Effects of Protected Area Size on Conservation Return on Investment with Spatial Spillovers

Kristen Thiel[a*], Seong-Hoon Cho[a], Paul Armsworth[b]

[a] Department of Agricultural and Resource Economics, The University of Tennessee

[b] Department of Ecology and Evolutionary Biology, The University of Tennessee

*Corresponding author at: 325 Morgan Hall 2621 Morgan Circle, Knoxville, TN 37996-4518, United States. *Email address:* kthiel@vols.utk.edu

Effects of Protected Area Size on Conservation Return on Investment with Spatial Spillovers

ABSTRACT

Conservation return on investment (ROI), for all spatial scales, varies according to a wide range of characteristics. One feature that makes conservation ROI at the parcel level different from larger scale ROI is the impact of parcel size variation on ecological and economic effectiveness. Protected area size maintains an important role in both the benefit and cost associated with conservation. However, few studies have explicitly focused on the role of protected area size on conservation ROI specifically at the parcel level. Therefore, conservation ROI has been limited in its effectiveness in prioritizing parcels for conservation. The objective of our research is to examine how protected area size influences a parcel's ecological and economic effectiveness through conservation ROI. This objective is accomplished by analyzing the parcel-level acquisition cost and the conservation benefit of protected areas acquired by a conservation organization, The Nature Conservancy (TNC). We develop an empirical model to examine how differences in protected area size influence conservation benefit as an ecological measurement, and how differences in the conservation benefit, as a measurement of conservation value, subsequently alter conservation cost. By assessing the sequential relationship in a spatial econometric modeling framework, we first examine the consequence of the size variation on conservation ROI and then we calculate and rank the ROI for each protected area with and without considering the spatial spillovers of conservation benefit and acquisition cost. We found that (1) protected areas acquired by TNC create more connected habitat, thereby improving species protection and mobility in the existing protected area network that existed prior to the TNC acquisition, and subsequently, such improvement is a major impetus to determine acquisition cost, (2) the increase in effective mesh size per dollar invested to acquire a parcel is greater for larger parcels than smaller parcels, implying that the overall efficiency that considers both ecological and economic efficiencies is higher for protecting larger areas relative to smaller ones, and (3) the inclusion of spillovers of both conservation benefit and cost in the ROI decision-making tool provides information about which parcels' locations affect conservation benefit and cost in their neighboring parcels and to what extent.

Effects of Protected Area Size on Conservation Return on Investment with Spatial Spillovers

1. INTRODUCTION

Habitat fragmentation, the process by which large, continuous habitats are divided into smaller, more isolated remnants, is recognized as a major threat to the world's biodiversity (Armenteras et al., 2003; Llausas and Nogue, 2012; Noss, 2001). The most common conservation effort to limit or reverse the process of habitat fragmentation is through the establishment of protected areas. This conservation action is achieved through conserving land by purchasing it entirely or by acquiring the development rights. Much literature has demonstrated that acquiring land for protection based on both the economic cost and the conservation benefit generated by the protected areas results in higher conservation outcomes at lower costs than what would have been achieved by conservation strategies which focus solely on maximizing benefit or minimizing cost (Balmford et al., 2000; Ferraro et al., 2003; Murdoch et al., 2007; Naidoo and Iwamura, 2007). This approach captures more conservation benefit at a lower cost (referred to as "ecological and economic effectiveness") for protected area acquisition than alternative conservation approaches (Balmford et al., 2000; Ferraro et al., 2003; Murdoch et al., 2007; Naidoo and Iwamura, 2007) and is commonly estimated as conservation return on investment (ROI) (Adams et al., 2010; Game, 2013; Murdoch et al., 2010). Conservation ROI is calculated by dividing the benefit gained from taking a particular conservation action by the economic cost associated with that action (i.e., Salafsky and Margoulis, 1998; Tear et al., 2014).

Conservation ROI for all spatial grains, or resolution, varies according to a wide range of characteristics (Armsworth et al., 2006). One feature that makes conservation ROI at the parcel level different from larger-grain ROI is the impact that variation in parcel size has on the parcels' ecological and economic effectiveness (Sutton and Armsworth, 2014). Protected area size maintains an important role in both the benefit and cost associated with conservation (Naidoo and Ricketts, 2006). Recent studies have demonstrated that conservation benefit, especially where species richness is defined as conservation benefit, increases with parcel size (Armsworth, et al. 2006; Underwood et al., 2008). Additionally, studies have found that protected areas exhibit economies of scale (Frazee et al., 2003; Kim et al., 2014). Despite the important role of parcel size, however, little, if any, research has explicitly focused on the role of protected area size on conservation ROI. Thus, conservation ROI has been limited in evaluating the role of protected area size on ecological and economic effectiveness in prioritizing parcels for conservation.

The objective of this research is to examine how protected area size influences the ecological and economic effectiveness of protected area acquisition through ROI analysis. In our case study, we use the change in effective mesh size of the area surrounding a parcel as the conservation benefit measure and the acquisition cost of the parcel as the conservation cost measure. The change in effective mesh size measurement is first used as a biological metric which is affected by environmental and biological factors. In the cost equation, the change in effective mesh size metric is a factor of acquisition cost, as it partially determines willingness to pay. Using these benefit and cost measures, we develop a sequential model to assess how variations in protected parcel size influence the effective mesh size, used as an ecological indicator, and how changes in the effective mesh size, included as a decision making factor, subsequently alter the parcel's acquisition cost. We use 82 fee-simple transactions conducted by The Nature Conservancy (TNC) without donative intent during 2000-2009 in Central and Southern Appalachian forest ecosystems (see Figure 1). TNC acquires land through fee-simple transactions, which transfer the full fee title, and easements, which transfer partial property rights

(Dana and Ramsey, 1989; Eagle, 2011; Fishburn et al., 2009). In our case study, we only use fee-simple transactions without donative intent as observations in estimating the sequential system of equations because parcels with donative intent offer poor estimates of acquisition costs and 91% (or 61 of 67) of easements acquired by TNC had donative intent during the study period.

A parcel-level analysis like ours presents inherent spatial dependencies. For example, land parcels located near one another may have unobserved characteristics that are correlated across parcels. These unobserved characteristics represent the spatial structure of the decision-making units (parcels) as an unobservable spatial process. By assessing the sequential relationship in a spatial econometric modeling framework, we first examine the effect of parcel size variation on conservation ROI and then calculate and rank the conservation ROI for each protected area with and without considering spatial spillovers in conservation benefit and acquisition cost. This analysis captures the role of protected area size, spatial dependence in the conservation benefit and acquisition cost, and their influences on relative conservation ROI ranking for the protected area acquisitions in this TNC case study.

In the remainder of this article, we present a literature review relevant to our objective followed by a conceptual framework that summarizes the sequential relationship. Then, we develop an empirical model that hypothesizes the sequential relationship in a spatial econometric modeling framework. Finally, we present and discuss the empirical results, followed by conclusions.

2. LITERATURE REVIEW

Five issues associated with the objective have been addressed in the literature: (1) the spatial scale of conservation ROI, (2) the cost component of conservation ROI, (3) the benefit component of conservation ROI, (4) the role of protected area size in determining conservation

ROI, and (5) the contribution of spatial spillovers to conservation site prioritization. Below, the five branches of literature are discussed in detail.

Studies addressing issue (1) have focused on the importance of the two components of spatial scale used in conservation prioritization decisions, spatial grain and extent, and whether they are large (e.g., global, transnational, ecoregional, or landscape level) (Carwardine et al., 2008a; Murdoch et al., 2007; Naidoo and Iwamura, 2007; Wilson et al., 2009) or small (e.g., parcel or protected area level) (Ferraro, 2003; Messer, 2006; Murdoch et al., 2010; Newburn et al., 2006; Sutton and Armsworth, 2014; Tear et al., 2014). Spatial grain refers to the physical size of the observation unit, whereas extent refers to the overall geographic dimension to which inferences are drawn (McGarigal, 2002).

While large-scale ROI studies can offer prioritization decisions among large political entities or different ecosystems, only parcel-level ROI has the unique ability to help conservation organizations select individual parcels (Murdoch et al., 2007; Naidoo and Iwamura, 2007; Tear et al., 2014). Thus, parcel-level ROI is especially useful in guiding site prioritization decisions at the local level. Nevertheless, estimating site-specific protected area effects has been a major challenge for conservation ROI research, in part because of limitations in collecting appropriate data at the parcel level (Tear et al., 2014).

In relation to issue (2), the literature has emphasized the wide variety of costs used in ROI as well as the considerable range of methods used to calculate them (Adams et al., 2010; Frazee et al., 2003; Murdoch et al., 2010; Naidoo et al., 2006). Some costs in the literature reflect the market value of alternative land uses (e.g., opportunity costs) while others reflect the ecological needs of the protected area (e.g., management costs) (Armsworth et al., 2011). Although many different cost options exist for calculating conservation ROI (e.g., acquisition, transaction, opportunity, damage, and/or management costs), studies rarely include multiple costs due to the difficulty in finding and calculating even one type of conservation cost (Adams et al., 2010; Naidoo et al., 2006) and the redundancy in including every cost category in conservation ROI calculation. A better approach is to include the most relevant and accurately estimable cost considered in making the conservation decision (Game, 2013). In our TNC case study, acquisition cost is most relevant because TNC frequently purchases land with the intent of transferring it to partners and government agencies (Kareiva et al., 2014). Thus, other costs such as management costs are not as critical as acquisition costs to TNC's decision making process.

Concerning issue (3), previous literature has commonly quantified conservation benefit by focusing on biodiversity protection of the greatest number of species or species which have the greatest conservation value (Boyd et al., 2015). To measure the biodiversity conservation that a protected area provides, early conservation ROI studies used direct counts of species richness (Ando et al., 1998; Carwardine et al., 2008b; Polasky et al., 2001). However, some researchers found total species richness measurements unavailable, so they used the species richness of single or multiple groups of species as surrogates (e.g., Murdoch et al., 2007; Polasky et al., 2001). Other studies used habitat protection as a proxy for species protection with the assumption that the protected area will conserve a pre-determined acceptable percentage of species (Balmford et al., 2000; Carwardine et al., 2008b; Naidoo and Iwamura, 2007). Some of these studies set fixed targets of habitat type (Balmford et al., 2000) or species' historic ranges for protection (Kark et al., 2009).

In our case study, conservation benefit reflects the goals of TNC by adopting a proxy metric for species richness based on habitat protection. The conservation benefit of a TNC-acquired parcel is defined as the change in effective mesh size, which is measured by the difference in the effective mesh size before and after the TNC acquisition in the landscape surrounding the parcel. This landscape is created as a 5 km^2 buffer around the central point, or centroid, of each protected parcel. The effective mesh size metric was developed by Jaeger (2000) as a measure of habitat destruction and fragmentation and addresses TNC's conservation goals: conserving targeted species and increasing habitat protection (TNC 2000; TNC 2001; TNC 2003) (see section *3.3.* for the details).

Related to issue (4), protected area size and the ecological consequences of size variability have been a central concern of conservation biologists for decades (Diamond, 1975; Higgs, 1981; Lahti and Ranta, 1985; Simberloff and Abele, 1982), although the relationship between protected area size and conservation cost has only been researched recently (Armsworth et al., 2011; Ausden, 2007; Ausden and Hirons, 2002; Balmford et al., 2003; Frazee et al., 2003; James et al., 2000; Kim et al., 2014; Moore et al., 2004; Strange et al., 2006). The literature on the relationship between conservation benefit and protected area size commonly finds that the larger a protected area is, the greater the number of species it contains (Bender et al., 1998; Debinski and Holt, 2000; Wiens, 2009), although recent literature advocates for the importance of smaller protected areas (Wiens and Bachelet, 2014). In regards to the relationship between conservation cost and protected area size, recent literature has found that acquisition costs for protected areas show pronounced economies of size, suggesting more economically efficiency in establishing a larger protected area than a smaller one, all else being equal (Kim et al., 2014). Even so, few studies calculate conservation benefit and cost at the parcel-level (Sutton and Armsworth, 2014). Disaggregating benefit and cost measurements to a geographical scale fine enough to capture site-specific effects of protected areas has been a major challenge to conservation ROI (Tear et al., 2014). The limited parcel-level ROI research focusing on protected area size may be due, in part, to limitations in collecting the data appropriate to estimate conservation ROI at a finer scale (Tear et al., 2014).

Relating to issue (5), the literature stresses the importance of understanding the role of spatial spillovers in conservation benefit and cost when prioritizing sites (Kukkala and Moilanen, 2013; Williams, Revelle, and Levin, 2005). Conservation benefit spillovers promote protected area contiguity because the conservation value of a parcel is not limited to its internal qualities but also depends on the spatial structure of the rest of the protected area system. Acquisition cost spillovers examine the increase in cost that arises due to the spatial structure of the parcels. Including conservation benefit spillover effects in conservation ROI calculations captures the relationship between the potential benefits of neighboring protected areas, while including acquisition cost spillover effects highlights the spatial dependence of acquisition costs, which are largely dependent on the real estate market.

Our research contributes to the literature in three ways. First, we focus on the role of protected area size on conservation ROI, specifically at the parcel level—a key innovation that we deliver in this research. To do that, we take advantage of (a) a uniquely comprehensive data set provided by TNC that details acquisition costs of protected areas and (b) the change in effective mesh size that measures conservation benefit and coincides with TNC's conservation goals. Second, we assess the ecological and economic effectiveness of protected area size by estimating the impacts of the variation in protected parcel size on (i) the change in effective mesh size as a conservation benefit measure and (ii) the acquisition cost as a conservation cost measure. Third, we apply a spatial econometric modeling framework that captures the effects of spatial spillovers on the relationships between protected area size and conservation benefit and acquisition cost, and their impacts on conservation ROI ranking. Our three contributions to the literature provide a practical, easily implemented conservation tool for estimating protected-area ROI at the parcel level, the land unit for which protected-area decisions are made.

3. METHOD

3.1. Conceptual framework

The cost for which a conservation organization like TNC acquires land for protection is dependent on: the conservation organization's willingness to pay (WTP) to acquire the particular parcel and the landowner's willingness to accept (WTA) the transaction. TNC's WTP is a function of the protected area's size and other factors that determine the spatial connectivity of the protected area as set out by the organization's conservation goals (TNC, 2000; TNC, 2001; TNC, 2003; Lennox and Armsworth, 2013; Lennox, Dallimer, and Armsworth, 2012). We assume that, before acquisition, TNC has an approximation of the parcel's potential conservation benefit. This will affect TNC's WTP for the parcel, as parcels with greater conservation benefit will more fully be able to achieve TNC's goal of landscape contiguity. The landowner's WTA is, in part, a function of the opportunity cost of alternative land uses, which is largely dependent on the spatial structure of the real estate market. Conservation benefit, as it affects WTP, is assumed to be a function of cost. However, it is assumed that acquisition cost is not a function of conservation benefit. Cost of parcel acquisition will have no effect on conservation benefit, as it is an ecological or biological measurement of a habitat.

Given these assumptions about TNC's WTP and a landowner's WTA, the functional relationship for acquisition cost is:

$$C_i = C_i[B_i(S_i, B_{-i}, Z_i), C_{-i}, X_i], \tag{1}$$

where C_i, B_i, S_i, Z_i, X_i are acquisition cost, conservation benefit, protected area size, other factors determining the conservation benefit, and other factors determining the opportunity cost of alternative land uses, respectively, for protected parcel i. B_{-i} and C_{-i} are, respectively, conservation benefit and acquisition cost for the protected parcels neighboring parcel i. Equation (1) shows the conceptual framework for the sequential relationship defining how the size of protected parcel i, S_i, and the conservation benefit from protect parcels neighboring parcel i, B_{-i}, influence the conservation benefit from parcel i, B_i, and how B_i and the acquisition cost of protect parcels neighboring parcel i, C_{-i}, subsequently influence acquisition cost of protected parcel i, C_i.

3.2. Model specification

Our empirical model assumes the change in effective mesh size (representing conservation benefit) received from a protected parcel is endogenous in the following sequential system of equations:

$$\begin{aligned} lnC &= \rho_c W_1 lnC + \delta lnB + lnX\Phi + \varepsilon_c, \quad \varepsilon_c = \Theta_c W_1 \varepsilon_c + u_c \\ lnB &= \rho_B W_2 lnB + \Upsilon \ln S + lnZ\xi + \varepsilon_B, \quad \varepsilon_B = \Theta_B W_2 \varepsilon_B + u_B \end{aligned} \tag{2}$$

where *ln* is natural log, *C* is acquisition cost, *B* is change in effective mesh size due to protecting a parcel, *S* is size of the protected parcel, δ, Υ, Φ, and ξ are scalar parameters, X and Z are matrices of exogenous variables, W_1 and W_2 are (possibly identical) nonstochastic, positive definite, exogenous matrices defining interrelationships between spatial units of protected parcels, ρ_c and ρ_B are spatial-lag coefficients, Θ_c and Θ_B are spatial autocorrelation coefficients, ε_c and ε_B are spatial autocorrelated disturbances, and u_c and u_B are i.i.d. disturbances with zero mean and variance $\sigma^2 I$.

Here, *X* and *Z* include categories of geophysical characteristics (average slope and average elevation), distance related variables (distance to major city, waterbody, park, and highway), and the initial stock of conservation benefit located in the 5 km^2 buffer before the acquisition of the protected parcel (effective mesh size before acquisition, weighted species richness, and percentage of the landscape already protected). *X* also includes socioeconomic characteristics (median income and population of the census block group in which the parcel is located). The variables for each category are chosen following the general guidance of the literature. For example, we include the geophysical characteristics of slope and elevation as geophysical characteristics because they have been found to determine acquisition cost and the location of protected areas (Andam et al., 2010; Joppa and Pfaff, 2009; Kim et al., 2014; Sims, 2010). We use proximity to the nearest major city, waterbody, park, and highway as distance related variables because proximities to these amenities are expected to positively affect acquisition cost through the real estate market (Cho et al., 2006; Kruse and Ahmann, 2009; Land Policy Institute, 2007; McConnell and Walls, 2005; Snyder et al., 2007), and they also may affect the measure of effective mesh size (Ferraro et al., 2011; Newburn et al., 2006).

We also include weighted species richness, effective mesh size, and percentage of protected area in the landscape surrounding the parcel which is created by drawing a 5 km^2 buffer around the centroid of each protected parcel prior to TNC acquisition to capture the initial stock of conservation benefit. Like the change in effective mesh size variable, these variables are derived from publicly available data and can be calculated prior to parcel acquisition. Additionally, they are expected to affect TNC's WTP because TNC is interested in targeting parcels surrounded by or adjacent to established protected areas and/or acquiring areas with abundant species richness (TNC, 2000; TNC, 2001; TNC, 2003). Likewise, a landowner's WTA may be influenced by the initial stock of conservation benefit because of the higher land value the real estate market places on parcels near protected or natural areas due to the aesthetic view or potential recreational use (Armsworth et al., 2006).

The socioeconomic characteristics (i.e., population and median household income at the census-block group level) are included in X to capture direct interdependency of acquisition costs within census-block group neighborhoods, which have similar real estate market characteristics. Population is included to measure how population pressure on land and natural resources affects acquisition cost. Median household income is included to capture the effect of the relative economic status of a neighborhood on acquisition cost. (We report definitions of the variables used in the regressions and their detailed statistics in Table 1.)

The change in effective mesh size is selected based on our goal of choosing parcels that have the highest measure of ecological and economic effectiveness, given TNC's acquisition budget and two broad conservation goals: conserving targeted species and increasing habitat protection through the creation of contiguous landscape (TNC 2000; TNC 2001; TNC 2003). Also, it can be calculated prior to acquisition, as the metric utilizes public data. To accomplish TNC's two broad conservation goals of conserving targeted species and increasing habitat protection within their budget (TNC 2000; TNC 2001; TNC 2003), TNC seeks to acquire a mix of protected areas, some that contribute to the habitat connectivity of the landscape, some that specifically protect targeted species, and some that do both (TNC, 2000; TNC, 2001; TNC, 2003). The effective mesh size variable quantifies the probability that two random points (i.e., representing the locations of a pair of animals or plants) appear in the same patch of non-fragmented natural cover of land (Jaeger, 2000), and thus the change in the effective mesh size is a good quantifiable indicator of the achievement of TNC's conservation goals, reflecting the gain in conservation benefit by the acquisition of a particular protected parcel.

Following Jaeger (2000)'s notation, the effective mesh size, *M*, is obtained by multiplying the total area of the 5 km^2 buffer around the centroid of each protected parcel, A_t, by the probability, *P*, that a pair of animals or plants located randomly in the buffer end up occurring in the same contiguous patch of protected area within the 5 km^2 buffer[1]:

$$M = A_t \cdot P = \frac{1}{A_t} \sum_{j=1}^{n} A_j^2 \quad (3)$$

where $P = \sum_{j=1}^{n} \left(\frac{A_j}{A_t}\right)^2$, A_j = size of patch *j* (*j* = 1, …, *n*) of protected area within the 5 km^2 buffer.

The 5 km^2 buffer is used because it is the average separation protocol to convert animal survey data (i.e., a targeted species was seen in a particular location) into more meaningful element occurrences (i.e., a population of this species exists) (Sutton and Armsworth, 2014). The change in *M* depends on *M* before the TNC acquisition and the size and distribution of protected areas established before the TNC acquisition. (See Supplementary Materials S1 for a numerical example of the change in *M* for different types of acquisitions.)

The weighted species richness variable is calculated as part of the initial stock of conservation benefit based on element occurrences in GIS form that is downloaded from the Biodiversity Information Serving Our Nation (BISON) database (USGS 2014). We choose element occurrences of 328 target species that are listed as high level conservation concerns

---

[1] The probability that only one individual of a species is located in A_t is $\frac{A_j}{A_t}$. Therefore, *P* is the probability that two animals or plants will be in the same parcel where $\frac{A_j}{A_t} \cdot \frac{A_j}{A_t} = \left(\frac{A_j}{A_t}\right)^2$. See Supplementary Materials S2 to see how effective mesh size is calculated using probabilities.

according to the ecoregional portfolios created by TNC (USGS 2014). Using the downloaded database, we spatially aggregate element occurrences of species of conservation concern within each of the 5 km^2 buffers prior to the TNC acquisitions (referred to as “target species richness”). Then, the weighted species richness variable is created by multiplying target species richness by the quotient of the size of the protected parcel and the total area of the landscape, or the 5 km^2 within the buffer.

3.3. Model estimation

Equation (2) was estimated using a two-stage, instrumental variable regression model with autoregressive disturbances (GS2SLS model) (Kelejian and Prucha, 1999) (See Supplementary Materials S3. for the details) with three endogenous variables.

3.3.1. Endogeneity test

In estimating equation (2), we hypothesize that the change in effective mesh size B, the spatial lag of acquisition cost W_1C, and the spatial lag of change in effective mesh size W_2B are endogenous variables. We use the percentage of protected area within the 5 km^2 buffer prior to TNC acquisition and the size of the protected area as instruments for the endogeneity test of B. These instrument were tested for validity using three identification tests: under-, weak-, and over-identification. In the under-identification test, Anderson’s (1951) Lagrange Multiplier statistic of 35.68 suggested that the instruments are identified at the 5% significance level. (The 5% level is identified as significant throughout the manuscript.) Cragg-Donald’s (1993) Wald statistic of 17.72 for the weak identification test suggested that the instruments are not weak. Sargan’s (1958) statistic of 5.22 for the over-identification test implied failure to reject the null hypothesis that the instruments are uncorrelated with the error term. Methods to obtain instruments for the spatial lags are described in Supplementary Materials S3.

3.3.2. Spatial tests

The spatial dependence of acquisition cost likely exists because acquisition costs are influenced by land values in real estate markets that tend to be highly spatially clustered (Anselin and Lozano-Gracia, 2008; Kim et al., 2014). Likewise, changes in effective mesh size are likely spatially correlated, because landscape fragmentations, such as effective mesh size and their causal factors, are usually location-dependent (Carwardine et al., 2008a; Gao and Li, 2011; Hernandez-Manrique, et al., 2012). We conducted robust spatial Lagrange multiplier (LM) lag and error tests (Anselin, 1988) for each equation separately using different row-standardized weight matrices (i.e., inverse distance, K nearest neighbors (KNN), and hybrids between inverse distance and KNN matrices, where K = 2, 3, 4, 9).

Robust spatial LM-lag statistics of 2.46-60.91 and robust spatial LM-error statistics of 9.16-88.20 for the conservation benefit equation (See equation (2)) indicated rejection of the aspatial model in favor of the spatial lag and spatial error models for all nine row-standardized spatial weight matrices. Additionally, robust spatial LM-lag statistics of 0.01-1.86 and robust spatial LM-error statistics of 0.00-2.18 for the acquisition cost equation (See equation (2)) indicated rejection of the aspatial model in favor of the spatial lag and spatial error models for five of the nine row-standardized spatial weight matrices. These spatial LM test results support using GS2SLS to estimate the system of equations in equation (2).

3.3.3. Conservation ROI analysis

Using the empirical estimates from equation (2), we assess how the size of a protected area influences its ecological and economic effectiveness through conservation ROI analysis. We calculate conservation ROI with and without spatial spillovers. Specifically, conservation ROI for each acquired parcel under the observed *status quo* of protected area size is calculated by dividing the predicted change in effective mesh size, $\hat{B}$, by the predicted acquisition cost, $\hat{C}$. In estimating $\hat{B}$ and $\hat{C}$, we use the spatial lag coefficients (ρ_B and ρ_c) to calculate ROI with the spatial spillovers while we assume the spatial lag coefficients are zero in calculating ROI without spatial spillovers. We then regress the calculated ROIs with spatial spillovers on parcel size to estimate the overall effect of protected area size on calculated ROI with spatial spillovers. We perform a similar regression without spatial spillovers. Then, we rank the parcels by their descending order of calculated ROI for each case. Finally, we compare the rankings between the two cases to understand the role of protected area size and spatial dependencies on the ecological and economic effectiveness of the protected areas.

We use calculated ROI instead of observed ROI in the two regressions because of the information that can be observable by TNC. By using calculated ROI, we assume any factors that are not included in the regression are unobservable to TNC just as they are unobservable to us. Thus, we assume TNC makes its prioritization decisions based on calculated ROI, absent information on the unobserved factors.

4. DATA

For our regression analyses, we used six data sets: TNC acquisition data for the fee simple transactions, landscape data for the effective mesh size, data for geophysical characteristics, data for distance related variables, data for socioeconomic characteristics, and target species richness data for the weighted species richness variable. The TNC acquisition data were obtained from TNC documents that contain information regarding contract type, acquisition cost, parcel size, and location (TNC, 2000; TNC, 2001; TNC, 2003).

The effective mesh size variables (i.e., effective mesh size before and after TNC acquisition) and percentage of the protected area prior to TNC acquisition were calculated through FRAGSTATS software (McGarigal et al., 2012). The 5 km^2 buffer was drawn around each of the 82 protected area centroids to create 82 separate landscapes. First, the centroid of each protected area parcel was identified. Next, a buffer was drawn to create an area of 5 km^2 around each central point. The existing protected areas within a landscape were downloaded from the Protected Areas Database of the United States (PAD-US) (USGS, 2012). Two maps of protected areas were created using GIS software ArcMap version 10.2 (ESRI, 2012) for each protected area landscape: one immediately prior to the TNC acquisition and one immediately after. These maps were then exported into FRAGSTATS where effective mesh size and percentage of protected area within each landscape were calculated. The effective mesh size tables were exported into Excel where effective mesh size before acquisition was subtracted from effective mesh size after acquisition to create the change in effective mesh size variable.

The data for geophysical characteristics (i.e., average slope and elevation) were obtained from the 30-meter Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 2 (V2) (NASA JPL, 2011). Using the data and the Zonal Statistics tool in ArcGIS 10.1 (ESRI 2012) based on raster grids, we calculated average slope and elevation of the 82 protected areas. The data for distance-related variables were created using the Near Analysis tool in ArcGIS 10.1 (ESRI, 2012). These variables represent the proximity between parcel centroids and the centroids of the nearest cities with a population of 10,000 or more, or the proximity between parcel centroids and the distance to the nearest water body, park, or major highway. Shapefiles of the cities, water bodies, parks, and major highways were acquired from ESRI Data & Map 10 (ESRI, 2011) and shapefiles of the parcels were obtained from TNC (TNC, 2000; TNC, 2001; TNC, 2003).

The data for socioeconomic characteristics (i.e., population and median household income) were obtained from the 2000 US Census and the 2007 US Census (US Census Bureau, 2000; US Census Bureau, 2007). The 2000 and 2007 census-block group data were assigned to all transactions within a census-block group made during the periods of 2000–2006 and 2007–2009, respectively. The weighted species richness variable was calculated using TNC's target species data. Lists of targeted species were obtained through TNC ecoregional plans (TNC, 2000; TNC, 2001; TNC, 2003).

5. EMPRICAL RESULTS

5.1. Overall estimates and parameter analysis

The selection of a spatial weight matrix had little effect on the overall goodness of fit for the conservation benefit equation or the acquisition cost equation (see Table 2). Our results suggest that the prior imposition of spatial structure does not appear to be a critical factor in model identification. Given the overall measure of fit, we chose spatial weight matrices using K-nearest neighbor (KNN = 3). About 27% and 58% of the variations observed across the protected parcels were explained by the change in effective mesh size and acquisition cost, respectively. In the conservation benefit equation, the coefficient of protected parcel size is 0.59 and significant, suggesting that a 1% increase in a protected parcel size increases its change in effective mesh size due to TNC acquisition by 0.59% (see Table 3). In the acquisition cost equation, the coefficient for change in effective mesh size was 0.47 and significant, suggesting that a 1%

increase in the change in effective mesh size of a protected parcel increases its acquisition cost by 0.47%. These two combined results suggest failure to reject our hypothesis that protected area size influences TNC's measure of conservation benefit, and the change in conservation benefit subsequently alters acquisition cost.

In the conservation benefit equation, the coefficient for the percentage of 5 km^2 landscape already covered in protected area is significant and positive. This finding suggests that an increase of the percentage of existing protected area surrounding a protected parcel increases the effective mesh size in the area surrounding the protected parcel. In the acquisition cost equation, the coefficients for proximity to water body, average slope, and effective mesh size before TNC acquisition were negative and significant, and the coefficient for weighted species richness was positive and significant. The findings suggest that the acquisition cost paid by TNC is greater for flatter protected parcels that are closer to water bodies, farther from established protected areas, and have targeted species inside the landscape's 5 km^2 buffer. Given the positive correlations between acquisition cost, which depend heavily on the real estate market, and proximity to amenities like water sources and protected areas in the literature (Ayan and Erkin, 2014; Mueller and Loomis, 2008), the positive correlations we found suggest that locations with high market value tend to have potential for increased acquisition cost.

5.2. Conservation ROI analysis

Figure 2 shows that a 1% increase in protected area size significantly increases ROI by 0.67% (0.35%) based on the ROI regression calculated with consideration of (without) spatial spillovers. These findings also suggest that the difference in the overall ecological and economic efficiencies between protecting smaller areas and protecting larger areas would be underestimated by about 32% (0.67% with minus 0.35% without) if the spatial spillovers were not considered in the ROI analysis. The positive effect of protected area size on ROI scores can be explained by its positive effects on change in effective mesh size and acquisition cost. As shown by the positive effect of protected area size on the change in effective mesh size and the change in effective mesh size's subsequent positive effect on acquisition cost, larger protected areas are associated with greater changes in effective mesh size (i.e., numerator of ROIs), which leads to an increase in acquisition cost (i.e., denominator of ROIs). While both conservation benefit and cost increase due to protected area size, the numerator increases proportionally more than the denominator, yielding greater increases in ROI for larger parcels than for smaller ones.

The spatial spillover effects of protected area size on ROI combine spatial lag effects on the change in effective mesh size and on acquisition cost. These spatial lag effects may be different across the 82 protected parcels if they have different spatial structures represented by the elements of the spatial weight matrices W_1 and W_2 in equation (2). Because of these potential differences, differences between ROIs with and without spatial spillovers may vary across protected parcels, and thus the parcels' rankings may change. Among the 82 protected parcels, 63 rankings remain unchanged (referred to as "Group 1"), 9 parcels have higher rankings using the ROIs with spatial spillovers (referred to as "Group 2"), and 10 parcels have lower rankings using the ROIs with spatial spillovers (referred to as "Group 3").

We compare across the three groups the average percentage differences in the predicted changes in effective mesh size, the predicted acquisition cost, and the ROIs with and without the spatial spillover effects. We find that the relative magnitudes of the spatial spillover effects on the ROI numerator (i.e., change in effective mesh size) and on the ROI denominator (i.e., acquisition cost) are the driving forces behind the change (or no change) in ROI rankings. For example, the effective mesh size increases after acquisition by 7.8%, 7.8%, and 92% with spatial spillovers and the acquisition cost increases by 10.5%, 10.5%, and 89.5% with spatial spillovers for Groups, 1, 2, and 3, respectively. Because acquisition costs have consistently higher spatial spillover effects on the ROI denominator than on the effective mesh size (i.e., ROI numerator), the ROIs with spatial spillovers are 10.86%, 11.03%, and 89% lower than without spatial spillovers. The rankings in Group 3 become worse when considering spatial spillover effects whereas in Group 2, they improve. This is because the decreases in ROI due to the spatial spillovers in Group 2 are larger than those in Group 1 relative to the decreases in ROI in Group 2 as compared to the decreases in Group 1. The rankings do not change in Group 1.

6. CONCLUSION

Our findings contribute to a new strain of literature dealing with the ecological and economic effectiveness of protected area size at the parcel level. Our methods for site prioritization rankings using ROI scores give organizations like TNC an easy-to-understand plan for deciding which parcels best achieve their conservation goals. We summarize below our empirical results with three key findings and their implications.

First, we found that an increase in protected area size increases the change in effective mesh size, and the increase in effective mesh size increases acquisition cost. This finding implies that the protected areas acquired by TNC create more connected habitat, thereby adding additional species mobility and protection to the protected area network than existed prior to TNC acquisition, and consequently, such improvements are a major impetus to determine acquisition cost.

Second, we found that the increase in effective mesh size per dollar invested to acquire a parcel is greater for larger parcels than for smaller parcels, implying that the overall ecological and economic effectiveness is higher in protecting larger areas relative to smaller ones. This finding is consistent with previous literature: better ecological effectiveness and better economic effectiveness of larger protected areas than smaller ones, when they are estimated separately. In addition, we find that the increase in ecological effectiveness from parcel acquisition is greater than the increase in economic effectiveness of acquisition. Recognizing that protected areas of different sizes may protect different species, better ecological and economic effectiveness of protection for larger parcels based on our finding does not mean that larger parcels necessarily provide a better deal for conservation. However, quantifying the influence of protected area size on the increase in effective mesh size per dollar invested to acquire a parcel, provides a benchmark for evaluating the ecological and economic effectiveness of protected areas.

Third, we found that calculated ROIs with spatial spillovers are always lower than those without spatial spillovers because of consistently higher spatial spillover effects on acquisition cost (i.e., ROI denominator) than those on the effective mesh size (i.e., ROI numerator). The spatial spillover effects on ROI scores are important enough to switch the rankings of some parcels. This change in rankings is due to how the close proximity of parcels creates more connected habitat, resulting in greater improvements in species mobility and protection than would exist with more distant proximity of parcels. However, such spatial spillovers exist not just on the benefit side but also on the cost side. Still, the inclusion of spillovers of both conservation benefit and cost in the ROI decision making tool provides information about which parcels' locations affect conservation benefit and acquisition cost in their neighboring parcels and to what extent.

ACKNOWLEDGEMENTS

We thankfully acknowledge NSF for funding (Award 1211142) through the project "CNH-Ex: The Influence of the Size of Protected Areas on Their Ecological and Economic Effectiveness," TNC for providing land acquisition data, Nate Sutton for obtaining targeted species information, Heather Jackson for creating ecological variables in FRAGSTATS, and Taeyoung Kim for obtaining socioeconomic, geophysical, and census-block group data.

REFERENCES

Adams, V. M., R. L. Pressey, and R. Naidoo. 2010. "Opportunity costs: Who really pays for conservation?" Biological Conservation 143(2):439– 448

Andam, K. S., P. J. Ferraro, A. Pfaff, G. A. Sanchez-Azofeifa, and J.A. Robalino. 2008. "Measuring the effectiveness of protected area networks in reducing deforestation." *Proceedings of the National Academy of Sciences, USA* 105(42):16089–16094.

Andam, K., P. Ferraro, K. Sims, A. Healy, and M. Holland. 2010. "Protected areas reduced poverty in Costa Rica and Thailand." *Proceedings of the National Academy of Sciences of the United States of America* 107(22): 9996–10001.

Ando A., J. Camm, S. Polasky, and A. Solow. 1998. "Species distributions, land values, and efficient conservation." *Science*. 279(5359):2126-2128.

Anselin, L. 1988. *Spatial Econometrics: Methods and Models*. Kluwer Academic Publishers, Dordrecht.

Anselin, L, and N. Lozano-Gracia. 2008. "Errors in variables and spatial effects in hedonic house price models of ambient air quality." *Empirical Economics* 34(1): 5–34

Armenteras, D., F. Gast, and H. Villareal. 2003."Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia*." Biological Conservation* 113(2): 245-256.

Armsworth, P.R., L. Cantu-Salazar, M. Parnell, Z.G. Davies, and R. Stoneman. 2011."Management costs for small protected areas and economies of scale in habitat conservation*."Biological Conservation* 144(1): 423-429.

Armsworth P.R. 2014. "Inclusion of costs in conservation planning depends on limited datasets and Hopeful assumptions."*Annals of the New York Academy of Sciences* 1322(1):61-76.

Ayan, E., and H.C. Erkin, 2014. "Hedonic Modeling for a Growing Housing Market: Valuation of Apartments in Complexes." International Journal of Economics and Finance 6(3):188–199.

Balmford, A., K.J. Gaston, A.S.L. Rodrigues, and A. James. 2000. “Integrating costs of conservation into international priority setting.” *Conservation Biology* 14(3):597–605.

Balmford, A, K.J. Gaston, S. Blyth, A. James, and V. Kapos. 2003. “Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs.” *Proceedings of the National Academies of Sciences of the United States of America* 100(3):1046-1050.

Boyd, J., R. Epanchin-Niell, and J. Siikamaki. 2015.“Conservation Planning: A Review of Return on Investment Analysis.”*Review of Environmental Economies and Policy* 9(1):23-42.

Carwardine, J., K.A. Wilson, G. Ceballos, P.R. Ehrlich, R. Naidoo, T. Iwamura, S.A. Hajkowicz, and H.P. Possingham. 2008a. “Cost-effective priorities for global mammal conservation.” *Proceedings of the National Academy of Sciences of the United States of America* 105(32):11446.

Carwardine, J., K.A. Wilson, M. Watts, A. Etter, C.J. Klein, and H.P. Possingham. 2008b. “Avoiding costly conservation mistakes: the importance of defining actions and costs in spatial priority setting.” *PLoS One* 3(7): 2586.

Dana, A., Ramsey, M. 1989. “Conservation Easements and the common law.” *Stanford Environmental Law Journal* 8(2) 2-45.

Diamond, D. 1975. “The island dilemma: lessons of modern biogeographic studies for the design of Natural reserves.” *Biological Conservation* 7(2): 129-136.

Eagle, J. 2011. "Notional generosity: explaining charitable donors' high willingness to part with Conservation Easements. Harvard Environmental Law Review 35(1): 47-90.

ESRI. Data Maps For ArcGIS (2011), p. 10

ESRI. ArcGIS Help 10.1: Spatial Analyst Toolsets, ArcGIS Resources Internet site: http://www.esri.com/ (Accessed April 12, 2013)

Ferraro, P.J. 2003."Conservation contracting in heterogeneous landscapes: an application to watershed protection with threshold constraints. "*Agricultural and Resource Economics Review* 32(1): 53-64.

Ferraro, P.J., M.M. Hanauer, and K.R.E. Sims. 2011. "Conditions associated with protected area success in conservation and poverty reduction."*Proceedings of the National Academies of Sciences of the United States of America* 108(34): 13913–13918.

Fisburn, I., P. Kareiva, K. Gaston, and P. Armsworth. 2009. "The Growth of Easements as a Conservation Tool." *PLoS One* 4(3): 1-6.

Frazee, S.R., R.M. Cowling, R.L. Pressey, J.K. Turpie, and N. Lindenberg. 2003."Estimating the costs of conserving a biodiversity hotspot: a case study of the Cape Floristic Region, South Africa." *Biological Conservation* 112(2): 275–290.

Game, E. 2013. "Identifying Conservation Priorities using a Return on Investment Analysis." *Encyclopedia of Biodiversity*, second edition, Volume 4, S. Levin, ed., Waltham, MA: Academic Press.

Gao, J. and S. Li. 2011. "Detecting spatially non-stationary and scale-dependent relationships between urban landscape fragmentation and related factors using Geographically Weighted Regression." *Applied Geography* 31(1): 292-302.

Hernandez-Marique, O., D. Sanchez-Fernandez, J. Verdu, C. Numa, E. Galante, and J. Lobo.

2012.“Using local autocorrelation analysis to identify conservation areas: an example considering threatened invertebrate species in Spain.” *Biodiversity and Conservation* 21(9):2127-2137.

Higgs, A.J. 1981. “Island biogeography theory and nature reserve design.” *Journal of Biogeography* 8(2):117-124.

Jaeger, J. 2000. “Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation.” *Landscape Ecology* 15(2):115-130

James, A.N, K.J. Gaston, and A. Balmford. 2000. “Integrating costs of conservation into international Priority setting.”*Conservation Biology* 14(3):597-605.

Joppa, L. N. and A. Pfaff. 2009. “Global protected area impacts.” *Proceedings of the Royal Society* 278:1633–1638.

Kareiva, P., C. Groves, and M. Marvier. 2014. “The evolving linkage between conservation science and practice at The Nature Conservancy.” *Journal of Applied Ecology* 51(5):1137-1147.

Kark, S., N. Levin, H.S. Grantham, and H.P. Possingham. 2009. “Between-country collaboration and consideration of costs increase conservation planning efficiency in the Mediterranean Basin.” *Proceedings of the National Academy of Sciences* 106(36): 15368

Kelejian, H.H. and I.R. Prucha. 1999. “A generalized moments estimator for the autoregressive parameter in a spatial model.” *International Economic Review* 40(2):509–533.

Kim, T, Cho, S.H., Larson, E.R., and P.R. Armsworth. 2014. “Protected area acquisition costs show economies of scale with area.” *Ecological Economics* 107(1):122-132.

Kruse, S.A. and J. Ahmann. 2009. “The value of lake adjacency: a hedonic pricing analysis on the Klamath river, California.” Working Paper Series No. 5. Ecotrust.

Kukkala, A., and A. Moilanen. 2013. "Core concepts of site prioritization in systematic conservation planning." *Biological Reviews* 88(2):443-464.

Lahti, T., and E. Ranta. 1985. "The SLOSS principle and conservation practice: an example." *Oikos* 44(3):369-370.

Lennox, G.D. and P.R. Armsworth. 2013. "The ability of landowners and their cooperatives to gain surplus from conservation contracts: worst-case scenarios, auctions and conservation objectives." *Conservation Biology* 27(3):625-634.

Lennox, G.D., M. Dallimer, and P.R. Armsworth. 2012. "Landowners' ability to leverage in negotiations over habitat conservation." *Theoretical Ecology* 5(1):115-128.

Llausas, A. and J. Nogue. 2012. "Indicators of landscape fragmentation: The case for combining ecological indices and the perceptive approach." *Ecological Indicators* 15(1): 85-91.

McConnell, V. and M. Walls. 2005. "The Value of Open Space: Evidence from Studies of Nonmarket Benefits." Resources for the Future, Washington D.C.

McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Internet site: http://www.umass.edu/landeco/research/fragstats/fragstats.html (Accessed May 15, 2015)

Merenlender, A., L. Huntsinger, G. Guthey, and S. Fairfax. 2004. "Land Trusts and Conservation Easements: Who Is Conserving What for Whom?" *Conservation Biology* 18(1): 65-75

Messer, K.D. 2006. "The conservation benefits of cost-effective land acquisition: A case study in Maryland." *Journal of Environmental Management* 79(3):305-315.

Moore, J., A. Balmford, T. Allnut, and N. Burgess. 2004. "Integrating costs into conservation planning across Africa." *Biological Conservation* 117(3):343-350.

Mueller, J.M., and J.B. Loomis. 2008. "Spatial Dependence in Hedonic Property Models: Do Different Corrections for Spatial Dependence Result in Economically Significant Differences in Estimated Implicit Prices?" *Journal of Agricultural and Resource Economics* 33(2): 212–231.

Murdoch, W., S. Polasky, K.A.Wilson, H.P. Possingham, P. Karieva, and R. Shaw. 2007. "Maximizing return on investment in conservation." *Biological Conservation* 39(3-4):375-388.

Murdoch W., J.Ranganathan, S. Polasky, and J. Regetz*. 2010. "*Using return on investment to Maximize conservation effectiveness in Argentine grasslands." *Proceedings of the National Academy of Sciences* 107(49):855-862.

Naidoo R., A. Balmford, P. Ferraro, S. Polasky, T. Ricketts, and M. Rouget. 2006. "Integrating economic costs into conservation planning." *Trends in Ecology and Evolution* 21(12):681-87.

Naidoo, R. and T. Iwamura. 2007. "Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities." *Biological Conservation* 140(1-2):40-49.

Naidoo, R. and T. Ricketts. 2006. "Mapping the economic costs and benefits of conservation."*PLoS Biology* 4(1):2153-2164.

Newburn, D.A., P. Berck, and A. M. Merenlender. 2006. "Habitat and open space at risk of landuse conversion: targeting strategies for land conservation." *American Journal of Agricultural Economics* 88(1):28-42.

Nhancale, B. and R. Smith. 2011. "The influence of planning unit characteristics on the efficiency and spatial pattern of systematic conservation planning assessments." *Biodiversity and Conservation* 20(8): 1821-1835.

Noss, R.F. 2001. “Forest Fragmentation in the Southern Rocky Mountains.” *Landscape Ecology* 16(4):371-372.

Polasky S., J.D. Camm, and B. Garber-Yonts. 2001. “Selecting biological reserve cost-effectively: an application to terrestrial vertebrate conservation in Oregon.” *Land Economics* 77(1):68-78.

Polasky, S., Lewis, D., A. Plantinga and E. Nelson. 2009. “Implementing the optimal provision of ecosystem services.” *Proceedings of the National Academy of Sciences* 111(2009): 6248-6253.

Salafsky, N., and R. Margoulis. 1998. “Measures of success: designing, managing, and monitoring conservation and development projects.” Washington, DC: Island Press.

Simberloff, D. S. and L. G. Abele. 1982. “Refuge design and island biogeograpic theory - effects of fragmentation.” *American Naturalist* 120(1):41-56.

Sims, K. 2010. “Conservation and development: Evidence from Thai protected areas.” *Journal of Environmental Economics and Management* 62(1):94-114.

Snyder, S.A., Kilgore, M.A., Hudson, R., and J. Donnay. 2007. “Determinants of forest land prices in Northern Minnesota: a hedonic pricing approach.” *Forest Science* 53(1):25–36.

Sutton, N. and P. Armsworth. 2014. “The Grain of Spatially Referenced Economic Cost and Biodiversity Benefit Data and the Effectiveness of a Cost Targeting Strategy.” *Conservation Biology* 28(6):1451-1461.

Tear, T., B.N. Stratton, E.T. Game, M.A. Brown, C.D. Apse and R.R. Shirer. 2014. “A return-on-investment framework to identify conservation priorities in Africa.” *Biological Conservation* 173(1):42-52.

The Nature Conservancy. 2000. Southern blue ridge ecoregional conservation plan. Technical report, The Nature Conservancy and the Southern Appalachian Forest Coalition.

The Nature Conservancy. 2001. Central Appalachian forest ecoregional plan. Technical report. The Nature Conservancy.

The Nature Conservancy. 2003. The Cumberlands and Southern Ridge and Valley ecoregion: A plan for biodiversity conservation. Technical report. The Nature Conservancy.

US Census Bureau. Census 2000 Summary File 3 (SF 3). Generated by Dr. Tae-young Kim. using American FactFinder. Internet site: http://factfinder2.census.gov. (accessed February 15, 2013).

US Census Bureau. TIGER/Line Shapefile. American Community Survey 5-year estimates. 2007-2011. Internet site: http://census.gov/geo/maps-data/tiger-data.html (accessed February 15, 2013).

United States Geological Survey (USGS). Biodiversity information serving our nation database. (BISON). Washington, D.C. Internet site: http://www.bison.ornl.gov (accessed August 20, 2013).

United States Geological Survey (USGS). Gap Analysis Program (GAP). Protected Areas Database of the United States (PADUS), version 1.3. (accessed November 10, 2012).

Wiens, J. and D. Bachelet. 2014. “Matching the Multiple Scales of Conservation with the Multiple Scales of Climate Change.” *Conservation Biology* 24: 51-62.

Wilson, K. A., J. Carwardine, and H. P. Possingham. 2009. “Setting conservation priorities.”*Annals of the New York Academy of Sciences* 1162(2009):237–64.

Wooldridge, J.M. 2010. Econometric *Analysis of Cross Section and Panel Data* 2nd ed. MIT Press, Cambridge, MA, 201

Table 1. **Variable definitions and descriptive statistics (n = 82)**

Variables	Definition	Mean (Std Dev)
Dependent variables		
Acquisition cost	Acquisition cost of protected area (2000 US dollar)	424,414.08 (849,426.70)
Change in effective mesh size	Difference between the effective mesh size within a 5 km^2 buffer around the centroid of a protected parcel after and before acquisition ($kilometer^2$)	24.02 (68.21)
Geophysical variables		
Protected area size	Size of protected area ($kilometer^2$)	108.82 (233.08)
Average slope	Average slope (degree)	12.53 (7.08)
Average elevation	Average elevation (meter)	519.87 (287.25)
Distance related variables		
Proximity to city	Distance to nearest major city with 10,000 or more population (kilometer)	26.52 (11.65)
Proximity to water body	Distance to nearest water body (kilometer)	17.51 (11.00)
Proximity to park	Distance to nearest state or national park (kilometer)	6.94 (5.87)
Proximity to major highway	Distance to nearest interstate or state highway (kilometer)	2.79 (2.11)
Socioeconomic variables		
Population	Population within census block-group	1,361.39 (575.45)
Median household income	Median household income within census block-group (2000 US dollar)	35,570.76 (9,258.60)
Initial stock of conservation benefit		
Weighted species richness	Target species richness multiplied by the quotient of the size of the protected parcel and the 5 km^2 buffer	0.007 (5.311)
Effective mesh size before acquisition	Effective mesh size before acquisition of the protected area ($kilometer^2$)	225.41 (532.38)
Percentage of protected area prior to acquisition	Percentage of 5 km^2 buffer that is protected area before acquisition (percentage)	12.64 (13.04)

Table 2. Goodness of fit for the GS2SLS model using different spatial weight matrices

Spatial weight matrices	Conservation Benefit		Acquisition Cost	
	Adjusted-R^2	Log-likelihood	Adjusted-R^2	Log-likelihood
K nearest neighbor (KNN)				
K=2	0.200	-64.234	0.635	-116.851
K=3	0.355	-64.119	0.644	-115.926
K=4	0.218	-64.426	0.643	-116.073
K=9	0.330	-64.801	0.763	-115.133
KNN × Inverse distance				
K=2	0.302	-63.868	0.653	-114.644
K=3	0.312	-63.590	0.650	-115.037
K=4	0.307	-63.537	0.650	-115.091
K=9	0.292	-63.369	0.659	-114.232
Inverse Distance	0.213	-63.491	0.659	-114.309

Table 3. Parameter Estimates from GS2SLS using a third-order KNN weight matrix

Variables	Change in Effective Mesh Size	Acquisition Cost
Constant	-4.578 (0.161)	13.566 (7.878)
Protected area size	0.590* (0.152)	-------
Change in effective mesh size	-------	0.467* (0.076)
Geophysical variables		
Average elevation	0.011 (0.430)	0.078 (0.220)
Average slope	0.172 (0.453)	-0.099* (0.045)
Distance related variables		
Proximity to the nearest major city	-0.426 (0.356)	0.235 (0.263)
Proximity to the nearest water body	0.246 (0.241)	-0.438* (0.177)
Proximity to the nearest park	0.021 (0.037)	-0.016 (0.026)
Proximity to the nearest major highway	0.172 (0.215)	-0.090 (0.098)
Socioeconomic variables		
Population	-------	0.427 (0.294)
Median household income	-------	-0.349 (0.535)
Initial stock of conservation benefit		
Weighted species richness	-0.102 (0.188)	0.299* (0.095)
Effective mesh size before acquisition	-1.00 (0.084)	-0.183* (0.051)
Percentage of protected area prior to acquisition	1.712* (0.000)	-------
Spatial lag	0.300 (0.770)	0.219 (0.152)
Spatial error	0.106 (0.770)	-0.260 (0.269)
Adjusted R^2	0.274	0.580
AIC	264.715	215.794

Note: Numbers in parentheses are standard errors, and * denotes significance at the 5% level.

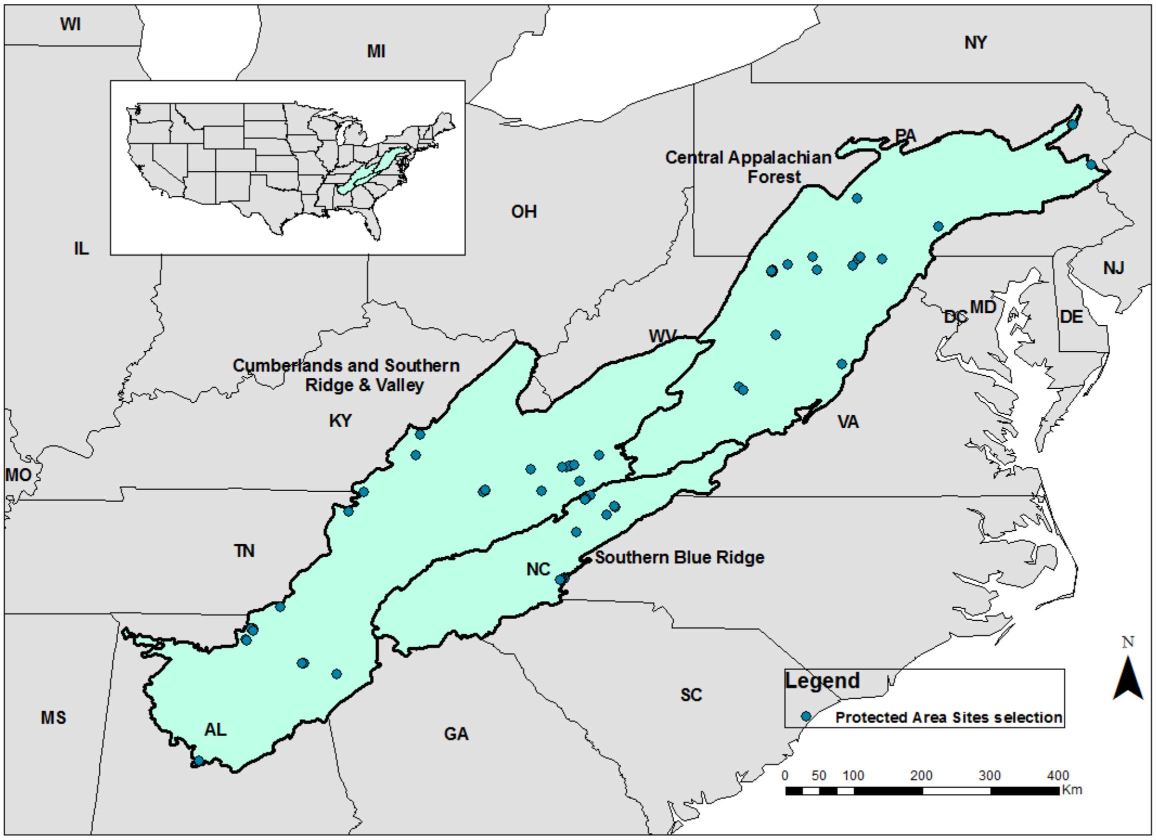
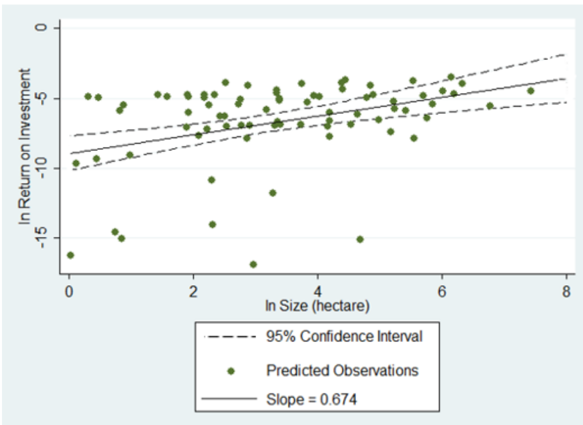


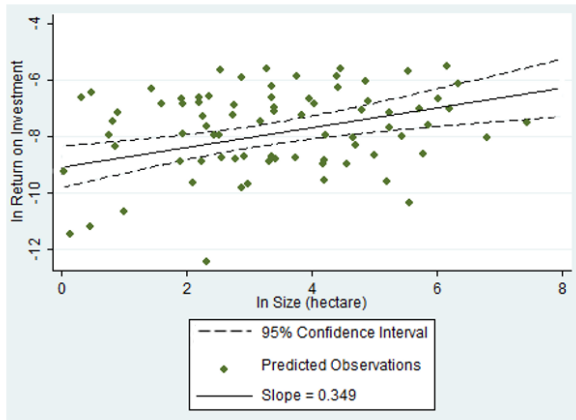
Figure 1. 82 Fee Simple Transactions Made by TNC in Central and Southern Appalachian Forest Ecosystems during 2000-2009

Figure 2. Empirical Results – ROI regressed on protected area size with and without spatial spillovers

a) with spatial spillovers



b) without spatial spillovers



Supplementary Materials

S1. Numerical example of change in the effective mesh size with small- and large-parcel acquisitions

Suppose Figure 3 illustrates a sample landscape before TNC acquisition where protected areas are 1 km^2 and 1 km^2 in size and the total area of the landscape is 5 km^2. Here, the effective mesh size is $(1^2 + 1^2)/5 = 0.40$ km^2.

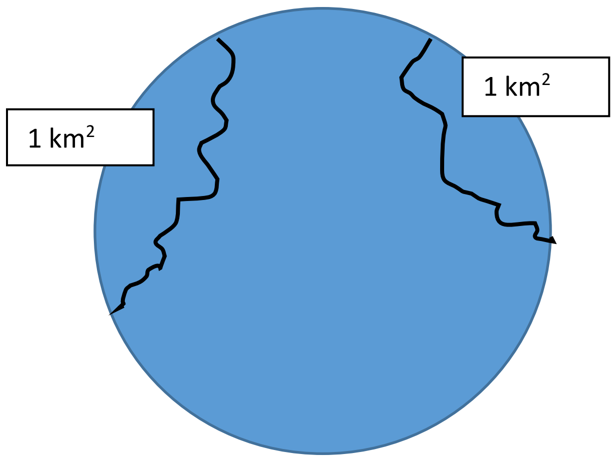


Figure 3. Sample landscapes before TNC acquisition

Now, suppose TNC acquired an additional 1 km^2 for the case of a small increase in effective mesh size (left in Figure 3) and a large increase in effective mesh size (right in Figure 3).

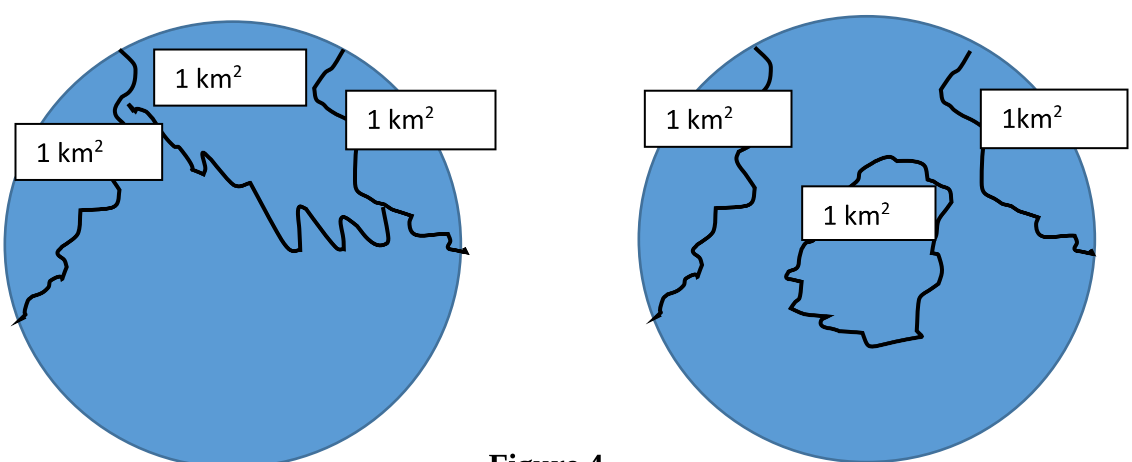


Figure 4.
Sample landscapes after TNC acquisition

The effective mesh size for the cases of connected parcel acquisitions and non-connected parcel acquisitions are, respectively, $((1+1+1)^2)/5 = 1.8$ km^2 and $(1^2 + 1^{2+} 1^2)/5 = 0.6$ km^2. The change in effective mesh size for the case of an acquisition that connects previously established protected areas is much larger (i.e., 1.8 km^2- 0.40 km^2 = 1.4 km^2) than the change in effective mesh size for the case of an acquisition in the landscape that does not connect established protected areas (i.e., 0.60 km^2 - 0.40 km^2 = 0.20 km^2). As illustrated in this numerical example, the effective mesh size will increase with acquisition of new protected area, and will increase more when a new protected area can join other protected areas already in the landscape.

As shown in Figure 4 above, an exceptionally small change in effective mesh size is usually related to a parcel that was completely unconnected to other protected areas, thereby bringing down the overall average patch size and decreasing the likelihood that two individuals dropped randomly into habitat in the landscape would be in the same patch.

S2. Calculation of effective mesh size using probabilities

Given the sample landscapes in Figure 3, the effective mesh size is 2.2 km^2 (i.e. $(1^2 + 1^2 + 3^2)/5 = 2.2$ km^2) using the second part of equation (3), $M = \frac{1}{A_t}\sum_{j=1}^{n} A_j^2$. Alternatively, the effective mesh size can be calculated by multiplying the total area by the probability of two individual animals being in the same parcel using the first part of equation (3), $M = A_t \cdot P$. In this application, we use the following logic to calculate the effective mesh size. The probabilities of one animal being in parcels A_1, A_2, and A_3 are $\frac{1}{5}, \frac{1}{5}$, and $\frac{3}{5}$, respectively. Then, the probabilities of two animals being in parcels A_1, A_2, and A_3 are $\frac{1}{25}, \frac{1}{25}$, and $\frac{9}{25}$, respectively. Consequently, the total probability of two animals being in the same parcel in this landscape is the sum of two animals being in parcels A_1, A_2 and A_3 (i.e. $\frac{1}{25} + \frac{1}{25} + \frac{9}{25} = \frac{11}{5}$). To convert this probability to effective mesh size, we multiply this total probability by total landscape size (i.e. $\frac{11}{25} \times 5\ km^2 = 2.2\ km^2$). This numerical exercise shows how the effective mesh size represents the conversion of total probability of two animals being in the same parcel in a given landscape into the size of connected habitat necessary for species survival.

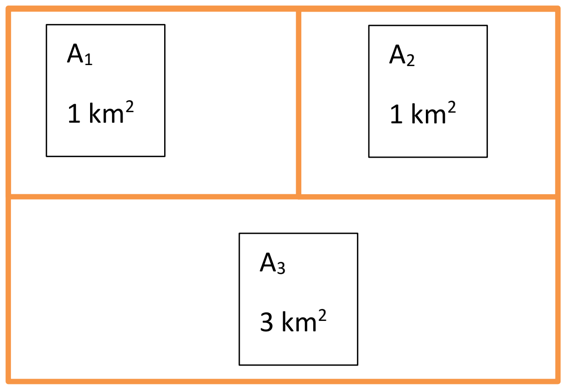


Figure 5. Sample landscape where divided areas represents parcels (i.e., A_1, A_2. and A_3)

S3. GS2SLS model

In the first stage of the GS2SLS model in equation (2), B is regressed on a set of instruments that consists of exogenous variables S and Z (referred to as "reduced form equation") to predict $\hat{B}$. Additionally, to create the spatial lag variables, $\widehat{\mathrm{H}}$ and $\widehat{\mathrm{A}}$, $\mathrm{H} = [B,\ \mathrm{X}]$ is regressed on a set of instruments (i.e., H, W(H), and WW(H)) to predict $\widehat{\mathrm{H}}$, and A= [S, Z] is regressed on a set of instruments (i.e., A, W (A), and WW(A)) to predict $\widehat{\mathrm{A}}$, equation (2) is re-estimated using OLS after substituting the predicted values from the reduced form equation $\hat{B}$ and the predicted values of the spatial lags for acquisition cost and change in effective mesh size, $\widehat{\mathrm{H}}$ and $\widehat{\mathrm{A}}$. The corrected standard errors for the acquisition cost equation are calculated as $V_e(\Phi') = \hat{\sigma}^2[X'X]^{-1}$ where $\hat{\sigma}^2 = \varepsilon'\varepsilon/(N - K_1)$; N is the number of observations; K_1 is the number of variables in the vector of exogenous and predetermined variables X in the second-stage cost equation including H and $\widehat{\mathrm{H}}$ and $\varepsilon = C - \Sigma B + X\Phi$ (Wooldridge, 2002, p. 100).