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Spatial Externalities in Agriculture: Empirical Analysis, Statistical Identification, and Policy Implications

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Abstract: Spatial externalities can affect economic welfare and landscape pattern by linking farm returns on adjoining parcels of land. While policy can be informed by research that documents spatial externalities, statistically quantifying the presence of externalities from landscape pattern is insufficient for policy guidance unless the underlying cause of the externality can be identified as positive or negative. This article provides a springboard for empirical research by examining the underlying structure, social-environmental interactions, and statistical identification strategies for the analysis and quantification of agricultural spatial externalities that are derived from observations of landscape change. The potential for original policy treatments of agricultural spatial externalities in development and environment outcomes are highlighted.

Keywords: Spatial externalities, agriculture, land use, Andes, organic.

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1. INTRODUCTION

Spatial externalities in agriculture have the potential to shape the land use decisions of farmers in developing and developed countries and in the process affect both local economic welfare and broader environmental sustainability (Parker and Munroe 2007; Belcher et al. 2005). Organic farming, cultivation of high-agrobiodiversity crops, co-existence of genetically and non-genetically modified crops, and management of invasive species in shifting cultivation systems offer examples of agricultural land uses where spatial externalities emanating from neighboring or proximate farms can shape farmer returns and hence land use decisions. Because agricultural landscapes typically involve multiple agents, transactions costs are likely to impede farmer-to-farmer coordination. Therefore, decentralized Coasian solutions may be hard to construct even to address the local externality concerns of farmer returns under alternate land use choices. To the extent that parcel-level land-use decisions aggregate to influence landscape-scale processes, spatial externalities can also influence public goods at the regional scale (e.g. sediment flows in watersheds) and the global scale (e.g. crop genetic diversity). Therefore, the potential lack of a decentralized Coasian solution to micro-scale spatial externalities may have local, regional, and global policy implications.

Effective policy requires an understanding of the types of externalities, the effects on land use decisions, and the impacts of these decisions on welfare in economic development and environmental outcomes. Policy instruments, in this context, can range from the work by local institutions and organizations to shape farmer interactions to the international agreements in support of economically and ecologically important activities through conventional policy instruments, such as subsidies or taxes. As illustrated below, the proper scope and combinations of policy depends on the particulars of the spatial externality and welfare concerns associated with the outcomes.

The primary goal of this article is to introduce and develop a new perspective into development and environment policy discussions and analyses: namely, the combined environmental and economic consequences of the spatial organization of agriculture that can result from a range of environmental and social externalities across parcels and farms. We examine these spatial dynamics of environment-agriculture ties through the combination of general discussion (Section 1), brief descriptions of four empirical cases, two from the Andean countries (Peru and Bolivia) and two from the U.S. (Section 2), a selective review of the relevant environmental, agricultural, and economic literatures on spatial interactions (Section 3), and the development of an analytical model (Section 4). The model is applied to the four case studies (Section 5) in order to show how the analytical structure provides strategies for identifying the presence and extent of these externalities. Section 6 considers the policy implications of spatial externalities in agriculture for both development and environment objectives. Section 7 summarizes our findings with an eye toward productive avenues for research on spatial externalities in agriculture.

The article is based on the idea of "spatial externalities" as a micro-level interaction that can result in the clustering of agricultural land use choices. The empirical case studies and the economic modeling serve to illustrate how environmental and social spatial externalities – either separately or in combination – can affect the return stream of farm income on adjoining individual parcels in either a positive or negative fashion and hence exert important influences on farmers' production choices. Environmental spatial externalities emerge because of the movements of such materials as water, soil, plant, pest, pollen, and contaminants between farms, and can vary in intensity and even direction depending on the biophysical landscape, local infrastructure, and production choices of neighboring farmers. For example, soil erosion is either a problem or a source of deposition for a downstream neighbor. Regardless, if environmental externalities from one farm create a sufficient increase or decrease in the returns to different crop choices or technological practices on neighboring farms, these externalities may then alter the choice of the neighbor, and thus could lead to the clustering of agricultural activities.

Social spatial externalities also give rise to changes in the return structure on neighboring farms, and result from processes related to changes in information flows, transaction costs, fixed costs, infrastructure, and so forth. A positive social-spatial externality that has been a major focus of recent work in technology adoption studies is the potential spillover from one farmer's learning about a new technology to his or her neighbors (e.g., Conley and Udry, 2005). Information is a positive social externality, in part because of its non-excludable feature, that could induce agricultural clustering with neighboring farmers adopting the same crop or technology based on a shared but not necessarily symmetric or coordinated learning process. An example of a negative social externality is the crop damage resulting from incursion of a neighbor's livestock in regions where grazing is common and property rights are not well defined or readily defended. Obviously, environmental and social externalities can be present together in some instances. In such cases they could exert positive or negative effects on returns to land uses depending on the environmental and social contexts.

Since our study is focused on spatial dynamics it is important to note at the outset that a variety of scales often come into play in both environmental spatial externalities as well as social spatial externalities. The model in this article focuses on the scale of the single field that is managed by an individual farm household (defined here as the "micro-scale"). Our examination treats the environmental and social externalities that spillover from the single field to adjoining parcels. As described below, this "micro-scale" of spatial externalities can create discernable clusters of certain field- and farm-types ("patches"). Worth noting also is that the micro-scale spatial externalities at the inter-field level that we focus on are also ones that can play a role in patterning over larger areas, such as community- and region-level effects. These larger area outcomes are many times of major interest for the combined reasons of environmental management and economic development impacts (Smithers et al., 2005).

Despite the recent advances in spatial economics (and spatial econometrics), very little attention has been given to the problem of quantifying the agricultural spatial externalities that might affect farmer land use decisions and resulting welfare impacts. Ultimately, the primary challenge to research and – if needed - policy is empirical analysis and statistical identification of the presence, extent, and direction of agricultural spatial externalities. Since information regarding return possibilities on individual parcels of land (in actual and counterfactual situations) is typically incomplete, we propose using spatial land use information as an alternative source for the analysis and quantification of spatial externalities. Geospatially referenced land use information is increasingly available in a variety of types and scales---we focus on GIS (Geographic Information Systems) data at the scale of individual farm parcels. However, using spatial land-use data for this purpose requires strategies for identifying environmental and social externalities with the help of structural models, temporal data, and empirical landscape-based experiments. Our hope is that this paper provides a springboard for empirical research on spatial externalities in different agricultural contexts by examining micro-level structure and strategies for empirical analysis and statistical identification.

2. FOUR CASES OF SPATIAL EXTERNALITIES AND ENVIRONMENTAL MANAGEMENT IN AGRICULTURE

For two cases from the Andes and two from the United States, this section offers an analysis of the basic logic of spatial externalities that appear to be key factors in farmers land use decisions and important environmental and economic outcomes. We postpone the challenge of identifying the extent and relative importance of the different types of externalities and the appropriate types of policy interventions for Sections 5 and 6.

(a) Externalities, Irrigation, and High-Biodiversity Andean Maize and Potatoes

Upstream-downstream effects of spatial externalities are common in irrigated agriculture of developing countries that has gained interest for a pair of reasons. First, many such irrigation systems belong to small- and meso-scale development efforts, whose environmental and social benefits (and lower costs) have led to the support of these systems as a growing alternative to, though only partial replacement of, big-dam projects (Ostrom et al., 1999; Siebert et al., 2005). Second, one of the environmental advantages of smaller-scale irrigation systems, in contrast to those associated with big-dam projects, is the continued cropping – known as *in situ* conservation – of biologically diverse food plants, such as the so-called creole types that represent local Farmer Varieties (FVs) of local food plants (Bellon et al. 2006; Riedsma et al., 2006; Zimmerer and Carter 2008). In Peru and Bolivia, Andean highland farmers cultivate numerous biological diverse types of Andean maize (Sanchez et al., 2006), several of which are still common in small- and medium-scale irrigation systems. These local maize types could contribute to sustainability by increasing agroecological resilience under increased market integration and a high degree of environmental uncertainty (Aggarwal, 2006; Brookfield, 2001)---the latter appears to be worsening as a consequence of climate change and presumed global warming. Since irrigation at the local and meso-scales is often only partially modernized and technified, the flows of water, as well as sediment transport, are only partly controlled. In such situations the problem of too much water or sediment can spill over into an adjacent field and create a negative spatial externality that may result in the downstream grower switching their land-use to activities that are potentially less valuable and less biologically diverse. While informal relationships and common-property management of irrigation infrastructure may exist, there are no formal legal restrictions regarding water or sediment spillover effects. On the other hand it may be that the clustering in cropping patterns by growers in adjacent upstream-downstream locations results in benefits that would be greater than the alternative case of the lack of clustering. These clustering outcomes could contain either high-agrobiodiversity or low-agrobiodiversity production.

In areas of high-agrobiodiversity Andean potatoes (similar to global biodiversity "hotspots"), which are mostly located in upper agricultural areas (above 3800 meters in areas from central Peru to central Bolivia), one of the main negative spatial externalities in land-use systems is the risk of livestock damage to crops. The latter is due to livestock, especially cattle and sheep (as well as alpacas and llamas), that graze on extensive rangelands---often with increasing herd sizes in conjunction with cropping decline and the disintensification of agro-pastoral coordination (Brush et al., 1992; Mayer 2002; Zimmerer 2002, 2004). One main reason for the generally high level of the risk of livestock (and wildlife) damage is that these high-agrobiodiversity fields are often located out of the way and out of sight of homes and settled areas. While informal remedies and common property regulations may exist, there is often the lack of readily accessible or formal legal methods for recovering damages from livestock. There could also be positive social spatial externalities associated with coordinated labor activities on remote fields, or in livestock supervision. Such coordination may involve field-level cropping decisions as well as multi-field systems (tens to hundreds) of common field agriculture or sectoral fallow (Zimmerer 2002). Understanding more about the interplay of externalities in these contexts is essential to understanding the microeconomic logic of environmental and economic outcomes in high-agrobiodiversity *in situ* conservation.

(b) Externalities, Conventional- Organic, and GM - Non-GM Relationships

Pesticide and pollen drift are recent and well known examples of neighboring land-use conflict in agriculture in the United States. Both types of drift are relevant to organic farmers that locate downwind from conventional farmers, because pesticides and GM pollen can contaminate organic produce, and thereby lower market returns associated with "organic" status. Legally, there is no formal protection afforded to organic farms from drift in the U.S. (Conner, 2003), while property rights are more contested elsewhere (e.g., Canada and Europe). Likewise, farmers choosing to produce corn or soybeans using non-GM varieties (potentially as part of a marketing strategy for securing a higher return) can be negatively affected by pollen drift from proximate GM producers if their product is found to contain GM residues or pollen. The legal restrictions regarding drift from GM crops generally vary across regions, with Europe having perhaps the most developed and variegated rules related to GM, non-GM coexistence and the United States having relatively little protection of non-GM producers (Beckmann et al., 2006). Both pesticide and pollen drift are negative, one-directional environmental externalities. And, while the focus in this paper is on organic versus conventional and GM versus non-GM farming strategies, the issue of pesticide drift is relevant to other cultivation choices. For example, in Northern California, rice farmers have been known to apply broad-spectrum phenoxy herbicides to their land. However, cotton is extremely sensitive to phenoxies and the application of phenoxy herbicide to rice fields led to a string of lawsuits from neighboring cotton growers in the late 1990s (Parker, 2000).

A fundamental difference between the organic-conventional and GM vs. Non-GM cases is that in the former the "new" production technology is the receiver of the negative externality while in the latter it is the source of the negative externality. Put differently, farmers choosing to use organic methods may have to choose their locale carefully to avoid or reduce the potential for negative externalities from neighboring conventional farmers, while farmers choosing to use GM crops do not face that issue at all. Instead, farmers that cultivate non-GM varieties may find the recent GM adoption of neighboring farmers threatening their farm strategy, which could prompt either a switch in strategy or the need to move. Negative externalities may be part of the story when it comes to the clustering of organic farms or GM crop production. Clustering could also be driven by positive social externalities associated with new technology adoption or other aspects of the operation (harvest labor recruitment, marketing and distribution cost reduction, and the like). We explore the implications of positive and negative externalities later in the paper.

3. RESEARCH ON SPATIAL INTERACTIONS AND AGROENVIRONMENTAL CLUSTERING

Externalities give rise to potentially inefficient private decision-making in the presence of significant transactions costs and potential free-riding. Until recently, studies of agricultural externalities have been focused almost entirely on non-point source pollution (usually soil erosion and associated nutrient flows), which is an environmental externality derived from the effect of individual farmer decisions on society (e.g. see Segerson 1988). However, spatial externalities operating between agricultural users have a different microeconomic structure than the case of non-point source pollution because of the externality effects of one parcel's land use on the *private* returns of neighboring land. The literature on spatial relationships within agriculture is primarily focused on testing econometric and statistical techniques to identify spatial correlation among agricultural producers, with little attention to the microeconomic structure governing spatial interactions within agriculture.[1] One recent theoretical exploration that is quite comparable to the modeling approach developed below is that of Beckmann and Wesseler (2006, 2007), as applied to the "co-existence" of transgenic and non-transgenic crops in Europe. They explore analytically (not empirically) how the *ex ante* regulations and *ex post* liability implications of "polluting" non-transgenic producers are likely to shape the transgenic adoption choices of European farmers.

Theoretical work in the forestry literature has addressed spatial externalities between stands (Swallow and Wear 1993) and spatial interactions within a single manager's landholdings (Albers 1996).[2] Likewise, a portion of the literature on the spatial aspects of Land Use/Cover Change (LUCC) has addressed the microeconomic structure of spatial interactions between land uses. Most prominent is the research documenting the positive open-space benefit generated by farmland and capitalized into adjacent urban lands (Irwin and Bockstael, 2002; Caruso et al., 2007). Irwin and Bockstael (2002) contend that the primary challenge of such analyses is the empirical identification of spatial externalities apart from unobserved landscape attributes, both of which may yield observationally equivalent landscape outcomes. For example, two adjacent parcels of land may convert to urban development because of spatial externalities between them, or because both parcels are located near a scenic hillside which provides amenities to potential residents. If the location of the hillside is unobserved by the researcher, it is not possible to identify the cause of the land-use decisions as arising from spatial externalities or from the hillside.[3] Irwin and Bockstael (2002) are able to identify a negative spatial externality associated with urban development which they claim is partly responsible for the phenomenon of "urban sprawl." By contrast, interactions and spatial interdependencies among the field units *within* agricultural areas---related to spatial externalities---have not been estimated thus far in the literature, nor have they been derived from a structural model of agricultural spatial externalities. A notable exception is the recent paper by Parker and Munroe (2007) that documents the presence of spatial externalities relevant to organic agriculture in California, although it does not identify the directionality (positive/negative) of these effects.[4]

Many studies belonging to the LUCC literature are designed to estimate the influence of various factors that may contribute to environmental outcomes (including the clustering of land use types), although most studies are not specifically focused on interactions *within* agriculture.[5] The factors commonly included in these LUCC models of spatial land use include distance effects (e.g., along transportation routes); population parameters (within rural households and locales); market integration (both products and labor); household portfolio effects (such as demography, labor availability, migration earnings, and access to machinery and other technology); commodity prices (crops, forest products), and environmental attributes. These LUCC studies typically employ large amounts of spatial data in Geographic Information Systems (GIS), and use a variety of econometric and statistical techniques to quantify relationships. While the LUCC literature is able to quantify the influence of many different variables on the spatial pattern of land use, the reduced-form nature of most of these models make it difficult to distinguish between correlation and causation. Understanding the causal relationships between individual land-use choices and landscape outcomes requires a structural economic framework to explain an individual's land-use decision (Irwin and Geoghegan, 2001).

A closely related literature that examines the structure of interactions among proximate producers is the social learning models of technology adoption (Foster and Rosenzweig, 1995; Conley and Udry, 2005). Researchers strive to identify the presence of social learning in the diffusion of agricultural technologies based on information (or assumptions) on the social "neighborhood" of farmers from which each producer might learn. Like other papers in the social effects literature (see Manski, 1995; Brock and Durlauf, 2001 for comprehensive reviews), the core challenge that demands both a careful structural model and econometric specification design is finding ways to effectively separate out learning processes from other potential explanations for why behavior might be clustered, such as similar growing conditions, access to key inputs, and endogenous groupings that do not necessarily indicate "learning". Specifically, the structure of these models focuses on identifying the relevant information neighborhood for farmers. This is typically constructed from social data related to whom they know and watch, rather than spatial data related to who are their physical location-based neighbors. In that sense, our focus below on social spatial externalities intersects with those papers, but it is also distinct because of our emphasis on the spatial dimension of these externalities.

Agroenvironmental and land use clustering is also often seen through the perspective of environmental management that is associated with common property resources (Agrawal and Chhatre, 2006; Berkes 2004; Ostrom et al., 1999; St. Martin, 2006). Here, the present research must be seen as contributing an examination of one of the main factors that leads to informal land- and resource-use coordination, namely the spatial externalities of agricultural management at the field level.

4. STATISTICAL IDENTIFICATION AND POLICY IMPLICATIONS OF SPATIAL EXTERNALITIES: A MODEL

The private allocation of land use will not necessarily maximize economic welfare—defined here as the total value of land—because i) spatial externalities that impact landowners' private return streams may be present, and ii) environmental quality associated with landscape pattern has public good characteristics that are typically ignored in private land allocation. The fact that most agricultural landscapes comprise multiple agents implies that decentralized Coasian bargaining approaches to externality problems may be difficult to construct. Since privately allocated landscape patterns depend on the aforementioned spatial externalities and do not depend on the public good values of environmental quality, we focus on spatial externalities rather than public good values.

Designing land-use policies to enhance economic welfare is only possible to the extent that spatial externalities can be quantified. If researchers have complete information on parcel-level economic returns to various land-uses, quantifying the presence of spatial externalities is a simple accounting exercise. Unfortunately, parcel-level net returns to alternative land uses are often not observable by researchers, making it difficult to document the effects of agricultural spatial externalities. Fortunately, recent advances in the availability of spatial land-use data from satellite imagery and aerial photography give rise to the possibility of inferring the presence of spatial externalities through the observation of landscape change. In this section we develop a simple model of land use to present conditions under which spatial externalities can be empirically identified by observing landscape outcomes. In particular, our model yields insights into potential empirical designs to document the presence of spatial externalities within agriculture.

Identifying the presence of a spatial externality is necessary but not sufficient to prescribe a welfare-enhancing policy. The ultimate design of such policies crucially depends on whether the externalities are positive or negative. For example, a negative externality associated with a specific land use choice suggests a policy to discourage that choice, while a positive externality suggests a policy to encourage the choice. As discussed below, negative or positive spatial externalities can lead to observationally equivalent landscape outcomes, making empirical documentation of the sign of externalities challenging. We illustrate the complexities of prescribing welfare-enhancing policies for spatial externalities by describing scenarios where mis-identifying the spatial externality results in both efficient and inefficient policy mechanisms.

(a) Model setup and the value to clustering

In this section we develop a simple model of one-directional spatial externalities—or the situation where the actions of one landowner have an impact on the land-use returns to another landowner, but not vice versa.[6] Consider a simple landscape with 2 profit-maximizing landowners (1 and 2) who share a border. For simplicity, we assume a frictionless world with no information or market imperfections other than the spatial externalities, though we highlight some real-world imperfections in section 6. We assume the productive and managerial characteristics of each parcel and landowner can be represented by a single index, q, which henceforth will be referred to as land quality. Land quality is assumed to be homogeneous *within* a parcel and heterogeneous *across* parcels. Heterogeneity in land quality is what gives rise to multiple uses coinciding on a single landscape.[7] We assume that there are two distinct agricultural uses to which each parcel can be devoted: A and B. For landowner 1, the net returns to uses A and B are defined as $R_1^A = f(q_1)$ and $R_1^B = g(q_1)$. For landowner 2, the net returns to uses A and B are affected by the land-use decision of landowner 1 and defined as $R_2^{A,u_1} = f(q_2 \mid u_1)$ and $R_2^{B,u_1} = g(q_2 \mid u_1)$ where u_1 indicates the land-use of landowner 1, and is equal to A or B.[8] The net return functions to both landowners are increasing and strictly concave in land quality.

Quantification of spatial externalities requires knowledge of the net returns to various land uses in-lieu-of the effects from neighboring land uses. Define R_2^A and R_2^B as the net returns to landowner 2 from use A and B for the situation where the landowner has no neighboring agricultural uses—and hence, no externalities affecting their net returns. These return functions R_2^A and R_2^B are henceforth referred to as baseline returns. Figure 1 provides an example of how baseline returns could be inferred. Suppose landowner 2's net returns are influenced by the decisions of landowner 1, while landowner 3 has net returns that are independent of the decisions of landowner 1. For landowner 3, the net returns to uses A and B are defined as $R_3^A = f(q_3)$ and $R_3^B = g(q_3)$. If land quality for landowner 3 is identical to landowner 2 (q_3=q_2), then R_3^A and R_3^B provide information as to the magnitude of R_2^A and R_2^B.

[INSERT FIGURE 1 HERE]

Suppose all parcel-specific return functions are known by researchers. In this context, the value of the spatial externality can be described by $R_2^{u_2,u_1} - R_2^{u_2}$, where u_i is equal to A or B. For example, a positive spatial externality from like uses would be observed if $R_2^{A,A} - R_2^A$ >0. Likewise, a negative spatial externality associated with different neighboring land uses would be observed if $R_2^{A,B} - R_2^A < 0$.

In this study, we assume that landowner 2's net returns to use A or B are lower if their land use choice is different than landowner 1: $R_2^{A,A} > R_2^{A,B}$ and $R_2^{B,B} > R_2^{B,A}$. Therefore, we confine our interest to two types of externalities relevant for agriculture: i) positive spatial externalities associated with identical neighboring land uses, and ii) negative spatial externalities associated with different neighboring land uses. More specifically, we assume that there is a non-negative value to the spatial clustering of identical land uses, although the cause of this value could be either a positive or negative spatial externality.

(b) Identification with partial information on land-use returns

Since parcel-level returns are difficult to observe in practice, an alternative approach to empirically identifying spatial externalities is through the observation of landscape pattern. Suppose the researcher cannot calculate the magnitude of baseline returns, but can infer the sign of $R_2^B - R_2^A$ as positive. For example, in the context of figure 1, $R_2^B - R_2^A > 0$ could be inferred by observing that parcel 3 is in use B, as long as $q_3 = q_2$. Information on the sign of $R_2^B - R_2^A$ can be combined with spatial information on landscape configuration to infer the presence of spatial externalities. In our simple model of two neighboring landowners, there are four potential landscape configurations (table 1). Observation of a particular landscape configuration allows inference as to which use is more profitable, which we term the equilibrium condition in table 1. However, identifying the presence of spatial externalities requires us to identify the sign of $R_2^{u_2,u_1} - R_2^{u_2}$, which is only possible when combined with information on the sign of $R_2^B - R_2^A$.

[INSERT TABLE 1 HERE]

Suppose the sign of $R_2^B - R_2^A$ is known to be positive, such that use B is the preferred baseline use. In this case, the presence of a spatial externality can be identified by observing the clustered (A, A) landscape configuration, since profit-maximizing landowner 2 would not place land into use A in the baseline. Since B is the preferred baseline use, observing the clustered (A, A) configuration suggests the presence of either a positive spatial externality associated with identical neighboring uses, or a negative spatial externality associated with different neighboring uses. A necessary condition for the clustered (A, A) configuration is

$(R_2^{A,A} - R_2^A) + (R_2^B - R_2^{B,A}) > 0$, which is consistent with a combination of positive and negative spatial externalities, or one externality and not the other. The clustered (A, A) configuration could be driven by only positive or only negative externalities if the magnitude of the externality exceeds $R_2^B - R_2^A$.[9] Therefore, while the clustered (A, A) configuration is sufficient to infer a positive value to clustering, it is not sufficient to infer the causality of such value as arising from a positive or negative spatial externality.

Now consider the observation of the other landscape configurations when B is the preferred baseline use. We can rule out the fragmented (B, A) configuration since we are assuming only non-negative values to clustering identical land uses. Observation of either the fragmented (A, B) or clustered (B, B) landscape configurations does not allow any inference regarding the spatial externality since landowner 2 would have placed their parcel in use B in the baseline.[10] Therefore, inference of spatial externalities when B is the preferred baseline use is only possible when the clustered (A, A) configuration is observed. Using the same logic, if A is the preferred baseline use ($R_2^B - R_2^A < 0$), the presence of a spatial externality could be identified by observation of the clustering (B, B) configuration, while either the fragmented (B, A) or the clustered (A, A) configurations do not allow inference, and the fragmented (A, B) configuration is inconsistent with our assumption about a non-negative value to clustering.

(c) *Identification with no information on land-use returns*

Suppose there is no way for the researcher to infer the sign of $R_2^B - R_2^A$. In this case, the preferred baseline use can not be discerned, and any inference made about the spatial externality is not possible in the absence of a natural experiment or exogenous shock which alters the configuration of the landscape. For illustration purposes, consider the clustering (A, A) configuration. Now suppose an exogenous shock strikes the landscape such that it converts to the fragmented (A, B) configuration, moving landowner 2 to land-use choice B. Such a shock allows us to identify the presence of a spatial externality if the shock can be interpreted as negating the value to clustering like land-uses. This interpretation is consistent with a shock that a) eliminated the positive spatial externality associated with similar land uses, b) eliminated the negative spatial externality associated with different land uses, or c) eliminated some combination of the two externalities. Experimental design could be used to identify the specific externality, and we provide examples below.

If the shock results in the clustered (B, B) configuration, it will generally not be possible to identify the externality because the spatial pattern of the landscape has not changed. However, inference of spatial externalities can also be achieved if there exists a shock that converts a landscape from the fragmented (A, B) to the clustered (A, A) configuration, the fragmented (B, A) to the clustered (B, B) configuration, or from the clustered (B, B) to the fragmented (B, A) configuration. All other conversions provide no information on spatial externalities because the parcel which is affected by the externality (parcel 2) does not change uses. Likewise, conversions between the fragmented configurations are inconsistent with a positive value to clustering. So, *a necessary condition for identification is a natural experiment which alters the use of the parcel affected by the externality, and alters the spatial configuration of the landscape*. Table 2 summarizes the conditions under which spatial externalities can be inferred from agricultural land-use data. As summarized in table 2, spatial data for one point in time can be used to identify spatial externalities if partial information on baseline returns is available. If baseline returns information is unavailable, spatial externalities can only be identified with spatial data for multiple points in time with landscape changes.

[INSERT TABLE 2 HERE]

(d) Welfare-enhancing policies

A welfare-enhancing policy mechanism may reward some land-uses, penalize some land-uses, or consist of a mix of rewards and penalties. Getting the policy mix right is only possible if the various spatial externalities at work can be empirically identified.[11] Thus, next we consider the design of welfare-enhancing economic incentives aimed at altering landscape configurations and internalizing spatial externalities. While we focus on policies to alter landscape configuration, it should be noted that the optimal policy only coincides with changing land use if the total value of land can be raised by altering landscape pattern. We show that wrongly identifying the cause of the value to clustering can result in policies which are not welfare enhancing, and may in fact be welfare decreasing.

First, consider the situation where the same efficient landscape can be achieved regardless of whether the value to clustering is correctly identified as arising from positive or negative externalities. For illustration purposes, suppose B is the preferred baseline use ($R_2^B - R_2^A$>0), clustered (A, A) is the observed configuration ($R_2^{B,A} - R_2^{A,A}$<0), and the maximum welfare possible from the landscape is derived from the clustered (B, B) configuration ($R_1^B + R_2^{B,B}$). Therefore, a policy which causes landowner 1 to switch to B would maximize welfare because landowner 2 would also switch to use B to maximize profits. If the externality is believed to be a negative externality arising from different neighboring uses, a tax on landowner 1 equal to the externality ($R_2^{B,A} - R_2^B$) would induce a switch to use B—and hence, a switch from the clustered (A, A) to the clustered (B, B) configuration.[12] Likewise, if the externality is believed to be positive and arising from similar neighboring uses, subsidizing landowner 1's decision to use B by $R_2^{B,B} - R_2^B$ would induce them to switch to use B. So, the efficiency consequences of either policy are the same, although the distributional consequences are clearly different.

Second, consider the situation where mis-identifying the cause of the value to clustering suggests an inefficient policy mechanism. As above, suppose B is the preferred baseline use to parcel 2, but that clustered (A, A) is the observed configuration. Now, however, suppose that the cause of the value to clustering is a negative externality from opposing land uses. Further, suppose that the negative externality from landowner 1's choice of use A could be eliminated at cost c without requiring a switch to use B. Therefore, if $R_1^A - c + R_2^B$ is the maximum possible value associated with a landscape configuration, a policy which eliminates the negative externality at cost c would maximize economic welfare.[13] However, if the researcher interprets the value to clustering as arising from a positive spatial externality, then a policy which encourages either of the clustered landscape configurations would be proposed, and welfare-maximization would not be achieved.

5. EMPIRICAL ANALYSIS OF SPATIAL EXTERNALITIES: CASE STUDIES

Sorting out which spatial externality—if any—is present requires careful experimental design and is necessary for the prescription of welfare-enhancing policies. Here we propose empirical experiments aimed at identifying spatial externalities associated with the four examples from section 2. Each example uses the model in section 4 as basis for an identification strategy. In practice, each identification strategy requires empirical control of all non-externality components of the return functions.

(a) Upstream-downstream landowners and irrigation projects

In many Andean countries, the movement of water and sediment transport occurs from upstream to downstream parcels and thus creates a one-directional spatial externality (introduced in Section 2a above). In this case, a downstream landowner's returns to specific crop choices depend on an upstream owner's irrigation practices, and we might expect to see clustered land uses in the absence of policy intervention. There are two potential empirical designs that could identify a spatial externality in this context. First, suppose we can get information on baseline returns by observing a landscape similar to figure 1. As discussed earlier, if parcel 1's land use choice impacts parcel 2 but not parcel 3, then baseline information on parcel 2's returns could be inferred by observing parcel 3's land use choice. If parcels 2 and 3 are in different uses, this observation could be used to identify the externality. Second, suppose there is no baseline information and we need to identify a landscape-converting shock. One potential shock is an irrigation project exogenously introduced by a development organization and unanticipated by resident landowners. If the irrigation project allows the downstream owner to control the timing of her irrigation independent of the upstream owner, *ex-post* observation of a change in landscape configuration from clustering to fragmentation—where the downstream parcel switches use—could be used to identify the presence of the spatial externality.

Now consider the interpretation of whether the externality is positive or negative when partial information on baseline returns can be discerned by observing the land use of parcel 3. We can infer the presence of a negative spatial externality if parcel 2's use is identical to parcel 1's, and different from parcel 3. This interpretation is possible because any positive spatial externality from neighboring landowner 1 to landowner 2 could also induce landowner 3 to choose use B. Therefore, the likely explanation for the clustering of landowners 1 and 2 would be a negative spatial externality from parcel 1. If there is no information on baseline returns, interpreting the sign of the *ex-ante* externality can be accomplished in a similar way. If an irrigation project causes the landscape to switch from clustering to fragmented, then one can infer that the original clustered landscape resulted more from the negative externality than the positive externality, because the irrigation project should only serve to reduce the negative externality. So, this example provides a clean approach to both identifying the presence and the sign of any potential upstream-downstream externalities.

(b) Organic and Conventional Farming

We expect clustering of organic and conventional farms, characterized by pesticide drift from conventional farming—a one-directional externality—and potential knowledge spillovers between organic farms—a two-directional externality. One way to setup an experiment of the organic-conventional farming relationship is to recognize that conventional farms have historically been the first-movers on most landscapes, while organic farms are typically faced with a choice of where to locate on a landscape of conventional farms. Since the clustering of the first organic farms on the landscape may be affected by high transaction costs associated with coordination, the first organic farms have an incentive to locate in areas where they are naturally isolated from pesticide drift and other environmental externalities that might affect their certification process—parcel 1 in Figure 2. Subsequent organic farms would then have incentive to locate on parcels 2 or 3 to take advantage of positive spillovers from organic farms and fewer conventional neighbors. Therefore, observation of landscape change of this type could be used to infer the presence of spatial externalities associated with conventional farms, provided that prices and soil quality can be adequately controlled for in the analysis.

[INSERT FIGURE 2 HERE]

Now consider the interpretation of whether the externality is positive or negative during the landscape conversions described above. If the first organic farms to populate the landscape locate in the heads of remote valleys (parcel 1 in figure 2), then this is clear evidence of negative spatial externalities associated with pesticide drift from conventional farms. If subsequent organic farms cluster near the first organic farms (parcels 2 and 3 in figure 2), this is evidence of either positive or negative spatial externalities, but not evidence of one and not the other. For example, if parcel 1 was the first organic farm, the next organic farm could choose to locate on parcel 2 to either avoid pesticide drift or to take advantage of knowledge spillovers from parcel 1. An observation that organic farms are clustered—without knowledge of the dynamic process used to arrive at that clustering—is insufficient to identify the sign of potential spatial externalities. The key to identifying pesticide drift or other contaminants as a significant spatial externality using landscape data is to observe the first organic farms locating in pockets isolated from conventional growers.

(c) Clustering of biodiverse Andean potatoes in relation to livestock management

Andean potato production may be affected by livestock from adjoining areas—a negative externality—and management coordination from adjacent remote potato fields—a positive externality. A potential empirical framework to analyze such externalities would be cross-sectional or panel analysis of a large landscape with significant variation in the locations at which potatoes and livestock are found. For example, a spatial externalities story would be consistent with the observation of potato production clustered together, livestock production clustered together, but little overlap between those competing land uses. More specifically, we might hypothesize a livestock to vulnerable land area threshold (e.g. percentage of a region in livestock production) at which we no longer observe potato production in conjunction with livestock production. An analysis of this type could be accomplished with satellite / aerial photography of a large region which could discern potatoes from livestock. Ideally, a panel data set could be constructed where any dynamic process of land conversion could be analyzed and a livestock threshold identified.

Interpretation of the sign of spatial externalities associated with potato and livestock production is not straightforward. If the cross-sectional—or panel—analysis only yields evidence that potato production is clustered, this result could be due to either positive or negative spatial externalities and is not sufficient to identify one or the other. However, if a livestock threshold can be identified, this could be used as evidence regarding the presence of negative livestock externalities. One key to using this result as evidence of the sign of spatial externalities will be the ability to control for the possibility of increasing returns to scale from the positive spatial externality (e.g. the reduced fixed costs of transporting labor to remote fields)..

(d) GMO and Non-GMO Farms

Pollen drift from GMO to non-GMO fields represents a negative environmental externality, while technology adoption associated with neighboring GMO fields represents a positive externality. An experimental design of the GMO / Non-GMO relationship recognizes the symmetry with the organic / conventional experiment described above. Namely, non-GMO farms have historically been the first-movers, populating the landscape well before GMO farms, while GMO farms came later by selecting where to locate on a landscape of non-GMO farms.

Since the clustering of the first GMO farms on the landscape may be affected by high transactions costs associated with coordination, the first GMO farms are likely to locate randomly on the landscape. This is opposite to the organic farmer's incentive to locate in areas isolated from pesticide drift. Subsequent GMO farms may then have incentive to locate adjacent to the first GMO farms to take advantage of knowledge spillovers associated with technology adoption (a positive spatial externality), while those non-GMO farms that were adjacent to the initial GMO farms have an incentive to move or adopt GMO practices to avoid pollen drift (a negative spatial externality). Therefore, observation of landscape conversion of this type could be used to infer the presence of spatial externalities associated with GMO farms. However, evidence of the first GMO farms locating randomly on the landscape is not suggestive of any particular spatial externality. Further, evidence of subsequent GMO farms clustering near the original GMO farms provides evidence of spatial externalities, but these externalities could be in the form of pollen drift (a negative externality) or technology adoption spillovers (a positive externality).

6. DEVELOPMENT AND ENVIRONMENT POLICY ISSUES ASSOCIATED WITH SPATIAL EXTERNALITIES IN AGRICULTURE

The previous sections explored analytical and empirical strategies for identifying spatial externalities in agriculture, both environmental and social, in order to help inform policy making that might improve development and sustainability outcomes. In this section, we unpack the policy challenge more carefully in order to inform future research and analysis that seeks to develop specific policy recommendations.

(a) Policy design and microeconomic foundations

Typically, resolving externalities, once they are properly identified, is a relatively simple task in economic analysis. Policy makers can use either a subsidy or a tax (the Pigouvian solution) to internalize the externality in the private decision-maker's problem and bring the private and social benefit-cost measures into alignment. Drawing from the Andean irrigated agriculture example, if the upstream landowner's decision to plant alfalfa is reducing the joint returns to land by compelling the downstream landowner(s) to also grow alfalfa rather than maize, then either a subsidy or a tax could accomplish a change in the upstream landowners land use and improve local economic returns.

Two features of spatial externalities in agriculture complicate the policy analysis considerably. First, heterogeneity among the farmers in terms of wealth, access to markets and technology, knowledge, and/or managerial skill could provide a basis for differences in return functions that in turn shape patterns of land use. As a result, resolving the spatial externality among local economic agents might be more complicated than it seems at first glance, because the pattern of returns resulting from different land uses could stem from constraints land users face on the best potential use. In the case of Andean irrigated agriculture, it is possible that downstream farmers would also enjoy higher returns from alfalfa if their wealth levels were higher or credit markets worked well, so they could afford to own and husband livestock. In that case, the best development policy (in terms of local economic returns) might be one that allowed the clustering of activity to center on alfalfa and livestock cultivation rather than Andean maize. The proper subsidy or policy intervention would be one that allowed the downstream owner to fully exploit the potential value of land in alfalfa production.

The second complicating feature is that the environmental benefits and costs associated with spatial externalities in agriculture generally will be experienced at a social level, which is well beyond the calculus of the local land users. Returning again to the Andean highlands case, the benefits of maintaining agrobiodiversity in maize production are generally geographically diffuse. While some of the benefits in terms of improving varieties and reducing risk are realized at a regional and national level, agrobiodiversity (like all forms of biodiversity) is inherently a global public good (Barrett et al., 2001; Cooper et al. 2005). Furthermore, neither the regional nor the national benefit streams, or the global ones, are likely to be captured through market mechanisms by local land owners. Yet, the potential costs of conservation associated with growing maize rather than cultivating alfalfa and livestock (if that latter combination was the optimal unconstrained private use) are experienced directly by the land users unless there is some sort of public or social transfer mechanism (policy or program) that reduces the burden. Thus, if the best land use outcome from a global perspective for the Andean highlands (taking into account both the local economic returns and the global benefits of agrobiodiverse maize production) is to have the land in agrobiodiverse maize, then an integrated development and environment policy would subsidize the cultivation of agrobiodiverse maize sufficiently to compensate for the foregone returns associated with the joint alfalfa-livestock system.

Taking stock of the policy implications of spatial externalities in agriculture, heterogeneity in return structure, and the mismatch of environmental benefits and costs associated with alternate land uses, we identified three distinctive policy interventions, each quite different in its orientation. The first one involved incentives to lead the upstream landowner to shift to maize cultivation in order to achieve the higher joint return outcome. The second helped the downstream landowner to overcome the constraint that limited the productivity of land in alfalfa to achieve an even higher joint return. The third compensated both upstream and downstream landowners for contributing to agrobiodiversity through maize production to compensate for the losses they would otherwise experience relative to the higher return combination of alfalfa and livestock. And, these different policy interventions hinged on one set of assumptions about the structure of returns and the benefits associated with agrobiodiversity from this particular locale. Other assumptions would generate different scenarios of externality effects and thus different sorts of policy implications and recommendations.

Explicit attention to spatial externalities in agriculture holds the potential to deepen our understanding of development and environment outcomes and hence ways in which policy interventions or institutional initiatives might be made more effective. Consider the likely possibility that some, but not all, parcels respond to a policy by converting their land to a different use. The presence of spatial externalities between parcels suggests that policy-induced change on parcel A may yield cascading effects whereby parcel A's neighbors alter their land use simply because A's conversion alters its production of spatial externalities. For example, suppose a policy to increase access to credit results in upstream maize growers switching uses to alfalfa. The presence of spatial externalities could then result in downstream neighbors switching to alfalfa as well – an indirect and potentially unintended consequence of the credit policy. Likewise, suppose an environmental organization wishes to encourage the production of biodiverse maize by offering payments to landowners to convert production from alfalfa to maize. If the payments were targeted to upstream landowners rather than uniformly offered across the landscape, the reduction of negative upstream externalities from alfalfa could result in downstream landowners switching to maize – a positive indirect consequence that has clear efficiency implications.

(b) Institutions at the local, regional, and global levels

The choice of policy-making and implementing institutions ranges widely in the development and environmental issues associated with spatial externalities. Appropriate institutions range from local to national and global organizations. Consider first the case of a positive spatial externality in agriculture that has local economic effects and possibly local environmental ones, but not discernable region- or global-level effects. In this instance, the main focus of policy or institutional interventions would be to encourage farmer-to-farmer interactions in order to “internalize” the externality through cooperation that could be facilitated in diverse ways, both formal and informal. Local-level extension personnel of government agencies, such as the important though still small number of farm agents that are supportive of organic farming (e.g., extension agents in western Wisconsin which has an actively growing organic-dairy sector), could aid in addressing externalities in this way. Local institutional innovations, such as production cooperatives or resource-users’ groups, also offer the capacity to design and implement policies, as well as information exchange and informal dispute resolution, which could effectively address spatial externalities.[14] Resource-users’ groups are common, for example, in many sites of irrigated agriculture, including the small- and meso-scale systems of irrigation in Andean countries, mentioned above, that are characterized by the cultivation of high-agrobiodiversity maize. Drawing on this example, the irrigation-users’ groups illustrate a potentially important local-level institution---whose membership includes the irrigators who own or have access otherwise to adjacent fields along canals---that can inform and aid in the determination and implementation of the policies needed to address spatial externalities.

National and region-level institutions (both regions within countries and multi-country regions) are important to the policy issues regarding such spatial externalities in development and environment as each of the agricultural landscape issues described above (see Section II). These institutions are most able to develop comparative assessments that are adequately fine-grain yet broad enough to address the *heterogeneity* that is characteristic of and crucial to guiding policy-analysis and policy-making. As described above (Part A), such heterogeneity includes the dimension of microeconomic structures and processes such as field-level return functions, household-level portfolio assets, and the role of risk management in crop choice and farm management. A national or region-level growers’ cooperative, such as the Organic Valley cooperative (based in western Wisconsin and currently operating in approximately 25 states within the USA), is therefore potentially useful in policy instruments, since its members represent a range of farm types within organic dairy-farming that nonetheless face certain similar "edge effects" (both potentially positive and negative) due to spatial externalities. Another dimension of heterogeneity involves the characterization of variation in the biophysical environment. High-biodiversity production Andean maize (versus low-biodiversity farming types), mentioned above, also is useful here as an example since policies on spatial externalities would need to account for the environmental properties of this biodiversity. Such information would include the level and uniqueness of biodiversity found within and among units of agricultural landscapes. Genetic variation is a component of this environmental heterogeneity whose analysis (e.g., maize genomics) and spatial-environmental properties (e.g., landscape or geo-genetics) are increasingly well-known and potentially well-suited to externality policies. With regard to both socioeconomic and environmental heterogeneity, as described above, we note that many national- and region-level institutions, such as government agencies, NGOs, or international agencies with emphasis on Andean or Latin American mountain agriculture, would serve as capable contributors regarding externality policies.[15]

Global institutions are also important to the public-goods character of issues, and hence as policy institutions, involving the spatial externalities of development-environment issues. Consider once again our example of agrobiodiverse maize where the global benefits of agrobiodiverse maize production are sufficiently large to warrant a subsidy to local producers to switch them out of the more profitable alfalfa-livestock combination that would otherwise be the optimal development policy. In that instance, the process of policy formulation and implementation would reach from local farmer organizations to national governments to global governance bodies, and back via the same institutions, in order to achieve the welfare-maximizing outcome. The policy intervention might still be simple, a subsidy to farmers growing agrobiodiverse maize, but the coordination required to achieve that goal would require the funding and support of appropriate policy institutions at the national-regional level as well as at the global level. Such global institutions that could contribute to policy on maize agrobiodiversity range from lending agencies with environmental mandates (World Bank, and the Global Environmental Facility, GEF, that is Bank-funded) to the global agricultural centers with development-environment mandates, which in the Andean countries would include CIAT (International Center for Tropical Agriculture, in Cali, Colombia) and CIP (International Potato Center, in Lima, Peru). Consider briefly also that global institutions with policy interests and influence have become increasingly active in the other cases of externalities described above (Section II). The International Federation of Organic Agriculture Movements (IFOAM), for example, offers a global institution with expanding policy-related activities. Without a multi-scale policy foundation that ranges from the local institutions and farmers' field-level logic of the spatial externalities under heterogeneous production conditions to the level of the global benefits of agrobiodiverse maize production, the policy is likely to be ill-formed.

7. CONCLUSION

This article aims to shed light on the challenge of identifying spatial externalities in agriculture, and the implications of such identification for both development and environmental policy. In particular, a key objective is to setup a conceptual foundation for quantifying spatial externalities within agriculture. Since parcel-level net returns to alternative land uses are often not observable by researchers, the increasing availability of spatial land-use data can be used as a means of quantifying such externalities. The primary challenge with such an exercise is that landscape patterns arising from positive or negative spatial externalities can be observationally equivalent. Therefore, a simple quantification of the presence of spatial externalities through standard statistical methods is not sufficient to identify whether such externalities are positive or negative. This point is critical because the ultimate design of welfare-enhancing landscape policies crucially depends on whether externalities are positive or negative. For example, a negative externality associated with a specific land use choice suggests a policy to discourage that choice, while a positive externality suggests a policy to encourage the choice. However, an important message of this paper is that the underlying identification problems associated with documenting spatial externalities from spatial land-use data can be solved by careful empirical design with a structural foundation and a multi-method approach.

In the presence of significant transactions costs or provision of global public goods, spatial externalities may provide a rationale for policy interventions at a variety of spatial scales and from a variety of institutions. While the ultimate role for policy depends on the specific land-use context, empirical identification of spatial externalities can highlight areas where the social value of land can be enhanced by policy. In addition, the presence of spatial externalities suggests that policy-induced land-use changes—whether from a policy specifically aimed at the externality, or a policy aimed at another outcome—can cascade to other parcels on the landscape, thereby creating potentially unintended consequences for both development and environmental outcomes. An understanding of the presence and source of spatial externalities can help avoid unintended consequences and improve the efficiency of policy making.

The goal of our paper is to open up and provide a conceptual foundation to a thematic area located within the general topic of spatial dynamics of land-use change. Our approach is similar to and related, yet also distinct, with respect to the current approaches that are associated with models of Land Use/Cover Change (LUCC). In summary one of our main contributions is to provide a spatially explicit micro-economic rationale and methodological approach, along with suggestions for research design, to complement and provide research strategies for better understanding the components of land-use change and the consequences for both development and environmental policies.

Figure 1 – One-Directional Spatial Externalities

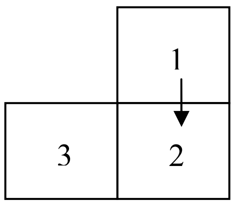

Figure 2 – Location of Organic Farms in a Conventional Landscape

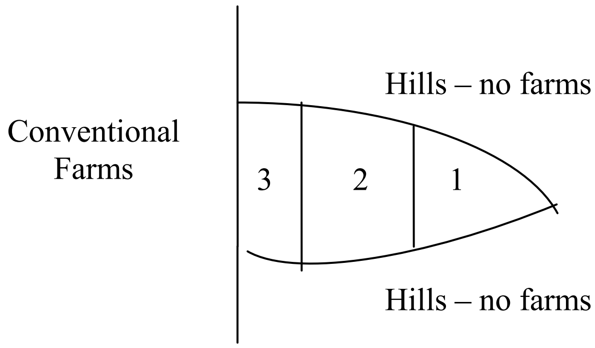

Table 1: Potential Landscape Configurations

Landscape Configuration	Parcel 1 Land Use	Parcel 1 Equilibrium Condition	Parcel 2 Land Use	Parcel 2 Equilibrium Condition	Landscape Welfare
Clustered (A, A)	A	$R_1^A > R_1^B$	A	$R_2^{A,A} > R_2^{B,A}$	$R_1^A + R_2^{A,A}$
Fragmented (A, B)	A	$R_1^A > R_1^B$	B	$R_2^{B,A} > R_2^{A,A}$	$R_1^A + R_2^{B,A}$
Fragmented (B, A)	B	$R_1^B > R_1^A$	A	$R_2^{A,B} > R_2^{B,B}$	$R_1^B + R_2^{A,B}$
Clustered (B, B)	B	$R_1^B > R_1^A$	B	$R_2^{B,B} > R_2^{A,B}$	$R_1^B + R_2^{B,B}$

Table 2: Identification of Spatial Externalities from Land-Use Data

Information	Baseline Condition	Landscape(s) which allow identification of externalities
Partial Information	$R_2^B - R_2^A > 0$	Clustered (A, A)
	$R_2^B - R_2^A < 0$	Clustered (B, B)
No Returns Information	NA	Clustered (A, A)↔Fragmented (A, B);
		Clustered (B, B)↔Fragmented (B, A)
Complete Information	$R_2^B - R_2^A <> 0$	any landscape

ENDNOTES

[1] Example applications include: Swinton, 2002; Case, 1992; Holloway et al., 2002; Roe et al., 2002; and Belcher et al. 2005.

[2] Swallow and Wear (1993) examine the externalities from one timber-producing forest stand on an adjacent stand where wildlife production is a management goal. Albers (1996) examines the interplay between irreversible land-uses and spatial interactions with a focus on the social benefits of land preservation.

[3] Unobserved landscape attributes end up in the error term of the econometric model and are typically correlated over space, providing multiple estimation challenges (Anselin 2002).

[4] Econometric estimation of spatial interaction parameters generally yields information regarding the average – or deviations from the average – interaction effect as opposed to each specific interaction between all adjacent parcels. Estimation of individual interaction effects would require parcel-specific returns data over time.

[5] The literature we surveyed in making this assessment of the LUCC approach included: Geoghegan et al., 2001; Lambin, Geist, et al., 2001; Lambin, Turner, et al., 2001; Lewis and Plantinga 2007; Mertens et al., 2000; Moran and Ostrom, 2005; Rindfuss et al., 2004; Vance and Geoghegan, 2002; Veldkamp and Lambin, 2001; Turner et al., 2001; and Walker, 2003.

[6] It's relatively simple to extend the model to two-directional spatial externalities, but a simple model of one-directional externalities provides the clearest results and is relevant to many agricultural scenarios.

[7] Heterogeneity in land quality can be driven by a variety of factors, such as wealth endowments, managerial skills, or other social characteristics of landowners.

[8] An alternative setup with very similar implications would be to simply assume that externalities flow from one land use (e.g. use A) rather than from one parcel.

[9] If there are no negative spatial externalities, then $R_2^{B,A} = R_2^B$, which implies that $R_2^{A,A} > R_2^B$ and $R_2^{A,A} - R_2^A > R_2^B - R_2^A$. If there are no positive spatial externalities, then $R_2^{A,A} = R_2^A$, which implies that $R_2^A > R_2^{B,A}$ and $R_2^B - R_2^A < R_2^B - R_2^{B,A}$.

[10] For example, the fragmented (A, B) configuration is consistent with either positive or negative spatial externalities, provided $R_2^B - R_2^A > R_2^{A,A} - R_2^A$, or $R_2^B - R_2^A > R_2^B - R_2^{B,A}$, or both. Fragmented (A, B) configuration is also consistent with no spatial externalities.

[11] While the optimal quantity of a particular land-use is beyond the scope of this paper, we note that the empirical identification of spatial externalities is necessary for understanding both the optimal pattern and the optimal quantity of alternative land uses.

[12] Proof: For the tax to induce landowner 1 to switch to use B, then $R_1^A - (R_2^B - R_2^{B,A}) < R_1^B$. Since $R_2^{B,B} - R_2^{A,A} > R_1^A - R_1^B$ by definition, then $R_2^B - R_2^A > R_1^A - R_1^B$ if we have only negative externalities. Therefore, since $R_2^{B,A} < R_2^{A,A} = R_2^A$, then $R_1^A - (R_2^B - R_2^{B,A}) < R_1^B$.

[13] If $c = (<) R_2^B - R_2^A$, the policy has distributional (efficiency) consequences.

[14] One can imagine local cooperation among farmers or institutional innovation (via a cooperative) that might obviate completely the need for any explicit policy intervention. These "win-win" scenarios would resemble the Coasian solution.

[15] Examples include CONDESAN (Consortium for Development and Sustainable Agriculture in the Andes), which is based in Lima, Peru, and the Latin American land use program within CIAT (International Center for Tropical Agriculture), which is based in Cali, Colombia.

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