (1995) adapt the micro-level decision model to reflect the present value of net benefits from participating in the wetlands reserve program. No returns from timber harvest are modeled, but the returns from converting farmland to wetlands equals the easement minus the owners share of the conversion costs. From this decision framework, an acreage response function is derived that describes agents' optimum allocation at different easement payments. The distribution in the quality of agriculture land invokes a distribution in the amount of land restored as a function of the easement value. The threshold quality associated with a given easement value is unobserved but assumed to be related to variables that can be measured, such as value of crops sold per acre and costs of production per acre.

The authors' empirical evidence suggests that participation rates increase with the easement payment and decrease with restoration costs and value of land in agriculture. They also find that average characteristics of farmers matter – participation rates rise with average age and proportion of land farmed by owner. In a related article, Parks and Schorr (1997) find that when urban development of farmland is a viable option, participation in the CRP is not sensitive to easement payments but is very sensitive to the growth rates in the market value of land.

These papers make clear the importance of the interplay among policies. Additional evidence of this is provided by Plantinga (1996), whose empirical work suggests that reductions in milk price supports would move land into hardwood production and out of agriculture in Wisconsin. In another example, Poe (1998) finds that differential property taxes across states provide differential disincentives for participation in the CRP, thus limiting the ability of the USDA to target the most environmentally sensitive lands.

Taking the Heterogeneity of the Environment into Account

One of the criticisms of agri-environmental programs in the U.S. and Europe is that their selection criteria do not necessarily result in efficient solutions to the conservation problem. These programs have targeted lands that have apparently high environmental values irrespective of the opportunity costs of preservation, or they have sought to maximize the number of acres enrolled for a given budget irrespective of the ecological value of this land. Once one recognizes the heterogeneity of land in all dimensions – desirability for development, agricultural returns, and ecological services – the targeting mechanism becomes critical.

Babcock, Lakshminarayan, Wu, and Zilberman (1997) measure the success of different CRP targeting criteria for four different environmental indices using Lorenz curves and Gini coefficients. For any fixed budget, the maximum amount of environmental benefits can be obtained by choosing land according to a ranking system that selects land on the basis of the environmental benefits relative to foregone agricultural returns. Targeting schemes that select only on environmental benefits or only on the basis of least cost will be more or less inferior to the optimal criterion, depending on the spatial distribution of environmental and agricultural benefits. If the benefit cost ratio of environmental returns to agricultural returns is homogenous across land, the selection criteria will not matter. Likewise, if environmental benefits are negatively correlated over space with agricultural returns, then all the targeting criteria will work equally well.

By using National Resource Inventory data to construct four indices of environmental benefits, the authors find that only their wildlife index appears to be uniformly distributed across CRP land. In the case of surface water quality and water erosion indices, environmental benefits and agricultural returns are positively correlated, spatially. However, for these indices, targeting based on the environmental sensitivity of the land is almost as good as conducting a full benefit cost analysis, since land tends to be far more heterogeneous with respect to environmental vulnerability than agricultural returns. In all but the wildlife case, a targeting criterion that selects land based on least cost performs dismally.

Swallow's 1994 analysis of conversion of coastal wetlands to agriculture on the Pamlico-Albermarle Peninsula of North Carolina is one of the only other analyses that seeks optimal land use solutions by linking the human activities and the lost ecological services. Land conversion leads to salinity changes that affect stocks of brown shrimp and ultimately impact fishermen's returns. He draws on available information to approximate these losses to fishermen in various areas of the Peninsula and compares the results with the gains to farmers. His illustrative analysis supports preservation in some areas and development in others. Of particular note, the optimal solution depends not only on the ecological type of the wetlands, but also their geographic location and the type of human activity that would replace them.

Some Observations on the Policy Analysis Literature

Ultimately we are interested in knowing whether, after taking into consideration all the market failures that policies aim to correct, land is optimally distributed across different uses. Using a simple classification of land use categories, we might state the problem in a very simple framework, such as that used by McConnell (1989), in which society attempts to maximize the benefits accruing from each land use subject to the total land use constraint:

$$max\ B^a(L_a) + B^p(L_p) + B^u(L_u) + \lambda(L - L_a - L_p - L_u)$$

The benefit functions (the B's) capture all net benefits accruing from the land use, where L represents amount of land subscripted by a for agriculture, p for public lands, and u for urban land. In this context. McConnell raises the dynamic problem: what is the optimal conversion of land over time from one use to another? This question focuses discussion on those factors that tend to shift each of the marginal benefit functions. The optimal solution will depend on how exogenous factors like population and income growth will shift the relevant functions and how marginal benefits will change along any function as the amount of land in that use is altered[18]. Presumably population and income growth will shift the demand for agricultural products upwards, but it will also raise the opportunity cost of supplying land to the agricultural sector, since land's value in urban uses will be bid up. More people and more income per capita will also raise the marginal amenity value of open space, but much depends on what non-market amenities and disamenities agricultural land actually provides.

The dynamic optimization problem is complicated by the likely irreversibility of some transitions; for example the conversion of land from urban back to undeveloped uses may be economically infeasible. Additional complications arise when the influence of the land use pattern on the benefits functions is considered. Due to spatial externalities, the benefits from any given amount of land in a particular use will depend not only on exogenous factors such as population, but also on the spatial distribution of all land uses and how this pattern changes over time. Considering both uncertainties about the value of public goods now and in the future, irreversibilities, and spillover effects, optimal solutions will deviate from the simple prescription of converting as soon as the marginal benefits of development exceed those of alternative land uses.

Much of the policy analysis reviewed in this chapter attempts to address this efficiency question, but generally with regard to one or two policies and two alternative

[18] Whether population and income growth are truly exogenous in a model of land allocation is debatable and depends on location. This assumption certainly is not true in many developing country contexts. It

land use states. In these analyses, a common theme has emerged: optimal resource allocation is very sensitive to location and pattern because the landscape is heterogeneous in many dimensions. Particularly in the agricultural papers reviewed, land quality enters the analyses and the optimal solutions depend on its distribution. As Babcock *et al.* illustrate, however, land is also heterogeneous in its ability to provide ecological services. Finally, even the most naïve of urban models recognizes that land is spatially heterogeneous in its value in developed uses.

Another theme that emerges relates to the impact of multiple policies on behavioral incentives for land use change. It is a considerable challenge to integrate the effects of multiple policies with the economic decisions of individuals who generate the ecological impacts – all the more challenging, given that the spatial extents of ecosystems, political jurisdictions, and land markets do not necessarily coincide. Increasingly, policies in both the U.S. and Europe are taking an ecosystem perspective to environmental regulation and management. As an example, the Water Quality Act of 1987 and the Coastal Zone Management Act of 1990 require states to develop non-point source pollution control strategies at the *watershed* level. An economic analysis of these policies, however, would require consideration of economic decisions and policies that impact the watershed, but whose values may be determined by events outside the watershed boundaries. It argues for explicitly spatial economic analyses that frame economic behavior in the context of the existing complex and overlapping policy settings; and for detailed analyses of both the economic and ecological systems with explicit links between the two.

SPATIAL MODELING OF LAND USE PATTERN

Because land use/land cover change has been recognized as the most important factor in affecting global environmental change, substantial research effort in the systems

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also is questionable in areas of developed countries where the regional economy is heavily dependent on natural resource related industry (e.g. the U.S. northwest.)

and landscape ecology disciplines has been directed towards modeling the science of this link. This research has led to the development of simulation models of regional landscapes that take as their input the pattern of land use/cover in the watershed or other ecological system of interest.

The dependence of these ecological models on the pattern of land use makes the modeling of land use change over a regional extent and in a spatially explicit way extremely important. In a recent discussion of research opportunities in environmental and resource economics, Deacon et al. (1998) observe that "the spatial dimension of resource use may turn out to be as important as the exhaustively studied temporal dimension in many contexts." This would appear especially applicable to the study of land use change, but the economic models of land conversion that we reviewed in the last section were not especially well suited for predicting the spatial pattern of change. The bid-rent model is a spatial economics model, but as we have seen, it is not sufficiently flexible to capture the complex nature of land use policies. In addition, it does not predict the pattern of development that is characteristic of the changing land use patterns we have been witnessing over the past few decades.

In the first part of this section, we return briefly to the bid-rent model and then move to other models in the urban and regional economics literature that have a spatial dimension. We consider the usefulness of these models for planners, ecologists, and others concerned with environmental outcomes of land use change and then turn to an overview of spatially explicit[19] models of land use change developed both within and outside of economics.

Economic Models of Urban Land Use Pattern

Economic models of urban land use pattern generally fall into one of two categories: (1) microeconomic spatial models that describe equilibrium land use pattern as the result of individual optimal decisions or (2) macroeconomic models that describe

[19] Here we use the term "spatially explicit" to imply a perspective that accounts for the spatial heterogeneity of the landscape, usually at a spatially disaggregate scale (e.g. parcel level).

aggregate changes in population, employment, or other economic flows across regions. By far the best known example of an economic spatial model that links individual decisions with a full description of aggregate land use pattern is the bid-rent model (or monocentric city model) of urban economics, described briefly in the last section. The model assumes that households seek to minimize commuting costs to a pre-determined urban center, in which all firms and employment are located.

The assumption of an exogenously determined urban center greatly simplifies the analysis by enabling space to be collapsed into a uni-dimensional measure of distance from the center. Equilibrium land rents determine a spatial equilibrium land use pattern that, in the simplest model, is described by a concentric ring of residential development around the urban center. Land use pattern is further described by the location of the outer urban boundary, identified as the point at which urban land rents are equal to agricultural land rents, and a declining population density gradient. Given either increases in household income or decreases in transportation costs, the model predicts a general population shift from central city to suburbs due to the decline in the equilibrium land rent and a corresponding change in the population density gradients. Empirical evidence exists that supports this characterization of growth for some cities (Margo, 1992; Anas and Kim, 1992; Macauley, 1985).

The monocentric model offers a description of equilibrium land use patterns resulting from individual optimizing behavior. While this parsimonious description of urban spatial structure has great appeal, the model fails to capture some observed complexities in pattern that are currently of chief concern. More complicated versions of the basic model have been introduced, e.g. multiple urban centers, heterogeneous preferences or incomes across households, and simple representations of externalities and policy impacts. However, even with these added complexities, the model's success as a predictor of observed urban land use pattern at a spatially disaggregate scale is quite limited. This is primarily due to the inability of the model to explain the *formation* and location of urban centers and the simplified manner in which it represents space. The city center is prespecified and space is reduced to a one-dimensional measure of distance from this center, necessitating a description of pattern either in terms of a continuously varying variable such as residential population density, or in terms of concentric rings comprised of homogeneous land uses.

More recent work in urban and regional economics has focused on understanding urban structures as evolving systems in which endogenous factors determine the resulting spatial structure of the city, e.g. *whether* a city is monocentric or polycentric. Some view individual developers as playing a paramount role in determining new urban patterns of development (Henderson and Mitra, 1996). In this case, large developers with market power attempt to internalize the benefits of firm agglomeration by facilitating the movement of firms from a center city to a new "edge city."[20] Strategic choices are made about capacity, employment, and location of these edge cities relative to the central urban core.

Other models treat the formation of urban and suburban centers as the result of the cumulative interactions among many economic agents distributed in space.[21] These models can explain a variety of observed urban spatial patterns, e.g. single center, multiple centers, and dispersion, and are consequently much more robust than the monocentric city model. While they vary in terms of the hypothesized sources and specification of the agent interdependence, their common theme is that urban land use patterns are driven by some type of linkages or interactions among spatially distributed agents. These interactions may arise through market forces, such as transportation costs and pecuniary externalities. They may also occur directly through agents' preferences over the spatial distribution of other agents or through spatial externalities from "neighboring" land uses or economic activities (e.g. social interactions or knowledge spillovers) that affect agents' utility or profit functions. Because these interactions both influence future location decisions and are a function of past location decisions, the spatial distribution of agents across the landscape is endogenously determined. Add to

[20] Garreau (1991) characterizes an edge city as an area located outside the urban core that has large concentrations of office and retail space, often with residential development as well, and that is located near to major highway access points.

this the durability of most urban development and the result is the evolution of a complex urban spatial structure that is characterized by multiple equilibria, path dependence, and what Arthur (1989) terms "historical chance."

Models in which the urban spatial structure is determined by interdependencies among economic agents include Anas (1992), Anas and Kim (1996), Arthur (1988), Chen (1996), Fujita (1988), Krugman (1991, 1995, 1996), Page (1999), Papageorgiou and Smith (1983), and Zhang (1993). In many of these models, interdependencies among agents arise in the context of markets. For example, Anas and Kim (1996) develop a computable general equilibrium model of the consumer, firm, and transport sectors in which consumer shopping trips link the locations at which commodities are bought and sold; traffic congestion determines the cost of travel among these locations; and scale economies in shopping are present. They show that for sufficiently strong scale economies relative to traffic congestion, monocentric or polycentric urban structures with multiple equilibria are possible. Krugman (1991, 1995) draws upon recent developments in endogenous growth theory and models of imperfect competition to consider how linkages among economic agents generate industrial clustering and city formation. "Centripetal" forces arising from certain types of market interconnectedness lead to industry concentration, while "centrifugal" forces, due to transport costs, resist industry agglomeration. The result is a distance-related tension between the two forces that, depending on their relative magnitudes, generates either an equal dispersion of industry across regions or concentration of industry in one or several regions. Page (1999) develops a model of city formation in which a location's attractiveness depends on some combination of its population and its average distance to other agents. He shows that the spatial distribution of cities that emerges depends on whether agents' preferences over city size and average separation distance are positive or negative, the relative magnitudes of these effects, and whether agents are able to consider global or only local alternative locations.

[21] For discussions of some of these models, see Fujita, Krugman, and Venables (1999) and Anas, Arnott, and Small (1998).

These agent-based models are of importance because they provide a means of deriving aggregate level patterns from the microeconomic behavior of atomistic, but interdependent, agents. As such, they may be well-suited to incorporating the effects of spatial heterogeneity at a disaggregate scale on changes in regional land use patterns. But they have shortcomings as well. Empirical testing of the posited interactions has largely been absent. This is a challenging task, in part because the models ignore the many heterogeneous features of the landscape that are likely to influence location decisions (e.g. roads, zoning, natural features). This simplification allows for tractable analytical models that demonstrate the *potential* role of interactions, but that do not offer a means for identifying these effects using real world data. Empirically, the challenge is to separate the effects of endogenous interactions from exogenous landscape features, which may evoke land use patterns that are observationally equivalent. Because it is difficult to measure such interactions, separating these effects from unobserved exogenous heterogeneity is possible only for limited cases.[22] These challenges have been outlined in a separate literature on empirical models of social interactions, most notably by Manski (1993, 1995), Durlauf (1997), and Brock and Durlauf (1998).

Another shortcoming of these models is their focus on *equilibrium* patterns of urban land use that result from agent interactions. Many of the interacting-agent models discussed above do not account for how the pattern of land use change evolves out of equilibrium.[23] However, due to the durability of urban structures and the rapid changes in land use witnessed in many areas, the spatial process of land use change is often one that appears out of equilibrium. Models from the field of regional science have attempted to characterize the dynamic adjustment path by adopting nonlinear dynamic mathematical modeling techniques from mathematics, physics, and mathematical ecology (Allen and Sanglier, 1981; Wilson, 1981; Dendrinos and Barkley, 1992; Nijkamp and Reggiani, 1998).

[22] One possible case, in which the estimated interaction effect among agents converting land to residential development is found to be negative, is presented by Irwin and Bockstael (1999).
[23] An exception is Chen (1996), who develops a dynamic economic growth model that incorporates agglomeration and congestion externalities into a dynamic simulation model of economic spatial growth.

Some of this work draws analogies with thermodynamic systems in which dissipative systems can undergo self-organization and increasing complexity when they are in states that are far from equilibrium (Allen and Sanglier, 1981). Others derive insights from catastrophe theory. Wilson (1981) illustrates a wide variety of applications, e.g. sudden changes in the spatial structure of a city (e.g. subcenters appear or disappear abruptly), sudden urban growth, or switches in transportation mode choice. Yet other models draw from the so-called "master equation" approach, in which a two-way interaction between individual and group choices are posited to influence dynamic population flows across regions. The migration choice is represented as a Markovian process in which an individual's transition probability depends on the current state of the individual and on the aggregate configuration of all individual choices, described by the "master equation" (De Palma and Lefrevre, 1983,1985; Ben-Akiva and De Palma, 1986; Haag, 1989).

While these variations offer ways of characterizing the dynamics of urban spatial patterns, they are sometimes weak on underlying economic motivation and lack a spatially explicit framework that could make them useful to environmental scientists. Possible exceptions, although they are yet to be put to the empirical test, are the economic agent-based models of interaction that adopt modeling techniques from interacting particle systems. Krugman (1996) and Arthur (1988) are examples of economic models that apply these theories to city formation, although their focus is on characterizing the equilibria of such systems. Additional insights can be gained by using cellular automata[24] and other simulation techniques used to study interacting particle systems to characterize the out-of-equilibrium dynamics of urban land use patterns.

Large-scale urban simulation models represent an alternative approach to modeling urban spatial structure. These models originate from a diverse set of literature and background, but have several common features (for a full review, see Wegener, 1994). They are comprehensive models that seek to integrate the basic processes of

[24] Geographers have used these models to simulate spatially explicit changes in urban spatial structure. This approach is discussed below.

urban development, which minimally include models of urban land use (including residential, commercial, and industrial uses) and transportation networks. Some models have focused exclusively on transportation–land use–environment linkages (e.g. see Berechman and Small, 1988). In this modeling context, the urban region is typically represented by a limited number of discrete zones, where each zone is identified with an aggregate number of households and industries. Despite this level of aggregation, most of these models are based on a random utility model of the microeconomic behavior of households and firms. By demonstrating the equivalence between aggregate gravity models and random utility models, Anas (1983) has provided a microeconomic theoretic basis for using gravity models to predict aggregate flows of economic agents across zones.[25] In using aggregate level data as input, predictions are in terms of aggregate numbers of households and firms within pre-specified urban zones. An exception is the model by Landis (1995) that uses micro-simulation techniques with spatially disaggregate data to generate results.

Many of the current models, such as those developed by Kain and Apgar (1985) and Anas (1982), are rigorous and well-grounded in microeconomic theory and have found favor with city and regional planners in addressing actual agency policy applications (Wegener, 1994). However, the usefulness of these models in predicting the environmental impacts of land use is limited. They are not designed to predict changes in land use pattern at a spatial resolution useful for capturing the heterogeneity of the ecological landscape. The micro-level, spatially explicit model of Landis (1995) is once again an exception. This model makes use of spatially articulated data from a geographic information system (GIS) to generate spatially disaggregate predictions of land use change. Such a model clearly has relevance for understanding environmental impacts and, for this reason, we provide a fuller consideration in a subsequent section.

[25] This result is predicated on the assumption that all individuals facing the same origin-destination choice are homogeneous in preferences and incomes (up to an additive random term) and that individuals' choices are independent.

Non-economic Spatial Models of Land Use Change

The growing recognition of the role land use change plays in affecting non-point source pollution, biodiversity, and global climate change has created a pressing need for models of land use change. The economic models of land use determination described in the last section provide some insights, but are in general limited for this purpose. Descriptions of the spatial pattern depend on equilibrium conditions, even though the spatial process of land use change may often be better characterized as one that is fundamentally out of equilibrium. In addition, they have ignored the types of spatial heterogeneity that are central to the science questions, in large part because they were developed with other interests in mind and, until very recently, have been confined by data limitations to spatially aggregate scales of analysis. As such, they are largely inapplicable to analyzing the spatially disaggregate consequences of the types of policies, such as environmental regulations and local growth controls, that are now of greatest concern (Lee, 1992).

The pressing need for more realistic land use change modeling has provoked a response, but not always from economists. Numerous spatially disaggregate and heterogeneous land use modeling attempts exist in the environmental science literature. This has been spurred by the vast amount of spatially disaggregate land data that are now available. Enormous amounts have been spent on documenting the land cover of the earth's surface at a variety of levels of spatial resolution – predominantly through remote sensing but also, in some areas, through aerial photography.[26] Digitized representations of actual land cover pattern for just about any part of the world are now available, although high resolution data and time series are more difficult to obtain. To some extent land *use* can be deduced from this information on land *cover*, depending on the quality and level of resolution of the images, and the extent of ground-truthing. At some levels, only broad categories of land cover such as cultivated, forested, and "other" can be documented, but with the more detailed imagery now becoming available different types

[26] These data are generated by Landsat (U.S.), SPOT (France), and other satellite systems. For a history of remote sensing efforts, see Morain (1998).

of crops, different stages of forest growth, and different types of development can be discerned.

The availability of these data has presented the opportunity to model land use change at spatially disaggregate scales rather than by regions or zones. Natural and physical scientists and geographers have taken the lead in this land use modeling enterprise, focusing on global environmental change and national concerns about habitat, air quality and nutrient enrichment of aquatic systems. Attempts by natural scientists to address land cover change were first aimed at mapping natural succession and the potential vegetative cover that would exist within a region if left undisturbed in the long run. Predictions of potential cover were based on measurable, locationally-specific attributes, such as temperature, soils, and precipitation. For ecosystems where more is known about the biophysical relationships, landscape ecology models have been constructed that incorporate the dynamics of nutrient uptake and growth, and disturbances associated with competition, predation, and pests.

Although a variety of modeling techniques have been employed, spatially explicit models that represent landscape data using a two-dimensional "mosaic" of grid cells are most often used for tracking land use change and for understanding environmental impacts. Each cell represents a particular spatial location and is associated with a land cover category and attributes such as soils, slopes, elevations, hydrology, etc. By explicitly modeling land use change in a two-dimensional framework, the spatial dependence among landscape attributes associated with nearby grid cells can be considered. Predictions from these models yield a spatially explicit description of land use change, which can then be linked to changes in environmental functioning.

Both deterministic and stochastic models have been developed in the literature on landscape change (Baker, 1989). Markov chain models, in which the change in land use state of each cell is modeled as a transition probability, are most common in modeling stochastic landscape change. Markovian or semi-Markovian constructs are especially useful since the transition probabilities can be made functions of exogenous factors, e.g.

higher-order effects that capture the influence of earlier states, sojourn times that capture the influence of duration, and interaction effects among neighboring cells (Baker, 1989). Also, the conversion probabilities can be made to reflect prior information, where laws of natural succession prevent certain state transitions or ergodic states prevent escape (e.g. development). Thus, these models offer a means for simulating potentially complex changes in large-scale pattern (e.g. threshold effects) in which the state of the system is dependent on spatial interactions and flows among cells and state transition of individual cells is described by non-linear processes.

While exceedingly complex with respect to the ecology of transition, these models are understandably simplistic with regard to the human dimension. Rather than explaining human-induced land use change, some landscape ecology models simply recognize the landscape change caused by humans and link these changes to subsequent impacts on ecological change. One example is the measurement of indices of landscape pattern, e.g. diversity, fragmentation, fractal dimension, and entropy,[27] and the association of different types of land use changes with different values of these indices. In these analyses, human-dominated landscapes have been found to be characterized by low fractal dimension and high entropy values (O'Neill, et al, 1988; Antrop, 1998).

Other landscape modelers have gone a step further in calculating transition probabilities for human induced land use change. In doing so, these models leave causal relationships unexplored, however, and assume that transition rates equal past percent changes, invariant over time and space. An example is some early work by Turner (1987) that uses data from Census of Agriculture and Forest Service surveys. Land use transition probabilities are calculated as the proportion of past cell transitions among cropland, pasture, forest, and urban uses. These probabilities are then used to simulate future changes in landscape pattern within a 13,000 hectare area of Georgia.[28]

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[27] In general, entropy refers to the amount of "uncertainty" or "disorder" in a system. Landscape ecologists have used this concept to develop measures of complexity and fragmentation of landscape pattern.

[28] In a follow-up study, Parks (1991) uses the same data, but estimates the transition probabilities at the county level as a function of socioeconomic characteristics associated with a representative county landowner. However, the spatial aggregation to the county level, which was necessary to incorporate the

Lastly, some landscape change models have sought to integrate the human dimension more fully by the inclusion of what are sometimes called "socio-economic drivers." These variables are human-induced features of the landscape and generally include distance measures (e.g. distance to city center or major road) and population density. In recognizing the importance of human activities in determining land use pattern, these models aim to elucidate the role of both physical and socio-economic variables in land use pattern changes. They do so by either estimating the relationships between land use change and these variables via statistical analysis or, in some cases, by simply applying "rules of thumb" to approximate these relationships based on case studies or other "user-supplied" information (Hall, et al., 1995). Examples of statistical analyses include regression models of changes in proportions of land uses and discrete models of changes in land use categories as functions of biophysical and socio-economic "land use drivers" (Mertens and Lambin, 1997; Liu, Iverson, and Brown, 1993; LaGro and DeGloria, 1992).

The estimates from these statistical models are often used to construct simulation models of land use change so that future changes in land use pattern can be predicted. For example, Veldkamp and Fresco (1996, 1997a, 1997b) use estimates from regression models that relate land use variability to biophysical and socio-economic "drivers" to calibrate a model of land use change in Costa Rica between 1973-1984. Berry and Minser (1997) estimate a multinomial logit model of land use change for study areas in western Washington state and western North Carolina. Exogenous variables include tree age, vegetation, slope, elevation, distance to town, distance to road, population density, and land ownership regime, with no particular justification for their presence.

These models can be instructive up to a point, but since no attempt is made to model the actual economic structural process, the validity of the implicit assumptions underlying variable choice and exogeneity is questionable. Failure to understand the

available socioeconomic data, limits the usefulness of the model's predictions for understanding spatially explicit environmental changes.

underlying structure of the process are likely to lead to incorrect policy conclusions. The simple means by which most landscape change models have accounted for human-induced influences is in some part due to the nature and availability of remote-sensing and other types of GIS data. Current technology (and funding) supports the acquisition of spatial information that can be "seen from above," which generally means the collection of information on physical, rather than economic, variables. Typically, spatial data sets incorporate vegetative land cover and hydrology. The only data on human activity records the *outcomes* of economic processes, e.g. location of road networks and centers of development. This simple fact explains the abundance of research in the environmental sciences literature that "explains" land use change as a function of physical features (e.g. soils, slopes, elevations, aspect or exposure), descriptions of landscape pattern (e.g. distance to edge of land cover polygon, patchiness of land cover pattern), and descriptions of manmade landscape features generated as the outcome of economic processes, specifically the distance to roads and towns.

Recent Economics Research in Spatially Explicit Land Use Change Modeling

Economists have not participated extensively in the enterprise of modeling spatially explicit land use change, in part because the data economists would think necessary to answer the underlying questions have not been available at appropriate spatial scales. Satellite imagery can not detect prices, income, parcel ownership, or tenure. Slowly economic data are being digitized, most notably in the U.S. and Europe, but at far greater marginal cost than that associated with physical features of the landscape. The paucity of strictly economics data does not preclude returns from economic reasoning, however, and may actually raise the value of ingenuity and thoughtful modeling. In the next section we review applications in two areas of land use change modeling – deforestation and urban fringe development – to make this point. In doing so, we highlight work by economists that has contributed to the development of models that are both spatially explicit and sufficiently disaggregate to be of use in understanding the land use–environment link.

Deforestation

Although the emphasis in this chapter has been restricted to issues and policy of relevance to the U.S. and Europe, we can not address spatially explicit models of the land use–environment link without mentioning deforestation. While this issue is of worldwide concern, many of the applications to date are found in the developing country context.[29] Examples within the *ecological* modeling literature include Liu, Iverson and Brown (1993) for the Philippines; Mertens and Lambin (1997) for Cameroon; Wilkie and Finn for Zaire; Ludeke, Maggio, and Reid (1990) for Honduras. These non-economic models are cell-based[30] and estimate transition probabilities using logit or probit models. Usually some subset of the following explanatory variables are found to be statistically significant in modeling land use change: soil type, slope, aspect or exposure, distance to town, distance to roads, distance to edge of contiguous forest, patchiness of landscape pattern. Some researchers add local measures of population or population density obtained from other sources.

What distinguishes economics work in this literature is not always the choice of explanatory variables, but the motivation for their inclusion. In contrast, the environmental science literature fails to develop models of the underlying economic processes at either the individual or market (aggregate) level that dictate the choice of the socioeconomic variables used to explain change. To illustrate the contribution of economists, we highlight two of the now increasing number of economic studies of deforestation in developing countries that rely on the same sort of satellite imagery of land use change, but manage to reveal something about the land cover change process.

In a study of deforestation in Belize, Chomitz and Gray (1996) depend solely on the sort of data that can be observed from satellite imagery.[31] The landscape is divided into cells and land use categories are defined to include forest, semi-subsistence agriculture and commercial agriculture. The underlying economic model is a simple one

[29] For an extent treatment of this literature, see van Kooten, Sedjo and Bulte (1999).
[30] By "cell-based" we mean that the unit of analysis is not a parcel (or human decision unit) but a cell in an arbitrary grid superimposed on the geographical extent of the study.
[31] A similar example, based on even more restrictive data, can be found in Nelson and Hellerstein (1997).

– land is expected to move into the use with the highest rents. Rents in an agricultural use are equal to returns minus costs of production and the production technology is a function of soil quality. Therefore the likelihood of forest conversion to either type of agriculture should be a function of soil quality and input and output prices at any given location.

While satellite imagery can be used to deduce something about soil quality, it tells us nothing about prices. Chomitz and Gray argue that cross-sectionally, prices will vary depending on transportation costs to and from marketing centers –because output will be sold there and inputs such as fertilizer will be purchased there. On the basis of this argument, distance or more specifically the time required to travel that distance (along roads of different quality) is introduced into the model as a proxy for price variation. But Chomitz and Gray further recognize the possibility that by incorporating this proxy for prices, they may be introducing some endogeneity into the problem; road location may actually be driven by activity.

The results of this study are illustrative. Evidence was found for the endogeneity of roads, suggesting that the commonly deduced effect of roads on deforestation may be overstated. The authors also found that the effects of distance to market and of soil quality differ with type of agriculture, the former being relatively more important to commercial agriculture location and the latter to semi-subsistence.

Given the paucity of location specific economic data, it has been impossible to introduce more economic content into the problem without going to a higher level of aggregation. Pfaff (1999) provides an example of work that depends on satellite imagery of land use but aggregates to the county level in Brazil in order to incorporate census data. In his model, the property rights regime dictates the underlying decision structure. A parcel is not owned until it is cleared, making the actual clearing decision the key modeling focus. Land is cleared in an area as long as the marginal benefits of clearing exceed the marginal costs. The marginal benefit of clearing land is a function of output price, transportation costs to market, soil quality, the costs of clearing (varying by the type of vegetative cover), the existence of development projects, and the prices of capital and labor. To prevent all or nothing solutions for the land conversion decision at the county level, an unobserved distribution of soil quality within each county is postulated, which invokes a distribution of decisions within counties. This allows the author to explain the percent of cleared land in each county as a cumulative distribution whose parameter is a function of marginal benefits minus marginal costs.

The role of population as a "driver" is a maintained hypothesis in many studies of deforestation. Pfaff discusses how population might enter into the structural problem (e.g. by lowering labor costs or increasing the number of "producers"). The results of his econometric investigations are particularly telling. Not surprisingly, he finds that population (even when lagged several years) is highly correlated across counties with other variables that belong in the model. Additionally his findings suggest that population is endogenously determined – in this case probably due to unobserved policies that encourage development in certain regions. Thus treating population as a "driver" may produce misleading policy implications.

Landscapes at the Urban Fringe

Perhaps the predominant form of land use change in the U.S. is the conversion of forest and agricultural lands to developed uses. This type of conversion has most often taken the form of low-density, fragmented development characterized largely by scattered residential subdivision development in rural-suburban fringe areas. As we discussed earlier, such "sprawl" patterns of land use have received significant attention from the public and from policymakers concerned with both the environmental consequences of such development and the increasing public service costs associated with a more decentralized population. These non-contiguous land use patterns are very different from those predicted by the standard urban economic models and suggest that land use changes are the result of a potentially more complex set of factors.

Over the past few years, a growing literature in geography has emerged on spatially explicit simulation models of urban growth patterns (Batty, 1995; Clarke, et al., 1997; White and Engelen. 1997; Wu and Webster, 1998). Of particular interest are cellular automata models that offer a spatially explicit and dynamic setting for modeling complex processes in which global patterns are generated by local, interdependent actions. Cellular automata are a class of mathematical models in which the behavior of a system is characterized by a set of deterministic or probabilistic rules that determine the discrete state of a cell based on the states of neighboring cells. States of individual cells are updated based on the values of neighboring cells in the previous time period. Local interactions between a cell and its neighbors is a defining characteristic of cellular automata. By explicitly modeling transition probabilities as a function of neighboring land use states, this approach allows for spatial interaction and spatial autocorrelation among land use states and state transitions. Even with simple transition rules, these models when simulated over many times periods often yield complex and highly-structured patterns. Stochastic processes can be modeled by introducing a random perturbation into the calculation of the transition matrix. Other landscape features, such as roads and land use controls, can also be considered. Theobold and Hobbs (1997) use spatial transition-based models such as these to forecast land use change explicitly for the purpose of assessing ecological (habitat) consequences.

Clarke, et al. (1997) develop an urban growth model of the San Francisco Bay region, in which several different "growth rules" are defined in the model, including spontaneous, diffusive, and organic growth, as well as growth that is influenced by roads. This model is simulated and shown to produce predicted growth patterns that are qualitatively consistent with observed historical growth in the region. White and Engelen (1997) develop a similar model using data from Cincinnati. In both cases, historical data are used to calibrate the values of the transition parameters so that simulations approximating observed urban growth result.

The appeal of the cellular automata models arises from the straightforward manner in which complex, spatially dynamic processes can be characterized. They offer insights into how urban spatial structure changes over time for a given set of parameter values and micro-level interactions among individual landscape cells. However, the geography models developed in the recent urban growth simulation literature ignore the underlying economic processes that drive conversion. Economists have begun to develop similar models, but rather than assigning growth rules or deriving transition probabilities from calibration, these models estimate transition probabilities using discrete choice models based on behavioral models of agents' land use decisions.

Landis (1995) and Landis and Zhang (1997) develop an urban simulation model (called the California Urban Futures Model) for the San Francisco Bay and Sacremento areas. Both public land use policies and private development decisions are incorporated into the model that predicts land use development at a spatially disaggregate scale. Landis and Zhang use econometric models to predict future household and employment projections by jurisdictions and a multinomial logit model to estimate the probability of land use change as a function of a variety of site and community characteristics. The resulting parameters are used to calculate land use transition probabilities for all cells that are "developable" and development is then allocated based on the highest probabilities or "bids" for development.

The Landis model does not directly explain land prices and ignores zoning. In addition, the unit of observation is the landscape cell rather than the land parcel, thus compromising the correspondence between the observational unit and the human decision. But the high spatial resolution of the model and the spatially explicit form of the predicted land use changes make the model's output readily useable as land use change inputs into an ecological model of environmental impacts. Because the underlying economic process is modeled, the influence of alternative policies on individuals' expected returns from land in alternative uses can be predicted, allowing simulation of changes in land use pattern under alternative policy scenarios.

Recent work by Bockstael (1996) and others[32] has also sought to develop economic models of land use change that are both spatially explicit and disaggregate, so

[32] Recent work includes Geoghegan, Wainger, and Bockstael, 1997; Bell and Bockstael, 1998; Bockstael and Bell, 1998; Irwin and Bockstael, 1999.

that predicted outcomes may be linked with ecological models of landscape changes. The observational unit is the land parcel and therefore the correspondence between observed land use changes and the micro-level land use decisions that are modeled is direct. This work is less comprehensive than the Landis model, however, in that only residential conversion is considered and the regional changes in population and employment are treated as exogenous. Nonetheless, results from this modeling effort are useful for understanding land use conversion in urban fringe areas, in which the vast majority of conversion is to residential land use.

The focus of these papers is on the conversion of suburban and exurban land parcels from agricultural or forest uses to residential use in the Patuxent Watershed region of the Chesapeake Bay. Conversion is assumed to occur as the result of profit-maximizing agents who own undeveloped land parcels and make decisions over time regarding the optimal conversion of their parcels to residential use. Expected net returns from conversion are modeled as a function of expected sales price of the land in residential use, conversion costs, and the opportunity cost in terms of alternative uses. The expected price of a newly converted parcel is treated as a function of commuting distance to urban centers, provision of public services, and zoning restrictions, as well as indices of surrounding land uses. Using panel data of parcel-level land use changes from this central Maryland region, a discrete choice model of the individual's conversion decision is estimated and the parameters are used to generate predictions of land use change in subsequent rounds of development.

This approach to modeling land use change provides a means by which future rounds of development can be predicted under different policy scenarios and provides insights into the environmental effects of alternative policies. For example, Bockstael and Bell (1997) examine the effects of differential regulatory policies across local jurisdictions on the regional pattern of residential land use conversion and on water quality outcomes. They find that differential zoning across counties deflects development from one county to another and that the amount of increased nitrogen loadings from a constant amount of new development varies from 4-12%, depending on the degree of difference across counties' minimum lot size zoning.

This spatially explicit approach to identifying the variables that are significant in land use change can also provide insight into the spatial and temporal dynamics of land use change. Drawing upon the agent-based interaction models discussed earlier, Irwin and Bockstael (1999) develop a model in which exogenous features create attracting effects (e.g. central city, road, public services) among developed land parcels and interactions among land use agents create net repelling effects. They demonstrate that such a model offers a viable explanation of the fragmented residential development pattern found in urban fringe areas. Assuming the presence of exogenous growth pressure effects that increase the likelihood of conversion over time, the time dimension is explicitly modeled as well by estimating a duration model of residential land use conversion. The conversion decision is treated as a function of both exogenous landscape features and a temporally lagged interaction effect among neighboring agents making a residential conversion decisions. Empirical evidence of a negative interaction effect among land parcels in a residential use is econometrically identified. A spatial simulation model incorporating both exogenous landscape features and interaction effects predicts a spatial pattern that is qualitatively quite similar to the scattered development observed in recent residential development.

What is apparent from the modeling efforts of Landis, Landis and Zhang, and Bockstael, et al. is that the spatial pattern of land use change can be explicitly modeled in terms of individuals' economic decisions. The expected net returns from conversion will be influenced by a host of factors, including locational attributes of the parcel, previous land use decisions in the surrounding area, and a variety of government policies that alter the expected returns from land in a particular use. What is also apparent is that these spatially disaggregated models have huge data requirements and such rich data sets are not yet commonly available. Nonetheless, it may be possible to use the insights garnered from the spatially disaggregate models, in which the micro-level decisions of individual land use agents are modeled, to provide an economic basis for models of land use change at more spatially aggregate scales.

CONCLUSIONS

The free market does not provide the optimal amount and pattern of land use. The environmental externalities, public good amenity/disamenities, and spatial spillovers that are associated with land use are so apparent as to make this statement trivial. While identification of these inefficiencies is one thing, instituting policy measures that successfully correct for them is another. The magnitude of an environmental externality associated with a human activity depends not only on its location in the ecological landscape, but the incentives for human activity are often dependent on location as well. In either case, it is not just location relative to physical features of the landscape that matters, but also relative to the human activities going on "next door." The ecological landscape is not fixed, but rather constantly evolving through natural processes and human interference. But since the amount of land in a region is relatively fixed and every acre of it is in one land use/cover or another, policies that seek to discourage one sort of human activity will inadvertently invoke another.

The process is further complicated by the path dependent and often irreversible nature of land use change. Interactions among economic agents that influence the location of households and firms, the durability of development, and the fixity of many natural features of the landscape suggest that the evolution of land use pattern is path dependent. Due to the endogeneity of location and land use decisions, many different land use pattern outcomes are possible and the pattern that actually results is determined by exogenous spatial heterogeneity (e.g. natural resource endowments) or random historical events (e.g. the location of a transportation route) that influence the future evolution of land use pattern. In addition, conversion of land to a developed use is often irreversible, at least over an intermediate time horizon, and particularly so in areas experiencing growth pressures. Such effects magnify the costs associated with inadvertent outcomes of policies.

The complexity of land use change presents challenges for researchers and policymakers alike. In this chapter, we have sought to review the literature and outline the challenges involved from both a policy and modeling perspective. The first part of the chapter considered specific policies and their impacts on land use within the context of economic models of markets or individual decision making. We found that the policy environment invokes changes in land use that are complex and indirect and that often result in unintended consequences. We also found that returns from human activities related to the land are spatially heterogeneous, as is the sensitivity of ecosystems to those actions.

The second part of the chapter begins from the perspective of ecological modelers. From this viewpoint, the spatial distribution and pattern of land use change is all important; so important in fact that ecologists and other environmental scientists have often assumed the role of land use change modeler to meet the pressing need for forecasting tools. Economists have been slow to enter this arena for some very good reasons – including the paucity of economics data at a spatially disaggregate level. However, it is apparent that even a modest amount of economic input can have real payoffs. This is particularly true when the interest is in understanding the potential two-way interactions between land use and environmental change. While landscape amenities may not have direct connections to ecological functioning, they may play a significant role in individuals' location and land use decisions. This suggests that changes in some characteristics of land use pattern may have economic consequences that lead to further changes in land use pattern. Modeling the dynamic evolution of land use is possible only by considering the economic causes and consequences of land use change.

While the returns to developing economic models of land use change are potentially high, conflicts can exist between economics and ecological modeling over such fundamental parameters as a common unit of observation or geographical domain. When micro-level data are available they relate to decision units – firms and households, as opposed to cells in the landscape. Likewise, when economists circumscribe the extent of their analysis, it is the extent of the relevant market or political jurisdiction that dictates the boundaries, rather than a watershed or other ecosystem.

Space poses a challenge for economists in a more fundamental way. The land use change problem is frequently one in which we are interested in understanding how the location specific decisions of individual economic agents aggregate to a changing spatial pattern over time. This is particularly important if we are to better understand how the cumulative effects of many individual land use decisions combine over space and time to generate externalities that have consequences for achieving socially more desirable spatial distribution of land use/cover.

Economists are familiar with the concept of aggregating up from an individual to a collective outcome, in the sense that a large number of individual agents making utility or profit maximizing decisions constitutes a market. In understanding how these individual actions aggregate up into market outcomes, the defining factor for economists is the distinction between what is endogenous and what is exogenous at each scale. Our usual way of crossing from one scale to the next is aspatial, though, and understanding spatially distributed aggregate outcomes is not straightforward. In this respect, the new agent-based spatial models of city formation by Krugman, Anas, Fujita, Page, and others are promising. This approach provides a description of large-scale, dynamic changes in urban and regional spatial structure based on the optimizing behavior of individual economic agents distributed across space. By building additional spatial heterogeneity into these models, more realist and useful economic models of land use change – i.e. ones that predict spatially explicit changes in land use pattern as the result of underlying economic forces – may emerge.

REFERENCES

Allen, P. and M. Sanglier (1981), 'A Dynamic Model of a Central Place System-II,' *Geographical Analysis*, **13**(2), 149-64.

Alonso, W. (1964), *Location and Land Use*, Cambridge: Harvard University Press.

American Farmland Trust (1992), *Does Farmland Protection Pay? The Cost of Community Services in Three Massachusetts Towns*, Lancaster, MA: Massachusetts Department of Food and Agriculture.

American Farmland Trust (1994), *Farmland and the Tax Bill: The Cost of Community Services in Three Minnesota Cities*, Washington, DC: American Farmland Trust.

Anas, A. (1982), *Residential Location Markets and Urban Transportation*, New York: Academic Press.

Anas, A. (1983), 'Discrete Choice Theory, Information Theory, and the Multinomial Logit and Gravity Models,' *Transportation Research B*, **17B**(1), 13-23.

Anas, A. (1992), 'On the Birth and Growth of Cities: Laissez-Faire and Planning Compared,' *Regional Science and Urban Economics*, **22**(2), 243-58.

Anas, A., R. Arnott, and K. Small (1998), 'Urban Spatial Structure,' *Journal of Economic Literature*, **36**, 1426-1464.

Anas, A. and I. Kim (1992), 'Income Distribution and the Residential Density Gradient,' *Journal of Urban Economics*, **31**(2), 164-80.

Anas, A. and I. Kim (1996), 'General Equilibrium Models of Polycentric Urban Land Use with Endogenous Congestion and Job Agglomeration,' *Journal of Urban Economics*, **40**(2), 232-256.

Anderson, J. E. (1986), 'Property Taxes and the Timing of Urban Land Development', *Regional Science and Urban Economics*, **16**, 483-492.

Anderson, J.E. (1993a), 'Use-Value Property Tax Assessment: Effects on Land Development', *Land Economics*, **69**(3), 263-69.

Anderson, J.E. (1993b), 'Land Development, Externalities, and Pigouvian Taxes', *Journal of Urban Economics*, **23**, 1-9.

Anselin, L. (1988), *Spatial Econometrics: Methods and Models*, The Netherlands: Kluwer Academic Publishers.

Antrop, M. (1998), 'Landscape Change: Plan or Chaos?' *Landscape and Urban Planning*, 41, 155-161.

Arnott, R. J. and F. D. Lewis (1979), 'The Transition of Land to Urban Use', *Journal of Political Economy*, 87(1), 161-170.

Arthur, W. B. (1988), 'Urban Systems and Historical Path Dependence,' in J. Ausubel and R. Herman (eds), *Cities and Their Vital Systems*, Washington, DC: National Academy Press.

Arthur, W. B. (1989), 'Competing Technologies, Increasing Returns, and Lock-In by Historical Events,' *Economic Journal*, 99, 116-31.

Babcock, B. A., P. G. Lakshminarayan, J. Wu, and D. Zilberman (1997), 'Targeting Tools for the Purchase of Environmental Amenities', *Land Economics*, 73(3), 325-340.

Baker, W. (1989), 'A Review of Models of Landscape Change,' *Landscape Ecology*, 2(2), 111-133.

Baldassare, M. and G. Wilson (1996), 'Changing Sources of Suburban Support for Local Growth Controls', *Urban Studies*, 33(3), 459-471.

Batty, M. (1994), 'A Chronicle of Scientific Planning: The Anglo-American Modeling Experience,' *Journal of the American Planning Association*, 60, 7-16.

Beasley, S. D., W. G. Workman, and N. A. Williams (1986), 'Estimating amenity Values of Urban Fringe Farmland: A Contingent Valuation Approach', *Growth and Change*, 17, 70-78.

Beaton, W. P. (1991), 'The Impact of Regional Land-Use controls on Property Values: The Case of the New jersey Pinelands,' *Land Economics*, 67(2), 172-194.

Beaton, W. P. and M. Pollock (1992), 'Economic Impact of Growth Management Policies Surrounding the Chesapeake Bay,' *Land Economics*, 68(4), 434-453.

Beaufoy, G. (1994), 'Impact of the CAP Reform on Land Use and Rural Amenities', in A. Dubgaard, I. Bateman, and M. Merlo (eds), *Economic Valuation of Benefits From Countryside Stewardship*, Proceedings of a Workshop Organized by the Commission of the European Communities Directorate General for Agriculture, Brussels, Wissenschaftsverlag Vauk Kiel KG.

Bell, K. and N. Bockstael (1999), 'Applying the Generalized Methods of Moments Approach to Spatial Problems Involving Micro-Level Data', *Review of Economics and Statistics*, forthcoming.

Ben-Akiva, M. and A. De Palma (1986), "Analysis of a Dynamic Residential Location Choice Model with Transaction Costs," *Journal of Regional Science*, **26**(2), 321-41.

Berechman, J. and K. Small (1988), 'Research Policy and Review 25. Modeling Land Use and Transportation: An Interpretive Review for Growth Areas,' *Environment and Planning* A, **20**, 1285-1309.

Bergstrom, J., B. L. Dillman, and J. Stoll (1985), 'Public Environmental Amenity Benefits of Private Land: The Case of Prime Agricultural Land', *Southern Journal of Agricultural Economics*, **17**(1), 139-149.

Berry, M., B. Hazen, and R. Flamm (1996), 'LUCAS: A System for Modeling Land-Use Change,' *IEEE Computational Science and Engineering*, **3**(1), 24-35.

Berry, M. and K. Minser (1997), 'Distributed Land-cover Change Simulation', *ACM-FIS '97: Proceedings of the Fifth International Workshop on Advances in Geographic Information Systems*, Las Vegas, NV.

Bockstael, N. and K. Bell, (1997), 'Land Use Patterns and Water Quality: The Effect of Differential Land Management Controls', in R. Just and S. Netanyahu (eds), *International Water and Resource Economics Consortium, Conflict and Cooperation on Trans-Boundary Water Resources*, Kluwer Publishing.

Bockstael, N. E. (1996), 'Modeling Economics and Ecology: The Importance of a Spatial Perspective', *American Journal of Agricultural Economics*, **78**(5), 1168-80.

Boisvert, R.N., N.L Bills and E. Bailey (1988), 'A Model to Explain Participation in New York's Agricultural Districts and Use-Value Assessment Programs', *Northeastern Journal of Agricultural and Resource Economics* ,**17**, 167-177.

Bramsnaes, A. (1992), 'The Landscape of Agriculture: Planning and Regulation of Agricultural Landscapes in the European Community,' *Landscape and Urban Planning*, **22**(1), 17-30.

Brock, W. and S. Durlauf (1998), "Discrete Choice with Social Interactions II: Econometrics," Mimeo, Dept. of Economics: University of Wisconsin.

Brondizio, E., et al. (1994), 'Land Use Change in the Amazon Estuary: Patterns of Caboclo Settlement and Landscape Management,' *Human Ecology*, **22**(3), 249-278.

Brueckner, J. K. (1990), 'Growth Controls and Land Values in an Open City', *Land Economics*, **66**(3), 237-48.

Brueckner, J K. and F-C Lai, (1996), 'Urban Growth Controls with Resident Landowners', *Regional Science and Urban Economics*, **26**(2), 125-43.

Brueckner, J. (1998), 'Testing for Strategic Interaction Among Local Governments: The Case of Growth Controls.' *Journal of Urban Economics*, 44, 438-467.

Buist, H., C. Fischer, J. Michos, and A. Tegene (1995), *Purchase of Development Rights and the Economics of Easements*, Economic Research Service, U.S. Department of Agriculture, Agricultural Economic Report Number 718.

Burby, R. J. and P. J. May (1997), *Making Governments Plan: State Experiments in Managing Land Use*, Baltimore: Johns Hopkins University Press.

Cappoza, D. R. and R. W. Helsely (1989), 'The Fundamentals of Land Prices and Urban Growth', *Journal of Urban Economics*, 26, 295-306.

Carriker, R. R. (1994), 'Wetlands and Environmental Legislation Issues', Journal of *Agriculture and Applied Economics*, 26(1), 80-89.

Carroll County Bureau of Planning (1996), *Managing Growth*, Issue No. 1, Carroll County, MD.

Case, F. E. and JU. Gale (1981), 'Farmland Values at the Urban Fringe: An Analysis of Sale Prices,' *American Real Estate and Urban Economics Association Journal*, 9, 345-366.

Cecil County Office of Economics Development (1994), *Fiscal Impacts of Residential, Commercial/Industrial and Agricultural Land Uses in Cecil County, MD* Elkton, MD: Cecil County Office of Economic Development.

Chen, H. (1996), 'The Simulation of a Proposed Nonlinear Dynamic Urban Growth Model,' *Annals of Regional Science*, 30(3), 305-319.

Chomitz, K. and D. Gray (1996), 'Roads, Land Use, and Deforestation. A Spatial Model Applied to Belize,' *World Bank Economic Review*, 10(3), 487-512.

Clarke, K. C. , Hoppen, S. and L. Gaydos (1997), 'A Self-Modifying Cellular Automaton Model of Historical Urbanization in the San Francisco Bay Area,' *Environment and Planning B: Planning and Design*, 24, 247-261.

Colman, D. (1994), 'Comparative Evaluation of Environmental Policies: ESA's in a Policy Context', in M. Whitby (ed), *Incentives for Countryside Management: The Case of Environmentally Sensitive Areas*, Cambridge, UK: University Press.

Cropper, M. and C. Griffiths (1994), 'The Interaction of Population Growth and Environmental Quality,' *American Economic Review Papers and Proceedings*, 84(2), 250-254.

Dale, V. H. (1997), 'The Relationship Between Land-use Change and Climate Change', *Ecological Applications*, 7(3), 753-769.

Deacon, R. (1994), 'Deforestation and the Rule of Law in a Cross-Section of Countries,' *Land Economics*, **70**(4), 414-30.

Deacon, R., D. Brookshire, A. Fisher, A. Kneese, C. Kolstad, D. Scrogin, V. K. Smith, M. Ward, J. Wilen (1998), "Research Trends and Opportunities in Environmental and Natural Resource Economics", *Environmental and Resource Economics*, **11**(3-4), 383-397.

Dendrinos, D. and J.B. Rosser (1992), "Fundamental Issues in Nonlinear Urban Population Dynamic Models: Theory and a Synthesis, *Annals of Regional Science*, **26**(2), 135-45.

De Palma, A. and C. Leferve (1983), "Individual Decision Making in Dynamic Collective Systems, " *Journal of Mathematical Sociology*, **9**,103-24.

De Palma, A. and C. Leferve (1985), "Residential Change and Individual Choice Behavior," *Regional Science and Urban Economics*, **15**,421-34.

Diamond, H.L. and P. F. Nooonan (1996), *Land Use in America, Lincoln Institute of Land Policy*, Washington, D.C.: Island Press.

Ding, C., G. Knaap, and L. Hopkins (1999), 'Managing Urban Growth with Urban Growth Boundaries: A Theoretical Analysis,' *Journal of Urban Economics*, **46**, 53-68.

Drake, L. (1992), 'The Non-Market Value of the Swedish Agricultural Landscape', *European Review of Agricultural Economics*, **19**(3), 351-364.

Dubgaard, A (1994), 'Valuing Recreation Benefits from the Mols Bjerge Area, Denmark', in A. Dubgaard, I. Bateman, and M. Merlo (eds), *Economic Valuation of Benefits From Countryside Stewardship*, Proceedings of a Workshop Organized by the Commission of the European Communities Directorate General for Agriculture, Brussels, Wissenschaftsverlag Vauk Kiel KG.

Dubin, J. A., D. R. Kiewiet, and C. Noussair (1992), 'Voting on Growth Control Measures: Preference and Strategies', *Economics and Politics*, 4(2), 191- 213.

Durlauf, S. (1997), 'Statistical Mechanics Approaches to Socioeconomic Behavior.' *The Economy As an Evolving Complex System II.* W. B. Arthur, S. Durlauf and D. Lane eds., 81-104. Vol. Vol. XXVII. Addison-Wesley, 1997.

Engle, R. P. Navarro, and R. Carson (1992), 'On the Theory of Growth Controls', *Journal of Urban Economics*, **32**, 269-283.

Farber, S. (1998), 'Undesirable Facilities and Property Values: A Summary of Empirical Studies', *Ecological Economics*, 24, 1-14.

Fernandez, L. and L. Karp (1998), 'Restoring Wetlands Through Wetlands Mitigation Banks', *Environmental and Resource Economics*, 12(3), 323-344.

Fischel, W. A. (1990), *Do Growth Controls Matter?*, Cambridge, Mass: Lincoln Institute of Land Policy.

Flamm, R. and M. Turner (1994), 'Alternative Model Formulations for a Stochastic Simulation of Landscape Change', *Landscape Ecology*, 9(1), 37-46.

Fujita, M. (1988), 'A Monopolistic Competition Model of Spatial Agglomeration: Differentiated Products Approach,' *Regional Science and Urban Economics*, 18(1), 87-124.

Fujita. M., P. Krugman, and A. Venables (1999), *The Spatial Economy: Cities, Regions, and International Trade*, Cambridge, Mass: M.I.T. Press.

Garrod, G. and K. Willis (1992b), 'The Environmental Economic Impact of Woodland: A Two Stage Hedonic Price Model of the Amenity Value of Forestry in Britain', *Applied Economics*, 24(7), 715-28.

Garrod, G. and K. Willis (1992c), 'The Amenity Value of Woodland in Great Britain: A Comparison of Economic Estimates', *Environmental and Resource Economics*, 2, 415-34.

Garrod, G. and K.Willis (1992a), 'Valuing Goods' Characteristics: An Application of the Hedonic Price Method to Environmental Attributes', *Journal of Environmental Management*, 34, 59-76.

Gatzlaff, D. H. and M. T. Smith (1993), 'Uncertainty, Growth Controls and the Efficiency of Development Patterns', *Journal of Real Estate Finance and Economics*, 6(2), 987-1002.

Geoghegan, J., L. Wainger, & N. E. Bockstael (1997), 'Spatial Landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS', *Ecological Economics*, 23(3), 251- 64.

Gin, A. and J. Sandy (1994), 'Evaluating the Demand for Residential Growth Controls', *Journal of Housing Economics*, 3(2), 109-120.

Haag, G. (1989), *Dynamic Decision Theory: Applications to Urban and Regional Topics*. Dordrecht: Kluwer Academic Publishers.

Hall,C., et al. (1995), 'Modelling Spatial and Temporal Patterns of Tropical Land Use Change,' *Journal-of-Biogeography*, 22(4-5), 753-757.

Halstead, J. (1984), 'Measuring the Nonmarket Value of Massachusetts Agricultural Land: A Case Study', *Journal of Northeastern Agricultural Economic Council*, **13**(1), 226-247.

Hansen, D.E. and S.I. Schwartz (1975), 'Landowner Behavior at the Rural-Urban Fringe in Response to Preferential Property Taxation', *Land Economics* **51**, 341-354.

Henderson, V. and A. Mitra (1996), 'The New Urban Landscape: Developers and Edge Cities,' *Regional Science and Urban Economics*, **26**, 613-643.

Hodge, I. (1995), 'Public Policies for Land Conservation', in D. W. Bromley (ed), *The Handbook of Environmental Economics*, Cambridge, MA: Blackwell Publishers.

Hunsacker, C. T. and D. A. Levine (1995), 'Hierarchical Approaches to the Study of Water in Rivers,' *BioScience*, **45**, 192-203.

Ingberman, D. E. (1995), 'Siting Noxious Facilities: Are Markets Efficient?' *Journal of Environmental Economics and Management*, **29**(3), part 2: S20-33.

Innes, R. (1997), 'Takings, Compensation, and Equal Treatment for Owners of Developed and Undeveloped Property', *Journal of Law and Economics*, **40**(2), 403-432.

Irwin, E. and N. E. Bockstael (1999), 'Interacting Agents, Spatial Externalities, and the Endogenous Evolution of Land Use Pattern,' Working Paper, Department of Agricultural and Resource Economics, University of Maryland.

Kain, J. and W. Apgar (1985), *Housing and Neighborhood Dynamics: A Simulation Study*, Cambridge, MA: Harvard University Press.

Katz, L. and K. T. Rosen (1990), 'The Interjurisdictional Effects of Growth Controls on Housing Prices', *Journal of Law and Economics*, **30**,149-160.

Kline, J. and D. Wichelns (1994), 'Using Referendum Data to Characterize Public Support for Purchasing Development Rights to Farmland', *Land Economics*, **70**(2), 223-233.

Kline, J. and D. Wichelns (1996a), 'Public Preferences and Farmland Preservation Programs', *Land Economics,* **72**(4):538-49.

Kline, J. and D. Wichelns (1996b), 'Measuring Public Preferences for the Environmental Amenities Provided by Farmland', *European Review of Agricultural Economics*, **23**(4), 421-36.

Kramer, R. A. and L. Shabman (1993), 'Wetland Drainage in the Mississippi Delta,' *Land Economics*, **69**(3), 249-262.

Krugman. P. (1991), 'Increasing Returns and Economic Geography,' *Journal of Political Economy*, 99, 438-99.

Krugman, P. (1995), *Development. Geography, and Economic Theory*, Cambridge, MA and London, England: MIT Press.

Krugman, P. (1996), *The Self-Organizing Economy*. Cambridge, MA: Blackwell Publishers.

Kunreuther, H., P. Kleindorfer, P. Knez, and R. Yaksick (1987), 'A Compensation Mechanism for Siting Noxious Facilities: Theory and Experimental Design,' *Journal of Environmental Economics and Management*, 14: 371-383.

Lagro, J. and S. DeGloria (1992), 'Land Use Dynamics within an Urbanizing Non-Metropolitan County in New York State (USA),' *Landscape Ecology*, 7(4), 275-289.

Landis, J. (1995), 'Imagining Land Use Futures. Applying the California Urban Futures Model,' *Journal of the American Planning Association*, 61(4), 438-457.

Landis, J. and M. Zhang (1997), 'Modeling Urban Land Use Change: The Next Generation of the California Urban Futures Model,' Working Paper, University of California, Berkeley.

Lee, R. G., R. O. Flamm, M. G. Turner, C. Bledsoe, P. Chandler, C. DeFerrare, R. Gottfried, R. J. Naiman. N. Schumaker, and D. Wear (1992), 'Integrating Sustainable Development and Environmental Vitality: A Landscape Ecology Approach,' in R. J. Naiman (ed), *Watershed Management: Balancing Sustainability and Environmental Change*, New York: Springer-Verlag.

Leggett, C. and N. E. Bockstael (1999), 'Evidence of the Effects of Water Quality on Residential Land Prices', *Journal of Environmental Economics and Management*, forthcoming.

Lenon, M., S. Chattopadhyay, and D. Heffley (1996), 'Zoning and Fiscal Interdependencies', *Journal of Real Estate Finance and Economics*, 12, 221-234.

Lewandrowski, J. J. Tobey, and Z. Cook (1997), 'Agricultural Assistance and the Environment', *Land Economics*, 73(3), 404-427.

Liu, D.S., L.R. Iverson, and S. Brown (1993), 'Rates and Patterns of Deforestation in the Philippines: Application of Geographic Information System Analysis,' *Forest Ecology and Management*, 57, 1-16.

Ludeke, A.K., Maggio, R.C. and Reid, L.M. (1990), "An Analysis of Anthropogenic Deforestation Using Logistic Regression and GIS," *Journal of Environmental Management*, 31, 247-259.

Macauley, M. (1985), 'Estimation and Recent Behavior of Urban Population and Employment Density Gradients,' *Journal of Urban Economics*, **18**, 251-260.

Manski, C. (1993), 'Identification of Endogenous Social Effects: The Reflection Problem,' *Review of Economic Studies*, **60**, 531-42.

Manski, C. (1995), *Identification Problems in the Social Sciences*. Cambridge, MA: Harvard University Press.

Margo, R. (1992), 'Explaining the Postwar Suburbanization in the United States: The Role of Income,' *Journal of Urban Economics*, **31**, 300-310.

McConnell, K. E. (1989), 'Optimal Quantity of Land in Agriculture', Northeastern *Journal of Agricultural and Resource Economics*, **18**(2), 63-72.

McMillen, D. P. and J.F. McDonald 91991), 'A Markov Chain Model of Zoning Change,' *Journal of Urban Economics*, **30**, 357-270.

Merlo, M. and F. Della Puppa (1994), 'Public Benefits Valuation in Italy: A Review of Forestry and Farming Applications, in A. Dubgaard, I. Bateman, and M. Merlo (eds), *Economic Valuation of Benefits From Countryside Stewardship*, Proceedings of a Workshop Organized by the Commission of the European Communities Directorate General for Agriculture, Brussels, Wissenschaftsverlag Vauk Kiel KG.

Mertens, B. and E. Lambin (1997), 'Spatial Modeling of Deforestation in Southern Cameroon,' *Applied Geography*, **17**(2), 143-162.

Meyer, W. B. and B. L. Turner II (1992), 'Human Population Growth and Global Land-Use/Cover Change', *Annual Review of Ecology and Systematics*, **23**, 39-61.

Miceli, T. J. and K. Segerson (1996), *Compensation for Regulatory Takings*, Greenwich, CT: Jai Press, Inc.

Mieszkowski, P. and E. S. Mills (1993), 'The Causes of Metropolitan Suburbanization', *Journal of Economic Perspectives*, 7(3), 135-47.

Mills E. S. (1967), 'An Aggregative Model of Resource Allocation in a Metropolitan Area', *American Economic Review*, **57**, 197-210.

Mills, D. E. (1989), 'Is Zoning a Negative-sum Game?', *Land Economics*, **65**(1), 1-12.

Morain, S. R. (1998), 'A Brief History of Remote Sensing Applications, with Emphasis on Landsat', in D. Liveman, E. F. Moran, R. R. Rindfuss, and P. C. Stern (eds), *People and Pixels: Linking Remote Sensing and Social Science*, Washington, D.C.: National Academy Press.

Muth R. 1969. *Cities and Housing*. Chicago: University of Chicago Press.

Naiman, R. J., H. Decamps, and M. Pollock (1993), 'The Role of Riparian Corridors in Maintaining Regional Biodiversity', *Ecological Applications*, 3(2), 209-212.

Nelson, G. and D. Hellerstein (1997), 'Do Roads Cause Deforestation? Using Satellite Images in Econometric Analysis of Land Use', *American Journal of Agricultural Economics*, 79(1), 80-88.

Nijkamp, P. and A. Reggiani (1998), *The Economics of Complex Spatial Systems*, Amsterdan: Elsevier.

O'Neill, R.V., Krummel. J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L. (1988), 'Indices of Landscape Pattern,' *Landscape Ecology*, 1(3), 153-162.

Opaluch, J., S. Swallow. T. Weaver, C. Wessells, and D. Wichelns (1993), 'Evaluating Impacts from Noxious Facilities: Including, Public Preferences in Current Siting Mechanisms,' *Journal of Environmental Economics and Management*, 24: 41-59.

Organisation for Economic Co-operation and Development (1997), *The Environmental Effects of Agricultural Land Diversion Schemes*, Paris, France.

O'Sullivan, A. (1993) 'Voluntary Auctions for Noxious Facilities: Incentives to Participate and the Efficiency of Siting Decisions,' *Journal of Environmental Economics and Management*, 25: s12-s26.

Page, Scott (1999) 'On the Emergence of Cities', *Journal of Urban Economics*, 45(1), 184-208.

Papageorgiou, Y. and T. Smith (1983), 'Agglomeration as Local Instability in Spatially Uniform Steady-States," *Econometrica*, 51(4), 1109-19.

Parks, P. (1991), 'Models of Forested and Agricultural Landscapes: Integrating Economics,' in M. Turner and R. Gardner (eds), *Quantitative Methods in Landscape Ecology*, New York: Springer-Verlag.

Parks, P. J. and J. P. Schorr (1997), 'Sustaining Open Space Benefits in the Northeast: An Evaluation of the Conservation Reserve Program', *Journal of Environmental Economics and Management*, 32(1), 85-94.

Parsons, G.R. (1992), 'The Effect of Coastal Land Use Restrictions on Housing Prices: A Repeat Sales Analysis', *Journal of Environmental Economics and Management*, 22(1), 25-37.

Parks, P. J. and R. A. Kramer (1995), 'A Policy Simulation of the Wetlands Reserve Program', *Journal of Environmental Economics and Management*, 28, 223-240.

Pfaff, A. (1999), 'What Drives Deforestation in the Brazilian Amazon?', *Journal of Environmental Economics and Management*, **37**(1), 26-43.

Phipps, T. (1983), 'Landowner Incentives to Participate in a Purchase of Development Rights Program with Application to Maryland', *Journal of the Northeastern Agricultural Economics Council,* **12**(1), 61-65.

Pitt, D.G., T. Phipps and B.V. Lessley (1988), 'Participation in Maryland's Agricultural Land Preservation Program: The Adoption of an Innovative Agricultural Land Policy', *Landscape Journal*, 7, 15-30.

Plantinga, A. J. (1996), 'Land Use and Environmental Quality', *American Journal of Agricultural Economics*, **78**(4), 1082-1091.

Poe, G. L. (1998), 'Property Tax Distortions and Participation in Federal Easement Programs: An Exploratory Analysis of the Wetland Reserve Program', *Agricultural and Resource Economics Review*, **27**(1), 117-124.

Pollakowski, H. O. and S. M .Wachter (1990), 'The Effects of Land Use Constraints on Housing Prices', *Land Economics*, **66**(3), 315-324.

Pruckner, G. J. (1995), 'Agricultural Landscape Cultivation in Austria: An Application of the CVM', *European Review of Agricultural Economics*, **22**(2), 173-190.

Ready, R.C., M.C. Berger, and G. Blomquist (1997), 'Measuring Benefits from Farmland: Hedonic Pricing vs. Contingent Valuation', *Growth and Change,* **28,** 438-58.

Riebsame, W. E., W. B. Meyer, and B. L. Turner II (1994), 'Modeling Land use and Cover as Part of Global Environmental Change', *Climatic Change*, **28**, 45-64.

Riera, P. (1994), 'Amenity Aspects of Spanish Countryside Policy', in A. Dubgaard, I. Bateman, and M. Merlo (eds), *Economic Valuation of Benefits From Countryside Stewardship*, Proceedings of a Workshop Organized by the Commission of the European Communities Directorate General for Agriculture, Brussels, Wissenschaftsverlag Vauk Kiel KG.

Schwartz, S. I., P. M. Zorn, and D. E. Hansen (1986), 'Research Design Issues and Pitfalls in Growth Control Studies', *Land Economics*, **62**, 223-233.

Southgate, D., R. Sierra, and L. Brown (1991), 'The Causes of Tropical Deforestation in Eucador: A Statistical Analysis,' *World Development*, **19**(9), 1145-1151.

Stavins, R. N. (1990), 'Alternative Renewable Resource Strategies: A Simulation of Optimal Use', *Journal of Environmental Economics and Management*, **19**(2), 143-159.

Stavins, R. N. and A. B. Jaffe (1990), 'Unintended Impacts of Public Investments on Private Decisions: The Depletion of Forested Wetlands', *American Economic Review*, 80(3), 337-352.

Swallow, S. K. (1994), 'Resource Economic Theory, Wetlands and Fisheries', *Marine Resource Economics*, 9(4), 291-310.

Theobold, d. M. and N. T. Hobbs (1998), 'Forecasting Rural Land-use Change: A comparison of Regression- and Spatial Transition-based Models', *Geographical and Environmental Modeling*, 2(1), 65-82.

Turner, M. (1987), 'Spatial Simulation of Landscape Changes in Georgia: A Comparison of Three Transition Models,' *Landscape Ecology*, 1(1), 29-36.

Turner, M. G. (1989), 'Landscape Ecology: The Effect of Pattern on Process', *Annual Review of Ecology and Systematics*, 20, 171-197.

van Kooten, C., R. Sedjo and E. Bulte (1999), 'Tropical Deforestation Issues and Policies', in H. Folmer and T. Tietenberg (eds), *The International Yearbook of Environmental and Resource Economics*, Cheltenham, UK: Edward Elgar.

Vane, T. and A. Larson (1988), *Fiscal Impact of Major Land Uses in Culpepper County*, Virginia, Warrenton, VA: Piedmont Environmental Council.

Veldkamp, A. and L. Fresco (1996), 'CLUE-CR: An Integrated Multi-Scale Model to Simulate Land Use Change Scenarios in Costa Rica,' *Ecological Modeling*, 91, 231-248.

Veldkamp, A. and L. Fresco (1997a), 'Exploring Land Use Scenarios, An Alternative Approach Based on Actual Land Use,' *Agricultural Systems*, 55(1), 1-17.

Veldkamp, A. and L. Fresco (1997b), 'Reconstructing Land Use Drivers and Their Spatial Scale Dependence for Costa Rica (1973 and 1984),' *Agricultural Systems*, 55(1), 19-43.

Vesterby, M., A. Daugherty, R. Heimlich, and R. Claassen (1997), *Major Land Use Changes in the Contiguous 48 States*, AREI Updates. No. 3. USDA, ERS, NRED.

Wallace, N. E. (1988), 'The Market Effects of Zoning Undeveloped Land: Does Zoning Follow the Market?', *Journal of Urban Economics*, 23, 307-326.

Watkins, C. (1994), 'Approaches to Landscape in Europe', in A. Dubgaard, I. Bateman, and M. Merlo (eds), *Economic Valuation of Benefits From Countryside Stewardship*, Proceedings of a Workshop Organized by the Commission of the European Communities Directorate General for Agriculture, Brussels, Wissenschaftsverlag Vauk Kiel KG.

Wegener, M. (1994), 'Operational Urban Models: State Of The Art,' *Journal of the American Planning Association*, 60(1), 17-29.

Whitby, M. and P. Lowe (1994), 'The Political and Economic Roots of Environmental Policy in Agriculture', in M. Whitby (ed), *Incentives for Countryside Management: The Case of Environmentally Sensitive Areas*, Cambridge, UK: University Press.

White, R. and G. Engelen (1993), 'Cellular Automata and Fractal Urban Form: A Cellular Modelling Approach to the Evolution of Urban Land Use Patterns,' *Environment and Planning A*, **25**, 1175-99.

White, R. G. Engelen, and I. Uljee (1997), 'The Use of Constrained Cellular Automata for High-resolution Modelling of Urban Land-Use Dynamics,' *Environment and Planning B*, **24**, 323-343.

Wilkie, D. S. and J. T. Finn (1988), 'A Spatial Model of Land Use and Forest Regeneration in the Ituri Forest of Northeastern Zaire', *Ecological Modelling*, **41**, 307-323.

Willis, K. G. (1994), 'The Value of Agricultural Landscapes in England and Wales', in A. Dubgaard, I. Bateman, and M. Merlo (eds), *Economic Valuation of Benefits From Countryside Stewardship*, Proceedings of a Workshop Organized by the Commission of the European Communities Directorate General for Agriculture, Brussels, Wissenschaftsverlag Vauk Kiel KG.

Wilson, A.G. (1981), *Catastrophe Theory and Bifurcation : Applications In Urban and Regional Geography*, London: Croom Helm; Berkeley: University of California Press.

Wu, F. and C.J. Webster (1998), 'Simulation of Land Development through the Integration of Cellular Automata and Multicriteria Evaluation,' *Environment and Planning B*, **25**, 103-126.

Zhang, W. (1993), 'Location Choice and Land Use in an Isolated State: Endogenous Capital and Knowledge Accumulation,' *Annals of Regional Science*, 27(1), 23-39.