2014

Spatial Environmental and Natural Resource Economics

Amy Ando, *University of Illinois at Urbana-Champaign*
Kathy Baylis, *University of Illinois at Urbana-Champaign*

January 2012

Spatial Environmental and Natural Resource Economics

Spatial Environmental and Natural Resource Economics

Amy W. Ando and Kathy Baylis
Department of Agricultural and Consumer Economics
University of Illinois at Urbana-Champaign

Abstract

Environmental and natural resource economics has long wrestled with spatial elements of human behavior, biophysical systems, and policy design. The treatment of space by academic environmental economists has evolved in important ways over time, moving from simple distance measures to more complex models of spatial processes. This chapter presents knowledge developed in several areas of research in spatial environmental and natural resource economics. First, it discusses the role played by spatial heterogeneity in designing optimal land conservation policies and efficient incentive policies to control pollution. Second, it describes the roles space plays in non-market valuation techniques, especially the hedonic and travel cost approaches which inherently use space as a means to identify values of non-market goods. Third, it explains a set of quasi- or natural-experimental empirical methods which use spatial shocks to estimate the effects of pollution or environmental policy on a wide range of outcomes such as human health, employment, firm location decisions, and deforestation. Finally, it describes spatial models of human behavior including locational sorting and the interaction of multiple agents in a land use/conservation setting. The chapter ends with a discussion of some promising future areas for further evolution of the modeling of space in environmental economics.

1. Introduction

Space is a key dimension of the physical, ecological, and human processes that affect environmental quality and the health of natural resource stocks. Therefore, environmental and natural resource economics has long wrestled with spatial elements of human behavior, biophysical systems, and policy design. The treatment of space by academic environmental economists has evolved in important ways over time, moving from simple distance measures to more complex models of spatial processes.

Researchers have long recognized that the environment is connected to space. Whether because of the distribution of resource quality across space, differential pollution loads or site-specific policies, space and location matter in environmental and resource economics. Further, there are spillover effects across space; emissions from one place can affect environmental quality in neighboring locations, and fragmentation can degrade the habitat benefits of a given area of conserved land.

Spatial work in environmental and natural resource economics has evolved over time. To take space into account, theoretical work by environmental economists began by including simple spatial resource heterogeneity and contiguity in research on optimal policy design. Initially, heterogeneity was usually defined as a simple uniform distribution over space, and a single contiguous area was assumed to generate higher ecosystem or habitat benefits than fractured parcels regardless of proximity or the intensity of intervening land uses.

Much of the early empirical work that used space came in the form of hedonic regressions to value location-specific environmental amenities. As a first step, as with the theoretical work, space was usually defined in terms of distance from environmental features of or location in certain polygons of the landscape. Spatial empirical work advanced with the introduction of spatial econometrics. Many empirical papers in environmental economics began to take space into account, initially treating it largely as a nuisance parameter that generated spatially-correlated error terms (Anselin 2002) instead of as an informational component of the data generating process.

Later innovation in environmental economics adopted more nuanced and detailed treatments of spatial processes. For example, research began to differentiate between neighbors on the basis of the directionality of pollution flows. More detailed modeling of the spatial nature of ecosystem services, such as habitat provision, is also becoming more common in the literature. Thus, instead of simply controlling for spatial interactions based on a pre-determined definition of 'neighbors', authors are now justifying why and how space might affect their model or empirical results, drawing from relevant literatures on natural processes or human interactions.

The most recent step in the evolution of spatial environmental and natural resource economics is the identification and estimation of strategic behavior over space. The idea that location affects land use has been around since Von Thunen. More recent work allows for human migration in response to transportation costs or differential preferences. For example, we have seen large growth in research on locational sorting. Another literature that has begun to explore spatial strategic behavior is in the sub-field studying land use. Some work models how actors respond to land use changes or policies and incorporates those reactions into models that target land for conservation. Recent papers have also begun to take the existence of multiple policy makers, private agents, and possible strategic responses into account to better reflect the multitude of principals and agents that collectively affect land use decisions.

In this chapter, we present knowledge developed in several areas of research in spatial environmental and natural resource economics, emphasizing areas that have been and continue to be foci of active research in recent years. We begin with models of simple spatial heterogeneity, beginning with a discussion of optimal land conservation policies and moving to analyze how special heterogeneity affects efficient pollution trading. We next discuss the use of space in non-market valuation techniques, especially the hedonic and travel cost approaches which inherently use space as a means to identify values of non-market goods. The third section of the chapter explains a set of quasi- or natural-experimental empirical methods which use spatial shocks to estimate the effects of pollution or environmental policy on a wide range of outcomes such as human health, employment, firm location decisions, and deforestation. Originally common in labor economics, these methods have been increasingly adopted in environmental economics as an alternative or at times, a complement to, the hedonic approach. Finally, we describe spatial models of human behavior including locational sorting and the interaction of multiple agents in a land use/conservation setting. We end with a discussion of some promising future areas for further evolution of the modeling of space in environmental economics. While this review is by no means comprehensive, it is intended to give the reader a sense of how space is treated in modern environmental and natural resource economics.

2. Spatial Heterogeneity and Optimal Policy

2.1 Spatial heterogeneity in land conservation

Early work in environmental and resource economics determined how to choose conservation and reserve sites optimally when costs and environmental benefits are heterogeneous across space (Ando 2012). Simple computational optimization routines can be used to choose sites or spatially target conservation funds to generate the maximum environmental benefits possible, often taking account of complementarities between multiple parcels in the landscape. With fixed parameters to the problem - budget size, benefits and costs of conserving the parcels - optimal site selection routines will select sets of parcels that have high benefit/cost ratios where benefits consider both the quality of ecological resources on a parcel and the likelihood that the parcel would be degraded in the absence of conservation (Polasky 2005).

Analysis of optimal protected-area network design can, however, also account for the role of space in complex ecological processes when such processes have important effects on optimal design. Production of ecosystem services from reserves often depends on the configuration as well as the total area of lands that are protected. Thus, the integer programming models often used for optimal reserve-site selection have been enriched to favor patterns of land that display certain levels of agglomeration.

Sophisticated versions of this work use programming models to choose cost-effective terrestrial reserves in light of detailed spatial idiosyncrasies of the conservation target at hand. Such a model can include details about the population dynamics of the species which is the focus of conservation activity, and models of how the species population depends on proximity to certain features of the landscape and the quality of the unprotected land that lies between reserves. Such models should also incorporate information about spatial heterogeneity in economic use and value. The outcome of such an analysis is identification of the network of lands that maximizes economic surplus in the area while satisfying ecological requirements related to species survival (Albers et al. 2010). Research in marine environments can also use spatial patch population dynamics, specifically knowledge of species source/sink features of different areas in a marine landscape to help policy makers design fishing regulations (including marine reserves) that serve to protect overharvested species and improve social surplus in commercial fisheries (Grafton et al. 2005). In both terrestrial and marine analyses, the best policy is not to place spatially homogenous restrictions on human behavior (protect all wetlands, reduce total fishing effort). Instead, heavy protection of core habitat (or population source sites) can be cost-effective approaches to increasing species populations (and possibly sustainable economic harvest rates) though attention must be paid to patterns of species dispersal through space when designing such policies.

Spatial environmental and natural resource economics has also developed tools for optimal non-reserve policy design that account for important spatial phenomena. For example, economic theory helps us understand how to make spatially-explicit conservation payments. Given that the marginal benefits of conservation on one parcel often depend on the spatial configuration of conservation (or lack thereof) on neighboring parcels, voluntary conservation programs can yield patterns of conservation that are sub-optimally fragmented. Effective policies can offer payments for conservation activities which depend on the status of nearby lands. Policy makers can offer agglomeration bonuses – extra payments to landowners for conservation if neighboring parcels are also conserved. Such payments provide incentives that can yield less fragmented patterns of conservation in a landscape (Albers et al. 2010); they may also, however, yield uncompetitive behavior in the bidding process. Auction mechanisms have been developed to provide incentives for agglomerated voluntary conservation while encouraging competitive bidding to minimize rent transfer from the conservation agency to the land owners (Reeson et al. 2011).

In addition, policies are sometimes needed to protect natural resources from threats. Economists have studied how to design such policies efficiently when spatial features of the threats are important. For example, developing countries establish parks and protected areas within which extraction of natural resources is illegal, but it can be difficult to design a cost-effective policy to prevent illegal extraction on the part of nearby villagers. Because extraction activities are carried out by people on foot, there is a strong spatial component to the costs and benefits of extraction in different places within a park. Optimal enforcement may be concentrated in a ring excluding the center and the perimeter of the park; for most cases, the commonly-used spatially homogeneous enforcement strategy is highly inefficient (Albers et al. 2010). Policies to control threats to natural resources from invasive species should be spatially explicit as well, using information about spatial heterogeneity in the expected costs and benefits of invasive species control to focus invasive-species detection and control activities cost-effectively (Kaiser and Burnett 2010).

Finally, spatial environmental economics makes clear that we need to be careful about spatial features of some policies designed to reduce pollution. For example, we would expect development of renewable energy sources such as solar and wind farms to reduce air pollution from the electricity and thus might put policies in place to encourage such investments. However, spatial idiosyncrasies of the national power transmission grid are such that renewable investments in some locations could actually increase total emissions from that sector by changing the intensity by which some existing fossil-fuel powered plants are utilized. Because the marginal benefits to society of renewable are spatially heterogeneous, incentives for renewable investments should be as well (Blumsack and Xu 2011).

2.2 Effect of space on market-based solutions

A standard result in environmental economics is that when pollution generates negative externalities – costs not borne by the polluter – then inefficiently large amounts of pollution will be produced by an unregulated market. In the simplest of cases, the problem of negative externalities from pollution can be solved by imposing a tax on pollution equal to the marginal external cost of the pollution evaluated at its efficient level (Cropper and Oates 1992).

However, pollution and resource use often have spatially-heterogeneous negative externalities. For example, air pollution is more harmful if it blows directly into populations of people, and water pollution is more harmful if emitted directly upstream from a sensitive receptor like a lake. Under these circumstances, the optimal policy response is not homogenous across space. Optimal pollution taxation in the spatial context, for example, might not only affect the quantity of emissions, but also shift the location of those emissions. Suppose the harm done by pollution increases with proximity of the emitter to an urban area. If emissions closer to the city have a higher marginal damage, they should be taxed at a higher rate. The difference in taxes would effectively flatten the slope of the transportation costs to the urban center, altering the standard von Thunen rings of economic activity around the center (Geoghegan and Gray 2005). However, this approach takes the location of the urban center as given. Tax policy could also alter the location of people who are affected by pollution; in some cases it is more efficient for affected persons to relocate than for the sources of pollution to be moved.

Market-based solutions to externalities such as creating tradable pollution permits are an alternative to taxation. Like the design of optimal taxation, market-based approaches to environmental regulation are complicated by heterogeneous spatial effects of pollution. While a simple trading regime would allow one polluter to buy a permit for one ton of emissions from another firm who reduces emissions by one ton, if these firms are in separate locations and the effect of emissions is not homogenous across space, this simple trading regime will not result in the optimal distribution of pollution among sources. For example, it is clearly not optimal to trade off one ton of emissions in a low-impact area against one ton of emissions in a region where pollution causes more harm. Thus, efficient trading can be complicated for pollutants that have specific regional impacts. One policy solution is to divide an area into sub-regions and only allow trading between sources that are in the same region, but this has the potential cost of creating thin markets. Another approach is to insist that pairs of sources trade permits at ratios that accurately reflect heterogeneity of marginal damages caused by pollution from different sources, but this solution creates administrative complexity. Spatial heterogeneity presents policy-makers with tradeoffs: charging firms their true marginal damage yields efficiency gains, costs of complexity (including the need for increased monitoring,) and concerns about distributional features of spatially heterogeneous policies (Tietenberg 1995; Olmstead 2010.)

3. Spatial Elements of Non-Market Valuation

Even before spatial analysis gained prominence in economics, some nonmarket valuation techniques (such as hedonic analysis and the travel-cost method) were always intrinsically spatial. Environmental economists have enhanced the use of space in those methods over time, and spatial concerns have been incorporated into other non-market valuation tools as well (Bateman et al. 2006.)

3.1 Hedonic valuation

Hedonic housing price analysis is grounded in the economic intuition that the price of a house will be a function of all its features including the environmental quality and access to natural amenities that are associated with its specific location in space. Sellers choose features to supply to maximize profit; buyers choose which house to buy (for a given price) to maximize utility. The market equilibrium yields a hedonic price function (price as a function of attributes) that can be estimated econometrically using spatially explicit data on houses, their sales prices, their conventional attributes (e.g. number of rooms, square footage) and their environmental attributes. One can interpret the marginal effect on price of an environmental feature as the marginal willingness to pay (WTP) of people in this market for that feature. These marginal WTP measures tell us things about the welfare effects of very localized changes in environmental quality. However, it is notoriously difficult to use hedonic analysis to estimate the welfare effects of a widespread change in environmental conditions (e.g. cleaner air in all of Southern California) because the market equilibrium would change and create an entirely new hedonic price function which can be difficult to predict from current conditions (Cropper and Oats 1992; Palmquist 2005).

Observations in hedonic analyses can display spatial autocorrelation because of two processes. A spatial lag process is when the outcome observed in one location is a function of the outcome of neighboring locations. For example, the price of one house may directly affect the price of the neighboring houses, perhaps by updating seller information about going market values. A spatial lag can also arise through the common use of a resource, such as neighbors competing with each other in the use of irrigation water (Anselin 2002). In contrast, a spatial error process refers to spatial correlation in the residuals. In the hedonic analysis literature, several studies have used econometric approaches that take into account possible spatial autocorrelation from both sources. Failure to account for autocorrelation can yield inconsistent estimates of the coefficients on environmental quality, while failure to capture spatial lag lead to bias, meaning that the estimates of the marginal effects of changing environmental quality in one location are missing spillovers into neighboring properties (Anselin 2002.)

Estimating how much pollution affects a specific house is non-trivial, since most pollution is usually only measured at a few locations in space. Thus, pollution measures are often spatially interpolated from these point data using kriging to generate an estimate of pollution at any specific latitude and longitude. Another approach to dealing with limited pollution data is to analyze housing prices within a larger spatial unit that either more closely conforms to the point data or uses geographic averages of the point measures.

One concern is that, like all interpolated variables, these environmental variables are measured with error, and this error may well be correlated with other unobservables that are also correlated with housing prices. For example, houses on a certain ridge could be subject to cooling ocean breezes that also result in a very localized drop in pollution. The potential heteroscedasticity induced by using estimates for pollution can be addressed by correcting for both spatial and heteroscedastic error terms. However, the more fundamental concern about omitted variable bias remains. Such bias may be present even without interpolated environmental variables, for there may always be important location-specific unobserved variables that are correlated across space with both the housing price and the environmental characteristic. The problem of omitted variables can be addressed by using repeated sales of the same house over time, or by including other regional fixed effects.

Traditional hedonic analysis has employed fairly simple notions of location, space, and neighbors. For example, it has usually used measures of environmental quality onsite (e.g. air pollution levels) or simple distance to an environmental amenity or disamenity (e.g. open space, hazardous waste site). However, such simple definitions may fail to capture important effects. For example, the walking or driving time to a park might affect the price of a house more than Euclidian distance, and having an amenity across a major road might increase the perceived distance of that amenity more than having it across a minor street. While the value of water quality improvements in a lake is diminishing with the distance of a house from a lake, there may be a discontinuous jump in value at the waterfront; there is often a complex story to be told about the actual ecosystem services that are being valued through the proxy of pollution measures (recreation, visual aesthetics, ecological health) and the role that space plays in mediating people's experiences of those services. Furthermore, when estimating how houses' prices might affect each other, such as when estimating a spatial lag, houses on the same block might affect each other's values more than houses one block over even if they are the same distance apart.

Such concerns can be addressed by taking a broader spatial view of the ways in which environmental quality might affect the relative desirability of homes in a housing market, and by taking care to define variables in hedonic models to reflect spatial realities and processes on the ground. The effects of pollution may not be simple - neither uniform, nor merely a matter of being in a polygon that is contiguous with a source, nor a linear function of distance from a source. In such cases, one can use detailed information on the dispersion of the effects of pollution to inform a hedonic analysis that estimates people's WTP to reduce it.

The hedonic spatial model can also be enriched by enhancing the interaction between space and time, extending the standard hedonic model to allow households to be forward looking and to face transaction costs of moving (Bishop and Murphy 2011.) Under such plausible circumstances, households weigh the cost of an environmental amenity (captured by the price premium associated with houses in locations with good environmental values) against the present discounted value of the stream of future utility they will obtain from the amenity. Incorporating forward-looking behavior yields much bigger estimates of consumer marginal WTP for a spatially heterogeneous environmental amenity.

3.2 Travel-cost analysis

The other nonmarket valuation that is most intrinsically spatial is the travel cost approach to estimating the values people place on the quality of natural resources. This method estimates demand for recreational sites such as beaches, lakes, and forests as a function of features of those natural sites; the results yield estimates of the values of the features (e.g. water quality, species populations) included in the analysis. The travel-cost approach uses data on how often people visit the sites of interest and how much those visits cost each individual in the data set, where travel cost depends in part on how close someone lives to a site. Single-site models use econometric analysis to estimate how quantity demanded of visits to a site depend on environmental quality; multiple-site models use a random-utility model (RUM) econometric approach to estimate how the choice of which of several sites to visit depends on the attributes of all the sites and how much travel to them costs (Cropper and Oates 1992.)

Travel-cost valuation methodology has evolved to include new features of space. The cost of travel was always measured as a function of how far a person lives from a site, but if people engage in locational sorting, distance from a site (and hence measured travel cost) will be correlated with unobservable preference heterogeneity, creating biased coefficient estimates. Latent class models can be used to control for this endogeneity (Barenklau 2010). Other problems can arise if multiple sites between which people choose for recreation (e.g. patches of a forest for hunting, lakes in a chain for fishing) are connected physically and ecologically across space. If, for example, a change in water quality at one lake causes fish populations to change and redistribute through an entire chain of lakes, then conventional travel-cost analysis can yield misleading information about the welfare effects of that change. A structural model of recreation site choice and harvest intensity must be coupled with a spatial model of population dynamics to understand the welfare effects of making improvements to features of one or more sites in such a system (Albers et al 2010.)

3.2 Stated preference valuation techniques

Stated preference valuation methodologies (contingent valuation (CV) and choice experiment (CE) studies) use information from hypothetical survey questions to estimate consumers' WTP for environmental goods and services even if the values they gain are not based in any way on direct use (Cropper and Oates 1992.) Non-use values may not be affected by distance to environmental amenities. However, distance may play a factor in WTP if people have a localized "sense of place" or if use values comprise a large fraction of the total value people place on environmental public goods.

Thus, space is recognized now to be an important part of even stated-preference valuation approaches. Data on how far people are from the amenities to be valued can be included directly in the specifications of such studies to measure how distance affects WTP for environmental goods and ascertain how that effect varies with income. Including distance explicitly in individual WTP functions helps benefit-cost analysts avoid making arbitrary choices about the spatial extent of the population of people that are affected by a project (Bateman et al. 2006.) The value people place on an environmental improvement may also depend on spatial variation in the current quality they experience for the amenity in question.

4. Spatial Empirical Identification Strategies

As noted in section 3.1 on hedonic analysis, space or location has long been used as a source of information to identify and estimate the effects of variation in environmental quality. As an alternative to the more structural hedonic model, the last decade has produced substantial growth in the application of quasi or natural experiments to estimate the effects of pollution and environmental policy. Spatial variation can be used to identify the effect of a treatment such as a policy shift or change in environmental conditions (Greenstone and Gayer 2009, Ferraro 2009.) If policies or shocks are specific to a location it is possible to use outcomes in these areas as compared to other untreated locations to measure the effect of the treatment. If the outcomes are observable before and after the treatment, one can control for time-invariant observables which can often confound estimates obtained from other approaches. Standard policy evaluation procedures (such as difference-in-difference, matching, or regression discontinuity methods) can then be applied to estimate the effect of the treatment.

Matching is a technique that compares treated to control observations on the basis of their observable characteristics. This technique addresses potential bias that might arise due to systematic differences in covariates between the treated and control observations. It does not, however, address the concern that treatment might be related to some unobservable characteristic that in turn affects the outcome of interest. A difference-in-difference approach compares treatment and control observations before and after the introduction of the treatment. This approach controls for time-invariant differences between the treated and control observations. Regression discontinuity design makes use of a fixed threshold that determines whether an observation is 'treated' or not. For example, if the treatment occurs when an individual turns 65, one can use the outcomes of 64 and ½ year-olds as controls. For a discussion of these and other program evaluation techniques, see Khandker et al. (2010.)

The shocks used for identification in spatial environmental and natural resource economics have ranged from a decrease in pollution (e.g. from a recession or a localized plant closure), to natural disasters, to the introduction of protected areas. Along with measuring the effect of policies on intended outcomes, the use of this quasi-experimental technique has been applied to estimate non-market valuation of environmental amenities and health outcomes. By definition, one requirement of the quasi-experimental approach is that, when using variation across space as a source of variation, one needs a spatially-varied shock. For example, spatially-heterogeneous policies, such as air-pollution emission standards that vary non-attainment status of a county, have become popular sources of identification to estimate willingness to pay for pollution or the influence of pollution on health or economic activity.

While it has some advantages, the quasi-experimental methodology has limitations as well. One challenge is in choosing the appropriate spatial scale for analysis. Often researchers cannot observe responses at the individual level and use regional housing values instead. At least two problems arise from that problem. First, patterns of correlation among variables across space are not always robust to the spatial units over which the data are aggregated. This problem of ecological fallacy (Anselin 2002) is most pronounced if individual variation within a region is large compared to the variation among regions. Second, non-parcel level data may not be fine enough to observe the effects of some environmental shocks on housing prices (Smith 2007.) Quasi-experimental studies may also yield biased results if they assume treatment effects that are constant with distance when, in fact, both the treatment itself and the impact of a treatment on housing prices is idiosyncratic across space (Auffhammer et al. 2009; Smith 2007.)

Last, one crucial assumption required for the use of quasi-experimental methods is that the treatment is not assigned based on unobservables that also affect the outcome. While some random shocks, such as weather variation, may well fall into this category, other shocks (such as a regional policy, the shut-down of a plant, or spatially delimited critical habitat for endangered species) are potentially more problematic. If those unobservables are time-invariant, the use of fixed effects may mediate the problem. Fixed effects, however, do not solve the problem of unobserved variation generating a differential effect of observed characteristics on the outcome. For example, if unobserved political influence affected the location of a new environmental policy and political influence also affected how that policy affected economic outcomes, one could still estimate a biased coefficient for the effect of the policy on economic outcomes even with fixed effects.

4.1 Environment and health

Arguably the largest growth area in the use of these natural or quasi-experiments in environmental economics has been on measuring the effect of pollution on health. As with the willingness to pay literature, this is a topic that has previously seen the broad application of hedonic analysis. There is a substantial literature that measures the costs of environmental health risks and disease that use epidemiological methods to estimate a dose-response function of, say, exposure to a chemical and health outcomes, and then use wage hedonics to estimate the perceived costs of those work-related risks (Viscusi and Gayer 2005). Other papers have estimated the cost of health effects using variation in housing prices.

Various authors have used natural experiments arising from a temporary plant closure or changes in traffic patterns to estimate the effect of emissions on health outcomes. Other authors have used economic downturns as an instrument for changes in county-level pollution to estimate the effect of pollution on health. As with the other quasi-experimental studies, one concern is finding the appropriate scale of analysis. More recent papers make use of smaller scale variation in pollution levels, using within zip-code or school district variation to be better able to control for other neighborhood fixed effects (Currie et al. 2009).

Another approach is to use natural and environmental disasters as a source of variation to estimate the effect of these disasters on health outcomes. A continuing challenge is how exactly to model the spatial and temporal exposure to these shocks, and to address human responses to either the threat or incidence of exposure (such as migration). In using this methodology, researchers also need to be careful to rule out potential spillovers resulting from the treatment into neighboring control regions; such spillovers could render the control group un-controlled, and therefore bias the estimate of treatment effect.

4.2 Evaluations of protected areas and PES programs

Spatial analysis has been and can be used to estimate the effectiveness of conservation measures in preventing environmental degradation such as deforestation. The methodology has been developed to study programs that establish protected areas policies that offer payments to landowners for activities that preserve or increase flows of environmental services - PES programs (Pattanyake et al. 2010). Location-specific attributes and the spatial process of land use play important roles in estimating the effects of these programs.

Early evaluations of conservation efforts compared outcomes (such as deforestation rates) in areas subject to a conservation measure, such as legal protection, to outcomes in plots outside the boundaries of this protection. The problem with this approach is that protected and unprotected areas frequently differ in ways that systematically bias the comparisons (Andam et al. 2008). For example, countries may naturally place their protected areas in regions that face lower deforestation pressure (Joppa and Pfaff 2010). In these circumstances, estimates from a simple comparison of outcomes inside and outside of the protected area boundaries would overstate the impact of conservation policies. To overcome these biases and develop more accurate comparisons, conservation research must consider realistic counterfactual scenarios (Ferraro 2009). Thus, researchers must adopt evaluation techniques that permit comparison of observed outcomes with what would have happened in the absence of a conservation effort. The difficulty lies in that counterfactuals cannot be observed directly and instead should be carefully estimated.

Some recent research has attempted to estimate a counterfactual in evaluations of conservation programs. Costa Rica's PES program has been assessed using linear regression models and two types of matching estimators to compare the deforestation rates of participating and non-participating PES communities when controlling for observable features of the landscape such as slope, distance to cities, and ecological zones; the results indicate the program had little effect on deforestation (Andam et al. 2008.) It is also possible to take an explicitly spatial approach to the analysis of conservation-program effectiveness. One technique is to control for possibility of spatially autocorrelated errors in the regressions that analyze the impact of conservation policy on landscape degradation (Alix-Garcia 2007). A second approach is to control for spatial spillovers from one observation to the next, by explicitly estimating the spatial lag associated with land use change Failure to control for such spillovers has been found to have large effects on the estimates of treatment effects (Honey-Roses et al. 2011.) A third spatial strategy is to estimate the effect of the program on nearby areas, or explicitly estimate the leakage caused by the policy. If there is a spatial lag process associated with deforestation, land use in observations on the boundary of the treatment area might well be affected by the treatment of the neighboring area, implying that they are not appropriate control observations.

5. Models of Behavior in Space

Until now, this chapter has largely focused on models where spatial effects arise from features of nature. Such models assume that resource locations are given and that the heterogeneous effects of pollution are determined by factors exogenous to humans, like wind or hydrology. However, spatial heterogeneity may arise from human behavior and the resulting economic forces. Research in environmental and natural resource economics has developed understanding of various spatial dimensions of human behavior.

From the simplest von Thunen model of land use being driven by variation in transport costs to market to the rise of New Economic Geography in the 1990s, we now have models that predict the growth of cities (Fujita et al. 1999.) The New Economic Geography approach models population centers as arising from tension between agglomeration economies (driven by monopolistic competitive firms) and congestion costs. These models still assume at their base a featureless plain, where migration is driven by differences in real wages. Once one introduces an influential spatial feature, those people with a strong preference for that amenity may migrate for other reasons. This innovation has led to the concept of spatial sorting.

Economics predicts that people respond to incentives. Incentives may themselves arise from features of the landscape other than just proximity to the nearest urban center. For example, zoning and other land-use rules may place restrictions on the use of some land, pushing these land uses elsewhere (an effect also known as leakage). As some land is removed from potential development, the price of development rights may increase in other regions. These and other behavioral responses are incorporated into modern models of land use and land conservation research.

Regulation of environment and natural resource use is complicated by the existence of multiple regulators and multiple regulated actors, giving rise to the potential for strategic behavior and collective action problems. These problems gain an extra dimension of complexity when the cooperation or competition occurs over space. Spatial environmental and natural resource economics now incorporates some of these multi-agent behaviors in space.

5.1 Spatial sorting models

One recent thread of research in the field of environmental and natural resource economics has rapidly become an established and influential feature of the literature: spatial sorting models (Palmquist 2005). This body of work evolved from early work by Tiebout (Banzhaf and Walsh 2008) on how people "vote with their feet" and move to places that have bundles of attributes – including environmental quality and cost – they prefer. Modern spatial sorting models are theoretically and computationally complex, and are used for a wide range of functions.

One category of research on sorting models is positive – just seeking to describe whether (and if so, how) people sort across space in the face of spatial heterogeneity of attributes. This research can help us to understand the forces that drive demographic patterns within urban areas, and shed important light on questions of environmental justice. These models can also be used to explore how proposed changes in environmental quality will affect the distribution of people in the landscape and their subsequent well-being.

Early theoretical models of spatial sorting equilibria assumed that households have heterogeneous incomes and preferences over housing and public good characteristics of a location. Communities vary in how expensive they are and in the level of the public good they provide. Individuals choose where to live to maximize their utilities subject to their budget constraints; housing prices in communities adjust until equilibrium is reached such that no household would prefer to live somewhere other than where they are living. Even in the simplest models, assumptions must be made about the structure of indirect utility functions in order to ensure that equilibrium exists. The models also assume (implicitly or explicitly) that all household have perfect information about community characteristics and the preferences of other households, all households are able to purchase as much housing as they want in their preferred locations, and moving is costless. The resulting equilibria have communities that are stratified by income if preferences are homogeneous, and households sorted differentially according to the features they care most about if preferences vary (Palmquist 2005).

Later models (e.g. Bayer and Timmins 2005) allow for spillovers between individuals that choose a given location; spillovers can either be positive (as in the case of agglomeration economies) or negative (if there is congestion). Under these circumstances, multiple equilibria are often possible, particularly if there is a strong agglomeration effect. One can still use data to estimate the features of models that have multiple equilibria, but multiplicity makes it more difficult to draw conclusions about what the re-sorting effects will be of major changes in a region such as cleaning up a hazardous waste site.

Empirical work has sought to identify whether sorting behavior in response to spatial environmental heterogeneity is an important factor in residential markets. Econometric approaches to this problem include estimation of simple logit models of the probabilities that households locate in neighborhoods as functions of neighborhood characteristics (Finney et al. 2011) and statistical analysis of changes over time in socio-demographic and housing characteristics of locations near sites that experience changes in environmental quality (Banzhaf and Walsh 2008). There is evidence that people locate at least partly in response to environmental features of neighborhoods, and that such dynamics can exacerbate income segregation in urban areas.

Because of their utility-theoretic underpinnings, sorting models have been used as the foundation for a new approach to estimating the values people place on elements of environmental quality that do not have market values. Researchers can use neighborhood-level land value data to obtain structural estimates of the parameters underpinning residential sorting models and thus estimate values of spatially differentiated environmental amenities such as air quality and open space (Klaiber and Phaneuf 2010). In addition to generating value estimates that can be used in cost-benefit analyses, this research reveals several insights about environmental policy and research. First, the benefits of an environmental improvement policy depend on how it is distributed in space. Second, benefit estimates based on traditional nonmarket-valuation techniques may be incorrect if the environmental changes to be valued are large enough to induce significant re-sorting. An example can illustrate. Suppose air quality in the neighborhood of Gryffind is originally much lower than in Slyther; people would sort such that the people who value clean air most intensely would pay a premium and live (disproportionately) in Slyther. If we improve air quality in Gryffind, there is initially just a small welfare increase because the people who live there care relatively little about air pollution. With resorting, there are two effects; (1) the people who value air quality more highly move to Gryffind, and thus the benefit to residents there is higher; (2) housing prices fall in Slyther and rise in Gryffind, causing indirect price effects on welfare that depend in size and spatial distribution on details of the situation.

The structural sorting-equilibrium approach does have the great advantage of taking dynamic factors into consideration. However, it requires analysts to impose much structure on the underlying model and to make arbitrary choices about the boundaries over which communities (which are the unit of observation) are defined. This latter activity may be extremely problematic given that results of spatial statistical analysis have long been known to be sensitive to the manner in which data are aggregated across space (Anselin 2002). Future work on this methodology may seek to resolve these issues.

5.2 Behavior in land use and conservation

Land use is an area that straddles several disciplines in economics (urban economics, environmental economics and economic geography), and has long recognized the importance of human interaction with space. Early models of land use often ignored the behavioral component and were largely meant to fit, as opposed to explain, the data.

More recently, models of optimal conservation planning have been developed that incorporate spatial heterogeneity of environmental costs and benefits with spatial economic models of the probability of land use change. Instead of merely conserving land based on selecting those parcels with the highest environmental benefit per dollar, it improves economic efficiency to target those parcels with the highest environmental benefit per dollar that are also under the highest threat of development.

Other models of land-use change have begun to take into account behavioral responses to development or development policy changes. In general, restrictions on land use in one part of space (such as zoning) can intensify the limited activity in other areas that are not controlled by the restrictions; this is the generalized phenomenon of leakage. Some land-use restrictions, such as urban policies mandating embedded open space, can increase the value of development in neighboring areas so much that they accelerate leapfrog urban sprawl (Irwin et al. 2009).

Finally, some research incorporates the fact that multiple actors are involved in conservation, and that these actors likely interact, and often interact strategically. Spatial strategic behavior is best known in models of how local governments set their levels of public goods, taxes and/or regulatory stringency. If firm location choice is endogenous, nearby jurisdictions may compete on the level of taxation and public goods. This competition is further complicated by economic activity induced by firm location having spillovers to neighboring locations. Strategic private responses can thwart governments in many of the actions they try to take to improve environmental quality, creating hold-up problems when an agent is trying to establish an agglomerated protected area that requires buy-in from multiple land owners, sometimes shifting private conservation into parts of a landscape that are spatially disparate from the locations of public conservation activities (Albers et al. 2010.)

The most recent generation of research on conservation reserve design uses economic theory to inform the strategic choice of lands for reserves taking into account the spatial responses of multiple human agents to those choices. Empirical research has identified many ways in which human behavior in space responds to changes in the environment; for example, the establishment of government protected lands can increase the price of land and the threat of development (or likelihood of conservation) in the area (Irwin et al. 2009.) Thus, optimal reserve choices by one agent should be strategic, taking into account the likely responses of other agents (Albers et al. 2008) and likely changes in the land market which affect the risk to other parcels of conversion and the cost to the decision maker of future conservation (Armsworth et al. 2006). Such strategic decision making can yield improved conservation outcomes, but can entail making seemingly counter-intuitive choices such as avoiding putting protected areas in some areas of high ecological value. Similarly, econometric work has documented how harvesting activity varies across space with changes in factors such as target (e.g. fish) populations and the presence of regulations such as spatial closures (Grafton et al. 2005; Albers et al. 2010). Endogenous harvesting behavior affects the outcomes of spatially explicit harvesting regulations – if one area is closed, harvesters work more intensively in another area, and if regulations increase target populations, harvesting effort will increase. Socially optimal spatial resource use regulations can be designed in ways that take such endogenous behavior into account (Grafton et al. 2005).

6. Conclusion

Some areas for future work in spatial environmental and natural resource economics seem to be particularly important and promising. In the area of spatial policy evaluation, one area where future work is needed is to more formally incorporate spatial data-generating processes into the quasi-experimental setting. For example, the use of propensity-score matching (PSM) is potentially biased in the presence of spatially-correlated error terms. Just as a probit estimation generates potentially biased estimates in the presence of heteroscedasticity, the initial probit regression used to generate the propensity of treatment may be inherently biased by the presence of spatial correlation. More fundamentally, in the presence of a spatial lag, estimates will likely be biased, and further, control observations neighboring treated regions may themselves be affected by the treatment (Honey-Roses et al. 2011). The bias in this instance could go either way depending on the nature of the lag process. While this spatial effect may complicate difference-in-difference analyses, it is even more potentially problematic for regression discontinuity design where the regression discontinuity is spatial in nature. Note that since the amount of spillover is not constant over time, and may be directly affected by the treatment, using observation-level fixed effects does not solve the bias.

A related area of concern is that a treatment itself may actually change the scale and scope of important spatial processes related to that treatment. For example, a fuel tax may affect the degree of spatial spillover from economic activity in one area to economic activity in neighboring areas by changing patterns of commuting behavior. These effects on spillovers may be substantial and have large effects on policy outcomes which have not systematically been studied.

In the area of spatial policy design, truly optimal policies need to take spatial strategic reactions into account rather than treating other actors as merely reactive. Papers that apply game theory to spatial policy decisions are rare (Albers et al. 2008); more work needs to be done in this area. For example, private actors are known anecdotally to buy land for speculation if they anticipate conservation agents wanting to buy it for protected areas. This phenomenon is different from that of markets responding to conservation with increased prices nearby, and should be worked into spatial-dynamic models of optimal reserve-site selection.

Future work in spatial environmental and natural resource economics may even move to redefine what we mean by "space." Extant research and knowledge in this field conceptualizes space in traditional geographic terms. However, other dimensions of space exist that may affect natural processes and human behavior. Economic interactions may facilitate technological adoption more than mere geographic proximity. Social distance and social networks can affect attitudes and behavior through facilitating both information flow and influence. As an example, information and influence can affect individual's valuation of a disamenity such as hazardous waste. Further, social influence can be used to improve monitoring, enforcement and therefore management of a local common pool resource, such as community pasture. Current research in spatial econometrics is moving forward to allow researchers to estimate spatial weights or spatial spillover patterns, as opposed to merely estimating the degree of spillover given an assumed structure of the extent to which different spatial units function as neighbors. These advances in spatial econometrics will facilitate future research that quantifies the effects of spillovers in environmental and natural resource economics.

Knowledge in spatial environmental and natural resource economics already includes theoretical and empirical models that inform spatial environmental policy design, evaluate policy effectiveness, help us predict human behavior in a landscape, and help place values on environmental goods that are spatially heterogeneous and convey benefits in ways that vary with spatial processes. However, work in this field of research is still very much ongoing and the field is still evolving; much more needs to be done.

7. Acknowledgements

This chapter is based in part on work supported by USDA-NIFA Hatch project number #ILLU-470-316. Lead authorship is equally shared by the two co-authors.

8. References

Albers, HJ, Ando, AW, Batz, M (2008) Patterns of multi-agent land conservation: Crowding in/out, agglomeration, and policy. Resource and Energy Economics 30(4): 492-508.

Albers, HJ, Ando, AW, Shogren, JF (2010) Introduction to spatial natural resource and environmental economics. Resource and Energy Economics 32(2): 93-97.

Alix-Garcia, J (2007) A spatial analysis of common property deforestation. Journal of Environmental Economics and Management 53: 141-157.

Ando, AW (2012) Optimization across space. Chapter 106 in: Shogren J (ed) Encyclopedia of energy, natural resource, and environmental economics. Elsevier, Amsterdam.

Anselin, L (2002) Under the hood: Issues in the specification and interpretation of spatial regression models. Agricultural Economics 27(3): 247–267.

Andam, K, Ferraro, PJ, Pfaff, A, Sanchez-Azofeifa, AG, Robalino, JA (2008) Measuring the effectiveness of protected area networks in reducing deforestation. Proceedings of the National Academy of Sciences 105: 16089-16084.

Armsworth, PR, Daily, GC, Kareiva, P, Sanchirico, JN (2006) Land market feedbacks can undermine biodiversity conservation. Proceedings of the National Academy of Sciences 103(14): 5403-5408.

Auffhammer, M, Bento, AM, Lowe, SE (2009) Measuring the effects of the Clean Air Act Amendments on ambient concentrations: The critical importance of a spatially disaggregated analysis. Journal of Environmental Economics and Management 58(1):15-26.

Banzhaf, HS, Walsh, RP (2008) Do people vote with their feet? An empirical test of Tiebout’s mechanism. American Economic Review 98(3): 843-863.

Barenklau, KA (2010) A latent class approach to modeling endogenous spatial sorting in zonal recreation demand models. Land Economics 86(4): 800–816.

Bateman, I, Yang, W, Boxall, P (2006) Geographical information systems (GIS) and spatial analysis in resource and environmental economics. In: Tietenberg, T and Folmer, H (eds) The international yearbook of environmental and resource economics 2006/2007: A survey of current issues. Edward Elgar, Northampton, MA, pp.43-92.

Bayer, P, Timmins, C (2005) On the equilibrium properties of locational sorting models. Journal of Urban Economics 57: 462-477.

Bishop, KC, Murphy, AD (2011) Estimating the willingness to pay to avoid violent crime: A dynamic approach. American Economic Review: Papers and Proceedings 101(3): 625-629.

Blumsack, S, Xu, J (2011) Spatial variation of emissions impacts due to renewable energy siting decisions in the Western U.S. under high-renewable penetration scenarios. Energy Policy 39(11): 6962-6971.

Cropper, ML, Oates, WE (1992) Environmental economics: A survey. Journal of Economic Literature 30(2): 675-740.

Currie, JE, Hanushek, A, Kahn, EM, Neidell, M, Rivkin, SG (2009) Does pollution increase school absences. Review of Economics and Statistics 91(4): 682–694.

Ferraro, PJ (2009) Counterfactual thinking and impact evaluation in environmental policy. New Directions for Evaluation: 75–84. doi: 10.1002/ev.297.

Finney, MM, Goetzke, F, Yoon, MJ (2011) Income sorting and the demand for clean air: Evidence from Southern California. Land Economics 87(1): 19-27.

Fujita, M, Krugman, P, Venables, AJ (1999) The spatial economy: Cities, regions, and international trade. MIT Press, Cambridge, MA.

Geoghegan, J, Gray, W (2005) Spatial environmental policy. In: Tietenberg, T and Folmer, H (eds) The international yearbook of environmental and resource economics 2005/2006: A survey of current issues. Edward Elgar Publishing, Northampton, MA, pp. 52 - 96.

Grafton, RQ, Kompas, T, Schneider, V (2005) The bioeconomics of marine reserves: A selected review with policy implications. Journal of Bioeconomics 7(2): 161-178.

Greenstone, M, Gayer, T (2009) Experiment and quasi-experimental valuation in environmental economics. Journal of Environmental Economics and Management 57(1): 21–44.

Honey-Roses, J, Baylis, K, and Ramirez, I (2011) Do our conservation programs work? A spatially explicit measure of avoided deforestation. Conservation Biology 25(5): 1032-1043.

Irwin, EG, Bell, KP, Bockstael, NE, Newburn, DA, Partridge, MD, Wu, J (2009) The economics of urban-rural space. Annual Review of Resource Economics 1: 435-459.

Joppa, L, Pfaff, A (2010) Reassessing the forest impacts of protection: The challenge of nonrandom location and a corrective method. Annals of the New York Academy of Sciences 1185: 135–149.

Kaiser, BA, Burnett, KM (2010) Spatial economic analysis of early detection and rapid response strategies for an invasive species. Resource and Energy Economics 32: 566–585.

Khandker, SJ, Koolwal, GB, Samand, HA (2010) Handbook on impact evaluation: Quantitative methods and practices. World Bank Publications, Washington.

Klaiber, HA, Phaneuf, DJ (2010) Valuing open space in a residential sorting model of the Twin Cities. Journal of Environmental Economics and Management 60(2): 57-77.

Olmstead, S (2010) The economics of water quality. Review of Environmental Economics and Policy 4(1): 44-62.

Palmquist, RB (2005) Property value models. Chapter 16 in: Handbook of Environmental Economics Volume 2. Elsevier, Amsterdam, pp 763-819.

Pattanayak, SK, Wunder, S, Ferraro, PJ (2010) Show me the money: Do payments supply environmental services in developing countries? Review of Environmental Economics and Policy 4(2): 254-274.

Polasky, S (2005) Strategies to conserve biodiversity. In: In: Tietenberg, T, Folmer, H (eds) The international yearbook of environmental and resource economics 2005/2006: A survey of current issues. Edward Elgar, Northampton, MA, pp. 157-184.

Reeson, AF, Rodriguez, LC, Whitten, SM, Williams, K, Nolles, K, Windle, J, Rolfe, J (2011) Adapting auctions for the provision of ecosystem services at the landscape scale. Ecological Economics 70 (2011): 1621–1627.

Smith, VK (2007) Reflections on the literature. Review of Environmental Economics and Policy 1(2): 300-318.

Tietenberg, T (1995) Tradeable permits for pollution control when emission location matters: What have we learned? Environmental and Resource Economics 5(2): 95-113.

Viscusi, K, Gayer, T (2005) Quantifying and valuing environmental health risks. Chapter 20 in: Handbook of Environmental Economics 2. Elsevier, Amsterdam., pp 1029-1103.