Environ Resource Econ (2016) 63:719–744
DOI 10.1007/s10640-014-9826-4

# Tradable Set-Aside Requirements (TSARs): Conserving Spatially Dependent Environmental Amenities

**Gregory M. Parkhurst · Jason F. Shogren · Thomas Crocker**

Accepted: 27 August 2014 / Published online: 19 September 2014


**Abstract** Land conversion patterns can conflict with endangered species protection by fragmenting the landscape. Incentive mechanisms can help mitigate the threat of habitat fragmentation by aggregating landowner conservation decisions across the landscape. The optimal conservation strategy for endangered species can target the most connected habitat cluster as an initial starting point, and then expand the conservation patch to maximize connectivity. Herein we present an incentive mechanism, the tradable set-aside requirements (TSARs), designed to target the low cost contiguous conservation landscape and share the burden of conservation among landowners. In the lab, we examine the performance of two land use conservation policies: TSARs, and the TSARs combined with an agglomeration bonus. Evaluated by economic and biological measures of efficiency, we find that TSARs, relative to a command and control policy, increases patch size and habitat connectivity within the landscape. Additionally, combining TSARS with the agglomeration bonus increases biological efficiency (habitat connectivity and patch size within the landscape) but at a price—higher opportunity cost. TSARs with the agglomeration bonus can be more cost-effective than a TSARs only policy for species sensitive to large core habitat requirements and landscape connectivity.

Thanks to participants at workshop on *Mechanism Design and the Environment* at the Royal Society of Edinburgh for their helpful comments and funding. We also thank Brandon Koford, Travis Warziniack, and the reviewers for their insightful comments. Thanks to the US Department of Agriculture, and the University of Wyoming Stroock and Bugas funds for partial financial support. We thank the Norwegian University of Life Sciences for their support while working on this project.

G. M. Parkhurst
Department of Economics, Weber State University, Ogden, UT 84408, USA
e-mail: gregoryparkhurst@weber.edu

J. F. Shogren (✉) · T. Crocker
Department of Economics and Finance, University of Wyoming, Laramie, WY 82071, USA
e-mail: jramses@uwyo.edu

T. Crocker
e-mail: tcrocker@uwyo.edu

**Keywords** Mechanism design · Conservation · Tradable set-aside requirements · Agglomeration bonus · Experimental economics

## 1 Introduction

Economists believe that positive financial incentives can help induce private landowners to cooperate with regulatory protection of endangered species.[1] Over the last decade, economists have focused on how best to design incentives to help create spatially dependent reserves that cost-effectively reduce habitat fragmentation (see for example Parkhurst et al. 2002; Polasky et al. 2008). The primary mechanism to provide these incentives is to create market prices by constructing a scarce and tradable habitat conservation "good". Based on Crocker's (1966) original idea of tradable pollution permits, market-based institutions to protect habitat fall into two categories: (1) tradable development rights; and (2) conservation banking. Tradable development rights (TDR) can have desirable economic efficiency properties (Thornes and Simons 1999; Boyd et al. 2000). For a TDR policy, a regulator establishes conservation areas (sending zones) and development areas (receiving zones), sets the maximum amount of allowed development in the receiving zones, allocates TDRs to sending zone landowners (i.e., the sellers). A market is then created so receiving zone landowners (the buyers) and sellers can reallocate TDRs. Buyers purchase TDRs to increase their density above a pre-established level set by the regulator (Mills 1980).

TDR policies have been used to protect environmental amenities for the past 40 years. Over 190 TDR programs exist in the United States. On-the-ground experience suggest TDRs work better when the demand for increased development is thick, areas allocated for conservation and development are delineated and adhered to strictly, regulations specifying the method for transferring development rights are transparent and rigidly enforced, mutually beneficial trades exist and their prices are made common knowledge, and program regulations are simple and credible (Pruetz and Standridge 2009).

In most current TDR programs, development density is the traded commodity; buyers of TDRs can increase density on their land while sellers forego the right to increased development. Further, sending zones and receiving zones are specified prior to market interactions, preempting the market from determining the allocation of conservation within the landscape (Pruetz and Standridge 2009). A variant to a traditional TDR policy would allow for trade in biodiversity in which the commodity being traded is habitat, and where ownership of a tradable biodiversity credit allows the owner to destroy the habitat on his parcel (see, e.g., Drechsler and Wätzold 2009; Wissel and Wätzold 2010). Drechsler and Wätzold (2009) model a tradable biodiversity credit approach where trade can occur when the increase in biodiversity is greater than the loss of biodiversity. Biodiversity value is location dependent and increases with the number of conserved bordering parcels. The greater the opportunity cost heterogeneity and the lower the level of spatial interaction across the landscape, the less cost-effective is a tradable biodiversity credit policy (Drechsler and Wätzold 2009). Location-dependent trading ratios, however, introduce a level of complexity into the biodiversity credit market, potentially reducing the performance of the market institution to protect endangered species (Pruetz and Standridge 2009).

[1] See for example the work of Latacz-Lohmann and Van der Hamsvoort (1997), Bean (1998), Shogren et al. (1999), Ferraro and Kiss (2002), Smith and Shogren (2002), Parkhurst and Shogren (2003), Stoneham et al. (2003), Langpap (2004, 2006), Lewis and Plantinga (2007), Feng (2007), Adler (2008), Ferraro (2008), Lewis et al. (2009, 2011), and Hanley et al. (2012).

Conservation banking is a second market approach for protecting endangered species (see Parkhurst and Shogren 2003). Conservation banks create permanent habitat reserves to mitigate the impacts of development on endangered species populations (USFWS 2012). Owners of conservation banks can be government or private entities. Increasingly, private for-profit entities own and operate conservation (mitigation) banks (Fox and Nino-Murcia 2005; Robertson and Hayden 2008). As of 2011, over 45 conservation banking programs exist around the world, many with numerous conservation sites (Madsen et al. 2011).

Credits are awarded to conservation banks based on the established critical habitat or the number of endangered species protected within the bank. Credit awards depend on many factors including acreage, number and types of species, and type of habitat and vegetation. They are negotiated on a case-by-case basis (Parkhurst and Shogren 2003; Madsen et al. 2010; USFWS 2012). Conservation bank owners can sell credits within the area the conservation bank services to developers to mitigate the adverse impacts of development on endangered species. Developers can purchase credits on an as needed basis, or purchase additional credits and bank them for future projects. The market determines the price of credits. Developers participate when the benefit of the credit exceeds the credit price and the credit price is less than alternative forms of onsite mitigation. Any profits made by bank owners encourage the creation of additional conservation banks (Parkhurst and Shogren 2003).

These two market-based institutions are economically efficient, maximizing benefits (environmental and pecuniary), provided certain conditions are satisfied. Conservation banking can maximize benefits when the price of credits is sufficiently high to induce environmental entrepreneurs to establish conservation banks to satisfy demand. Conservation banks are subject to extensive regulatory oversight, maintenance and reporting criteria (Madsen et al. 2010) creating significant sunk costs which may deter entry if the expected prices for credits are too low (Robertson and Hayden 2008). A TDR program can maximize benefits when the demand is strong, and when either low land development values are perfectly correlated with high conservation values, or the regulator has perfect information and can assign conservation to the low opportunity cost conservation landscape design, or both. In the absence of these conditions, conservation banking and TDRs are unlikely to fully meet desired biological objectives. These competitive markets work best when they are "thick" with buyers and sellers of habitat. Meeting these two conditions successfully creates a challenge for cost-effective habitat conservation on private land because conservation markets are typically "thin".

Herein we introduce the idea of a tradable set-aside requirement (TSARs) mechanism, without and with the agglomeration bonus, as a tool to both thicken the market and promote coordination. TSARs address the question of thickening thin markets through full participation of relevant landowners and burden sharing, which uses heterogeneous productive values to its advantage. We propose and testbed a mechanism—the TSARs mechanism—designed to work even with thin markets for development and imperfect correlation between conservation and least-cost objectives. The TSARs mechanism works in three steps. First, a regulator specifies a conservation objective (e.g., contiguous habitat which implies the total number of acres needed).[2] Second, the regulator allocates the set-aside requirements proportionally among landowners. Third, a market opens up to trade the set-aside requirements—one landowner pays another to take a requirement off his or her hands. The net effect is to share the cost of conservation across all regional landowners, thereby tempering their resistance to preserving biodiversity on private lands (see Parkhurst and Crocker 2002).

[2] See for example Nelson et al. (2008), Drechsler et al. (2010), Hennessy and Lapan (2010), and Werling et al. (2014); promote the use of spatially explicit incentive mechanisms in agricultural landscapes. Warziniack et al. (2007) apply the agglomeration bonus to a forest landscape. Polasky et al. (2011) discuss implications of spatially explicit incentives in a landscape that provides numerous and competing environmental amenities.

We then add an *agglomeration bonus* game to the TSARs market to address the coordination challenge needed for cost-effective species protection.[3] To induce the desired habitat configuration the regulator pays a landowner a government-financed bonus for each border shared between two conserved parcels (Parkhurst et al. 2002). The bonus induces all landowners to coordinate their conserved parcels into contiguous habitat reserves. The agglomeration bonus can be structured to satisfy numerous spatial configurations (see Parkhurst and Shogren 2007, 2008).[4] Combining the TSARs with agglomeration bonus does not increase the "quantity" of trades—rather the goal is to increase the biological accuracy and precision with which the trades satisfy the biological objective in a least cost manner. The TSARs with agglomeration bonus works by changing relative land prices enough to create more "high-habitat quality" trade than the TSARs alone.[5]

Anyone interested in how incentive devices like TSARs can induce landowners to be accountable for their spatial interdependencies must balance a clear and logically precise articulate of simple relationships with a realistic description of complex processes. Bertrand Russell is reported to have said scientific progress is made by "analysis and artificial isolation" (Russell 2009).[6] Here we use the artificial isolation inherent in experimental procedures to help logical articulations of spatial independent incentives move a bit closer to reality. Test-bedding the TSARs without and with the bonus in the laboratory, we compare three bioeconomic efficiency measures (defined in detail in the results section) of these two institutions to a benchmark command and control approach that forces each landowner to conserve an equal amount of land. We observe that the TSARs-only policy, relative to command and control, increases patch size and habitat connectivity within the landscape. We also find that combining TSARS with the agglomeration bonus increases biological efficiency (habitat connectivity and patch size within the landscape) but at a price—higher opportunity cost. The TSARs with bonus could translate into an overall gain as the regulator spends more resources to get even more biodiversity value (e.g., greater landscape connectivity).

[3] Parkhurst et al. (2002) introduced the idea of the agglomeration bonus to facilitate the coordination of land retirement decisions across landowners or landscape attributes. Albers et al. (2008) find the agglomeration bonus can attenuate the "crowding out" effect. As one might expect based on transaction cost theory, Banerjee et al. (2012) find agglomeration bonus induced coordination occurs less frequently in larger networks. Reeson et al. (2011) show a multi-round auction with information feedback can improve coordination within the landscape. Wissel and Wätzold (2010) proposed a tradable scheme that adds a "neighborhood bonus" to the value of the permit through the alteration of the trade ratio. The neighborhood bonus is similar to the agglomeration bonus idea, but differs in two ways: (1) it is internalized in the value of the biodiversity credit—more connected, more biodiversity value; and (2) it is based on the Moore (the eight cells surrounding a central cell) rather than the von Neumann Neighborhood (the four cells orthogonally surrounding a central cell).

[4] The agglomeration bonus mechanism we use in this paper coordinates land within a landowners land holdings, but not across landowners. The agglomeration bonus is a menu of subsidies that can meet numerous conservation objectives including coordinating across landowners, coordinating within an individual's own landholdings, coordinating along an environmental amenity such as a river or protected wilderness area, and coordinating to create large or small reserves and corridors (see Parkhurst and Shogren 2007, 2008).

[5] Goldman et al. (2007) find an agglomeration bonus (cooperation bonus) to be more straightforward and more flexible than a conservation bank like mechanism (entrepreneur incentive). Adding the bonus to TSARs has the potential to improve on the design of the conservation landscape.

[6] By "artificial isolation" Russell points the reader toward the experimental method and mindset, in which the researcher gains insight into a complex mechanism by using a sterile environment to control for noise and confounding factors (see for example Conant 1951; Smith 2008).

## 2 The Model

Consider a landscape consisting of 100 parcels of identical size, in a $10 \times 10$ matrix configuration. Define $S_j$ (j = 1, 2, ..., 100) to be the spatial location of parcel $j$ within the landscape. The landscape is equally divided between four profit maximizing landowners each possessing fee-simple property rights to a continuous $5 \times 5$ section of the landscape, such that each landowner shares a common boundary with a row neighbor and a column neighbor, and each boundary is linked with 5 parcels. Let $L_i$ $(i = 1, 2, 3, 4)$ represent landowner $i$'s landholdings (see Fig. 1a).

Each parcel is suitable for either the production of a market good or for the conservation of a nonmarket ecosystem service—species protection. Let $d_j$ be an indicator variable taking a value of 1 if parcel $S_j$ produces a market good, and $d_j$ is 0 if parcel $S_j$ is conserved for its intrinsic value for species protection. Define $x_j$ to represent the pecuniary net return to the landowner from parcel $S_j$ when producing the market good. Assume all net returns are common knowledge. The net returns to production of the market good are heterogeneous and parcel specific, resulting from spatial differences in environmental factors and differences in landowner specific management practices. Eq. (1) represents the net return to the landowner:

$$\pi_i = \sum_{j \in L_i} d_j x_j \tag{1}$$

Conservation of endangered species is a pure public good. The environmental benefits from parcel $S_j$ depend on the spatial distribution of conserved parcels, with the environmental benefit contribution of parcel $S_j$ increasing the more connected is the cluster of conserved parcels. The location of conserved parcels impact the environmental benefits in two distinct ways: (1) when clustered parcels share common borders, core habitat area is increased, which reduces harmful edge effects (Saunders et al. 1991); and (2) the more connected are clustered parcels, the greater is the functional connectivity (Tischendorf and Fahrig 2000).

Assume the regulator knows the habitat configuration yielding the greatest environmental benefit. Let $V(K, M; \lambda)$ represent the biological benefits provided from the aggregate species protection produced across the landscape, where $K$ is core habitat area, $M$ is the overall connectivity of the landscape, and $\lambda$ is a vector of species specific characteristics such as breeding pairs, initial population, and dispersal ability. We capture the core habitat area $(K)$ by adjusting the total area of parcels conserved for species protection $(A)$ for edge effects $(E)$. We adapt the approach of Hof and Bevers (1998) and calculate core habitat as:

$$K = A - E \tag{2}$$

Such that,

$$A = B * H \tag{3}$$

$B$ is the total number of set-aside requirements allotted to the considered landscape and $H$ is the area of each parcel. We calculate the amount of area lost to edge as:

$$E = B * (4 - l) - \tau l \left[ \sum_{j=1}^{100} b_j \left( \sum_{-j=1}^{100} \gamma_{j,-j} b_{-j} \right) \right] + 4\tau^2 \mu, \tag{4}$$

$l$ is the length of a parcel side, $\tau$ is the percentage of one side of the parcel lost to edge, and $b_j$ $(b_{-j}) = 1$ if parcel $S_j$ $(S_{-j})$ produces the species protection; $b_j$ $(b_{-j}) = 0$ otherwise. $\gamma_{j,-j} = 1$ if parcels $b_j$ and $b_{-j}$ share a common border; $\gamma_{j,-j} = 0$ otherwise. Define $\mu$ to be

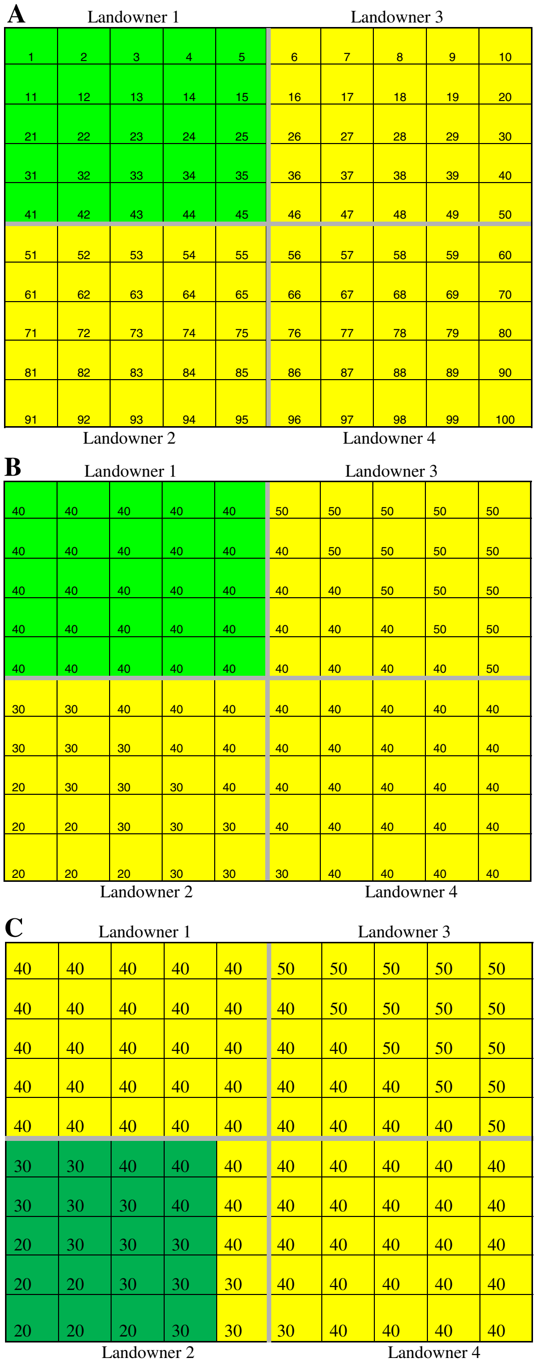


**Fig. 1** **a** Land grid: Spatial parcel location cell #s. **b** Experimental land grid: Production values by parcel. **c**. Land grid: Ideal landscape design

the number of isolated patches within the landscape. A conserved parcel is considered to be an isolated patch if it shares zero borders with other conserved parcels in its von Neumann Neighborhood (the four cells orthogonally surrounding a central cell).

Let $M$ represent the connectivity of the critical habitat across the landscape. Similar to Drechsler and Wätzold (2009) we use the concept of the Moore Neighborhood to establish a proxy for species protection connectivity within the landscape. The Moore Neighborhood is a square shaped set of parcels, surrounding the parcel of interest with range $r$. For $r = 1$, the Moore Neighborhood consists of the 8 parcels surrounding the center parcel of interest. When $r = 2$, the Moore neighborhood consists of the 24 parcels which make a square around the center parcel of interest. The more extensive the linkages with other conserved parcels, the higher the value of that parcel's Moore Neighborhood.

Let $m_j$ represent the value of the Moore Neighborhood for $S_j$, such that if every parcel within the Moore Neighborhood produces species habitat, $m_j = (2r + 1)^2 - 1$. For each parcel in the Moore Neighborhood of $S_j$ not producing species protection, $m_j$ decreases by 1. Aggregating across the landscape, we measure connectivity as:

$$M = \sum_{j=1}^{100} m_j \tag{5}$$

Assume the environmental benefits, $V(K, M; \lambda)$, increase with increases in both core habitat area and connectivity. Further we assume a threshold exists, $V^*(K^*, M^*; \lambda)$, such that for values of $K$ and $M$ smaller than the threshold, $V(K, M; \lambda)$ increases at an increasing rate. For values of $K$ and $M$ larger than the minimum threshold, $V(K, M; \lambda)$ increases at a decreasing rate.

$$\frac{\partial V}{\partial K} > 0; \frac{\partial^2 V}{\partial K^2} > 0; \forall K < K^* \text{ and } \frac{\partial V}{\partial K} > 0; \frac{\partial^2 V}{\partial K^2} < 0; \forall K > K^* \tag{6}$$

$$\frac{\partial V}{\partial M} > 0; \frac{\partial^2 V}{\partial M^2} > 0; \forall M < M^* \text{ and } \frac{\partial V}{\partial M} > 0; \frac{\partial^2 V}{\partial M^2} < 0; \forall M > M^* \tag{7}$$

Define the economic value of the environmental benefits as $Y(V)$,[7] with marginal benefit:

$$\frac{dY}{dV} > \left(x_j + 4Z\right) \forall x_j, \tag{8}$$

where $Z$ is a government-financed agglomeration bonus paid to the landowner when two of the landowners own parcels share a common border. For the considered landscape and the parcels satisfying (8), the marginal pecuniary value of environmental benefits exceeds the opportunity cost of producing species protection on $S_j$, with or without an agglomeration bonus $Z$, on the maximum of four shared borders.

A conservation agency is considering three policies to promote and protect the habitat critical to a species survival: (1) command and control, which we call the No-Trade Benchmark; (2) TSARs; and (3) TSARs with an Agglomeration Bonus. Consider each in turn.

### 2.1 No-Trade Benchmark

The agency allocates $b$ set-aside requirements to each of four landowners, such that $b$ is an equal share of $B (b = B/4)$. The landowner must set-aside one parcel for the provision of species protection for each set-aside requirement. The landowner faces the following maximization problem:

$$Maximize\ \pi_i = \sum_{j \in L_i} d_j x_j, \text{ subject to } \sum_{j \in L_i} d_j \leq 25 - b. \tag{9}$$

[7] See Martín-López et al. (2008) for an overview of the difficulties in calculating economic value of biodiversity for endangered species.

To maximize profits, the landowner sets $d_j = 1$ on the $(25 - b)$ parcels with the largest values for $x_j,\ j \in L_i$. All remaining parcels are allocated to the protection of critical habitat with no consideration of location effects on the public good. Paying landowners a flat subsidy for each parcel set-aside in critical habitat will not alter the spatial distribution of land uses across the landscape.

### 2.2 TSARs

The agency allocates an equal share of set-aside requirements to each landowner ($b = B/4$), and allows the landowners to trade set-aside requirements with other landowners within the landscape. The landowner faces the maximization problem:

$$Maximize\ \pi_i = \sum_{j \in L_i} d_j x_j + PT,\ \text{subject to} \sum_{j \in L_i} d_j \leq 25 - b + T, \tag{10}$$

where $T$ is the number of set-aside requirements traded and $P$ is the negotiated price per traded requirement. $T$ is positive if the landowner's net trades result in an inventory reduction of set aside requirements and negative if net trades result in an increased inventory of set-aside requirements. Trade is expected to result in an increased inventory of set-aside requirements for landowners with lower productive value parcels of the market good, and a decrease in inventory for landowners with higher productive value parcels of the market good. In addition, the expected price for the high-value landowners is negative—they expect to pay to induce low-value landowners to take the set-aside requirement liability.

Landowners maximize profits following trade by setting $d_j = 1$ on the (25 − b + T) parcels with the largest values for $x_j,\ j \in L_i$. The remaining parcels are conserved without consideration on how location affects the public good. Paying landowners a flat subsidy for each parcel set-aside for critical habitat would shift the market price, but would not change the distribution of critical habitat across the landscape.

### 2.3 TSARs with an Agglomeration Bonus

The regulator allocates an equal share of set-aside requirements to each landowner ($b = B/4$), allows landowners to trade set-aside requirements with other landowners within the landscape, and also pays an agglomeration bonus for each shared border between two of the landowner's own conserved parcels. This landowner faces the following maximization problem:

$$Maximize\ \pi_i = \sum_{j \in L_i} d_j x_j + PT + ZW_i,\ \text{subject to} \sum_{j \in L_i} d_j \leq 25 - b + T, \tag{11}$$

$$\text{and } W_i = \left[ \sum_{j=1}^{25} b_j \left( \sum_{-j=1}^{25} \gamma_{j,-j} b_{-j} \right) \right] \forall j, -j \in L_i, \tag{12}$$

$W_i$ is the number of shared borders within the landowner's parcel holdings. The agglomeration bonus has three impacts: (i) it creates a network externality among own conserved parcels; (ii) by setting the agglomeration bonus to exceed the opportunity cost of conservation the agglomeration bonus changes participants' perception of TSARs—they now see TSARs as an asset, not a liability; (iii) because TSARs with the agglomeration bonus is an asset, owners will participate voluntarily in the conservation program.

With the TSARs with agglomeration bonus policy, so long as $Z$ is strictly larger than the productive value of the market good, we expect P to be positive. Moreover, we expect the inventory of set-aside requirements to be reduced for landowners with parcels that have higher productive values for the market good and an increase in the inventory of set-aside requirements for landowners with lower productive values for the market good.

*Conservation Agency:* The agency will choose to implement the policy which maximizes net social benefits:

$$Maximize\ Y(V) - \sum_{j=1}^{100} \left(1 - d_j\right) x_j - Z \sum_{i=1}^{4} W_i, \text{ subject to} \sum_{j=1} d_j \le 100 - B \quad (13)$$

Pecuniary benefits from the provision of species protection depend both on the functional form of environmental benefits and the public's valuation of them (which we assume the regulator knows).

## 3 Experimental Design

Our experimental design was adapted from the procedures in Parkhurst and Shogren (2007, 2008). Forty-eight participants were recruited campus wide and were told to report to a computer lab at a given time. Participants were informed the experiment would take 2–3 h and average earnings would be between \$20 and \$50 (average earnings = \$39.98). Earnings were paid in cash at the end of the experiment and were private information. Experimental instructions, which the monitor read aloud, were provided to all participants.[8]

All experiments were conducted on computers. Participants were not told the objective of the experiment—all wording in the instructions and on the computer screens was context free. Participants had an opportunity to ask questions concerning the procedures, which the monitor answered. A quiz was administered to participants to insure comprehension of the experimental design. The monitor walked the participants through two practice rounds to further familiarize them with the experimental design. The monitor handed out the agglomeration bonus specification page, which participants were allowed to review. Each participant entered his or her name and student identification number into the computer, and the computer randomly assigned him or her into a group of four.

Our experimental design had five structural elements—(1) players, positioning, and the land grid; (2) treatments; (3) subsidies, strategies, and calculator; (4) market predictions; and (5) conservation predictions for minimum opportunity cost, core habitat area and landscape connectivity. Consider each in turn.

### 3.1 Number of participants, positioning, and land grid. Participants

Eight participants participated in each session. Each was told they would be randomly assigned to a group, in which each participant's placement within the land grid would remain fixed for the remainder of the experiment. *Positioning*. We chose fixed groupings and fixed placements to provide participants consistency such that past experience can be applied to current actions. *Grid*. Figure 1a, b show the 10 × 10 land grid and the positions of each participant within the grid—which we call Landowners 1–4. Each participant knew he owned a 5 × 5 portion of the 10 × 10 grid, and he could identify his portion relative to the rest of the land grid. The market production values of each participant's 25 cells ranged from

[8] Each session was constrained to eight subjects because the experimental lab had a maximum capacity of ten subjects and the experimental design required 4 subjects in each group. See the Appendix for the exact instructions, which is available on request from the authors.

$20 to $50 (Fig. 1b), creating asymmetries between participants with no two participants having identical grid values. Grid values for all four positions were common knowledge and participants had a specification page that delineated grid holdings and showed the land values for the entire 10 × 10 grid (Fig. 1b). No other values were directly or indirectly communicated. That is, participant choices were purposefully kept context-free, including the computer coloration as "green" parcels placed in market production and "brown" used for set-aside parcels. The land grid values in Fig. 1b were held constant across rounds and across groups. Note the land grid exhibits monotonically increasing productive values from the SW to the NE corner. These values were chosen to represent a landscape in which participants are asymmetric, productive values are heterogeneous, and are spatially auto-correlated to facilitate trade between participants.

### 3.2 Treatments

We tested the three institutional structures developed in the model: Command and control/No Trade benchmark (NT), TSARs only (TO), and TSARs with an agglomeration bonus (TAB). In the NT treatment, each participant was allocated 5 conservation set-aside requirements with one parcel of land satisfying each conservation set-aside requirement. Similarly, in the TO treatment each landowner was allocated 5 set-aside requirements, one parcel of land being set aside for each requirement. Participants in this treatment could trade their set-aside requirements. TSARs were seen as a liability—a landowner must forego productivity on one parcel of land to satisfy the TSAR. A TSAR recipient must be compensated. The TAB treatment was identical to the TO treatment except participants could receive an additional payment—the agglomeration bonus—for each border shared between two of their own conserved parcels. Two sessions with two groups each session were conducted for each treatment.

### 3.3 Subsidies, Strategies, and Calculator

In the NT and TO treatments no subsidies existed—the participants bore the costs of the set-asides. In the TAB treatment, participants earned an additional $50 payment for each border shared between two of their own retired cells—shifting the costs of conservation from the participant to the experiment monitor (proxy regulator). *Strategies*. Participants were instructed they could leave their cells *green*, in which case they earned the value in the cell, or they could *brown out* cells, which meant they earned the applicable subsidies but would forego the production value of the cell. Each subject was required (allowed in the TAB treatment) to "brown out" 5 cells. Note the large set of potential strategies. By presenting participants with the land grid and requiring participation, the participants have 53,130 potential strategies.[9] But in the TO and TAB treatments, the purchase and sales of TSARs changes the number of possible strategies. For the NT treatment, each participant has a dominant strategy of conserving their 5 lowest valued cells. In the TO treatment, each participant's dominant strategy is to conserve the low cost cells corresponding to the number of TSARs owned after trade. In the TAB treatment, the participant's dominant strategy is to conserve the lowest cost cells maximizing agglomeration dollars following trade (see Fig. 1c).

To help participants calculate profits a grid calculator was provided on the computer screen. The grid calculator was a 10 × 10 grid of cells with borders to differentiate each participant's 5 × 5 portion of the land grid. The participant used the calculator to estimate expected profits in two steps: (1) the participant turned green cells to brown cells directly on the land grid

[9] See Parkhurst and Shogren (2007) for an example of similar calculations of the potential strategy set when considering the agglomeration bonus incentive scheme.

calculator based on his or her expectations of the other three participant's set-aside choices; and (2) the participant chose the cells to set-aside on his own portion of the land grid. The participant's choice of grid cells to set-aside was linked directly to his portion of the land grid calculator. When a participant clicked on a cell, the color changed to brown from green, or visa versa. The participant's own potential profits, based on the grid configuration of brown and green cells on the calculator, were calculated and displayed on the computer screen.[10]

### 3.4 TSARs Market and Predictions

An auction window facilitated participant trade in brown out cell requirements (i.e., TSARs). Participants were informed they could be buyers or sellers and were allowed to submit both bids and asks. Further, they were informed that prices could be positive, negative, or zero. The implications of positive and negative prices were discussed. Participants were told all prices must be in whole integers and that they would have 7 min to send messages, use the calculator, send choices, and make trades. The auction window allowed them to make bids or asks for individual units or for multiple units—a separate bid (ask) could be made for each quantity of TSARs up to the maximum individual holdings of 25. This feature was important in the TAB treatment in which the agglomeration bonus created a sticky market when only single unit trading was allowed (purchase of a TSAR could increase the bidder's shared borders by one but diminish the seller's shared borders by two).

### 3.5 Predictions: Market

As an upper benchmark, our market predictions assume a best-case scenario—three transactions occur, one transaction between each landowner and Landowner 2, and the low cost land is conserved. The predicted TSARs quantity traded in the TO treatment is 14. Landowner 2 acquired TSARs from landowners 1 and 3, each trading 5 brown out cell requirements (TSARs) and landowner 4 selling 4 TSARs. Predicted market price is whole integers in the interval of −\$28.00 to −\$40.00{−\$28, −29, ..., −39, −40}.[11] For the TAB treatment, predicted quantity was 15, with Landowner 2 purchasing 5 TSARs from each other landowner. Predicted market price is {\$10, 11, ..., 59, 60}.

### 3.6 Predictions: Minimum Opportunity Cost, Core Habitat Area, and Landscape Connectivity

For the NT treatment, minimum opportunity cost (OC)—measured as the foregone land productivity and subsidy payments, is \$690. From Table 7, we see at the minimum OC, exposed edges fall in the range of 40–72, with 4–14 isolated patches, and landscape connectivity (M) is in the range of 14–64. When the edge effect is 25 %, core habitat (K) is between 5.75

[10] *Communication, Information, and History*. *Communication*. Participants were also provided the opportunity to communicate one message per round. Communication was non-binding, unstructured with no restrictions on timing or content, and in which a common language was implemented by allowing subjects to send messages in their natural language (Crawford 1998). *Information*. After all four participant's choices were submitted the resulting grid was presented to the group. They had common knowledge regarding payoffs and strategies. *History*. The entire $10 \times 10$ grid showing the configuration of brown cells and the payoffs for each subject within the group then appeared in the history box. Participants were also provided with record sheets to further help them keep track of their own and the other group members' choices of strategies and associated payoffs in previous rounds.

[11] The range of market prices is determined as the average price per TSAR for the seller on the lower bound and the average price per TSAR for the buyer on the upper bound.

and 11. For a 10 % edge effect, core habitat is between 13.36 and 16.16. For TO treatment, minimum OC is \$540. Now exposed edges equal 22, 1 patch emerges, and $M$ equals 106. For a 25 % edge effect, core habitat is 14.75; for a 10 % edge effect, core habitat is 17.84. For TAB treatment, minimum OC is \$2,120. Now exposed edges equal 18, only 1 patch results, and $M$ equals 110. When the edge effect is 25 %, core habitat is 15.75; for a 10 % edge effect, core habitat is 18.24.

## 4 Results

We present our experimental results in four steps—(1) an illustrative example to help give the reader a visual sense of the actual observed behavior, (2) group outcomes based on measures of bioeconomic efficiency: lost production efficiency, biological efficiency and rent efficiency, (3) group results for the TO and TAB treatments on two measures of market accuracy: prices and quantities, and (4) the impact of NT, TO, and TAB on opportunity cost (OC), core habitat creation (K), and connectivity (M).

### 4.1 Illustrative Example

Figures 2, 3, 4 illustrate the actual outcomes for one group in each of the three treatments. Figure 2 shows the NT treatment. We see the landowners' conserved cells are distributed in random patterns. In early rounds, Landowners 2 and 4 play dominated strategies, i.e., not conserving their least expensive parcels. By round 6, all four owners are playing their dominant strategies. But conserved parcels are seldom connected. They fall well short of the maximum level of connectivity.

Figure 3 shows a group for the TO treatment. Landowner 2 plays a dominated strategy in rounds 1–7 and 9. He could have increased earnings by spatially reallocating his TSARs to low cost parcels. In rounds 8 and 10–20, he does play his dominant strategy—no reallocation of TSARs can increase his earnings. Landowner 4 plays his dominant strategy in rounds 2–19. Landowners 1 and 3 play their dominant strategies in every round. Also, as the experiment progresses, Landowner 2 increases his inventory of TSARs through trade. In rounds 18–19 the group gets greatest economic aggregate returns. But because the TO treatment does not create incentives to link conserved parcels, maximum payoffs do not imply maximum connectivity. Rather, maximum payoffs imply the minimum productive land is conserved.

Figure 4 considers the group outcomes for TAB. Landowner 2 played his dominant strategy in rounds 2–20. Landowner 4 played dominated strategies whenever he failed to trade away his TSARs—rounds 1, 3–6, 9, 13, and 18. Landowner 1 played a dominated strategy in rounds 2–6, and 20 because he failed to capture the maximum number of agglomeration bonus dollars—a reallocation of conservation would yield an increase in own shared borders and associated subsidy dollars. Landowner 3 played his dominant strategy in every round. As expected, Landowner 2 used trade to increase his holdings of the TSAR asset. In round 16, maximum aggregate earnings and connectivity are achieved. Adding the agglomeration bonus with TSARs induced landowners to minimize the fragmentation of their joint conservation efforts.

### 4.2 Bioeconomic Efficiency

We now consider how the results relate to conservation targets. We evaluate bioeconomic efficiency: lost production efficiency, biological efficiency, and rent efficiency. Lost production

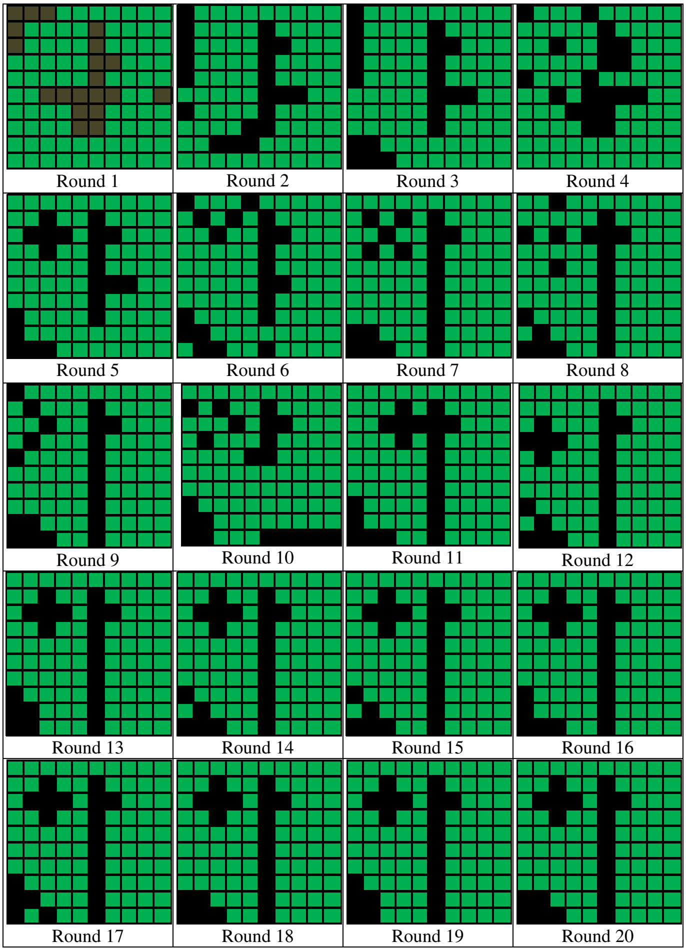


**Fig. 2** Illustrative example—no trade (NT treatment)

efficiency (LPE) captures the idea that we what to minimize losses in productivity due to the incentive scheme. LPE is the ratio of actual foregone productivity to the minimum foregone productivity: LPE = group foregone productivity/540. Biological efficiency (BE) is a gradient measure—the percentage of the shared borders between conserved parcels achieved by the group to the maximum number of shared borders.[12] Rent efficiency (RE) is the percentage of available program rents earned by the group: RE = group earnings/max earnings.[13] RE differs from LPE due to differences in available rents across treatments. The RE measure allows us to proxy how well the landowners understand the treatment mechanism, i.e., how much money they leave on the table. Table 1 presents the descriptive statistics for bioeconomic efficiency. LPE is largest for the NT treatment at 131 % of minimum foregone production

[12] We use Fig. 4 to clarify the BE gradient. In round 1, 28 of a maximum 31 borders are shared between conserved parcels, implying BE = 90.3 %. In round 3, BE = 71.0 % (22 of 31 borders shared). In round 16, BE = 100 % (31 of 31 borders shared).

[13] Maximum earnings depend on the institutional structure of the incentive mechanism, which differs across treatments. RE is an indicator of the ability of groups to earn the maximum available rents.

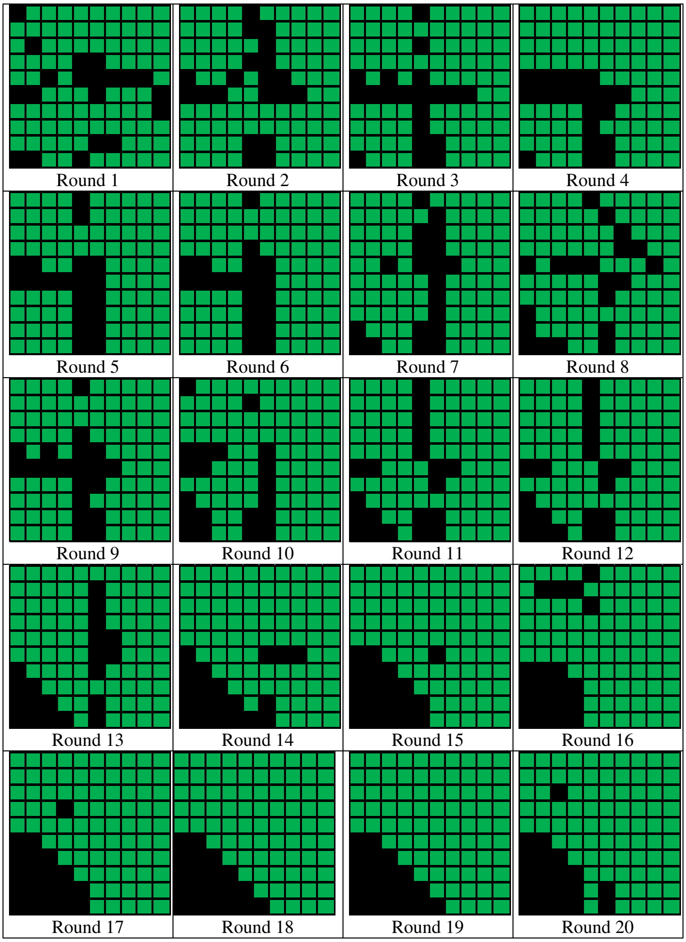


**Fig. 3** Illustrative example—TSARs only (TO treatment)

cost, and lowest for the TO treatment with an increase of 26 % over minimum foregone production cost. BE is lowest for the NT treatment connecting 42 % of the maximum possible number of shared borders, and highest for the TAB treatment in which 81 % of the maximum possible number of shared borders are connected. RE is lowest for the TAB treatment which left about 10 % of the rents on the table, and highest for the NT treatment capturing 99 % of available rents.

We now test the significance of these results using conditional regression analysis. We use a random effects two-limit tobit panel data model, which controls for group specific effects. The tobit model is specified as:

$$Y_{g,t} = \propto + \beta_1 TO_g + \beta_2 TAB_g + \mu_g + \varepsilon_{g,t} \tag{14}$$

In Eq (14), $Y_{g,t}$ denotes group $g$'s bioeconomic metric measurement (LPE, BE, or RE) in round t. $TO_g$ takes a value of 1 if group $g$ was in the TO treatment in round t; 0 otherwise. $TAB_g$ takes a value of 1 if group $g$ was in the TAB treatment in round t; 0 otherwise. $\mu_g$ denotes group-specific characteristics; and $\varepsilon_{it}$ is iid error.

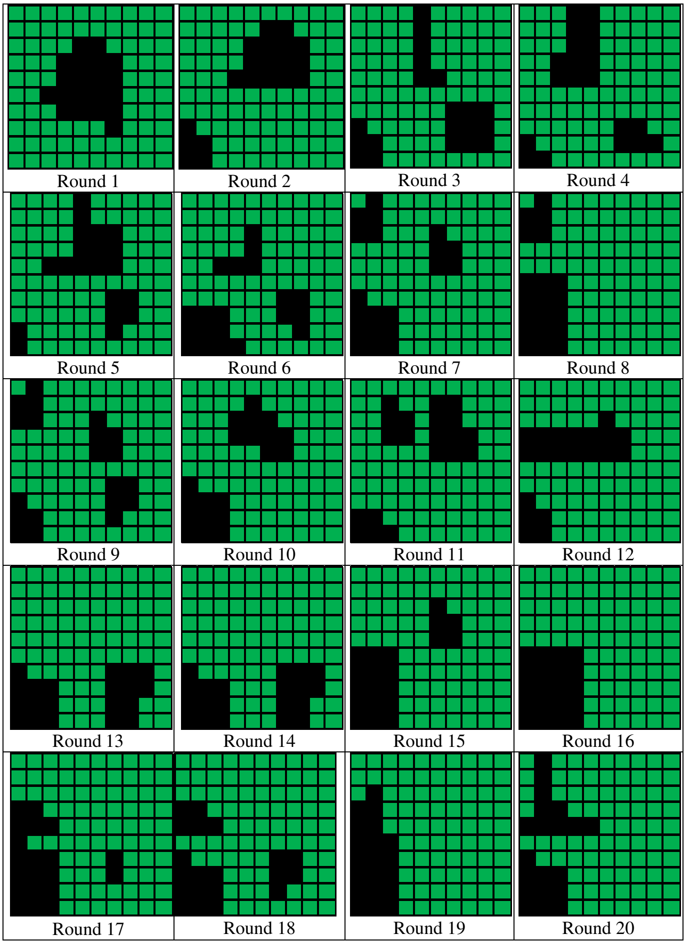


**Fig. 4** Illustrative example—TSARs with agglomeration bonus (TAB treatment)

**Table 1** Descriptive statistics for bioeconomic efficiency

| | NT | TO | TAB |
|---|---|---|---|
| LPE | 1.313 | 1.262 | 1.285 |
| | (0.0585) | (0.1277) | (0.1495) |
| RE | 0.994 | 0.958 | 0.904 |
| | (0.0099) | (0.0204) | (0.0384) |
| BE | 0.418 | 0.592 | 0.813 |
| | (0.1151) | (0.1818) | (0.0750) |
| N | 80 | 80 | 80 |

Table 2 presents the regression results. Consider each efficiency measure in turn.

*Lost Production Efficiency.* Implementing policies that allow for trade in set-aside requirements between individuals making land use decisions is expected to reduce the costs of conservation associated with foregone production. Adding the agglomeration bonus to trade,

**Table 2** Tobit analysis on measures of efficiency: random effects

| Variable | LPE | RE | BE |
|---|---|---|---|
| Constant | 1.338*** | 1.023*** | 0.400*** |
| | (0.026) | (0.010) | (0.020) |
| TO | −0.078 | −0.065*** | 0.176*** |
| | (0.049) | (0.012) | (0.044) |
| TAB | −0.053* | −0.125*** | 0.440*** |
| | (0.030) | (0.013) | (0.048) |
| Sigma (v) | 0.0997*** | 0.028*** | 0.1056*** |
| | (0.002) | (0.001) | (0.003) |
| Sigma (u) | 0.1054** | 0.025*** | 0.0730*** |
| | (0.045) | (0.006) | (0.017) |
| Lower censor | 1.00 | 0 | 0 |
| Upper censor | --- | 1.00 | 1.00 |
| Pseudo $R^2$ | −0.17 | −0.05 | −0.25 |
| N | 240 | 240 | 240 |

Standard errors in parentheses
*** Significant at the 1 % level,
** Significant at 5 % level,
* Significant at 10 % level

which creates spatial interdependencies, can increase the costs of conservation associated with foregone production. We summarize these expectations in three null hypotheses:

$$H_1: LPE_{NT} \geq LPE_{TO},$$
$$H_2: LPE_{NT} \geq LPE_{TAB},$$
$$H_3: LPE_{TAB} \leq LPE_{TO}$$

Our tobit results allow us to reject the first two hypotheses, but we fail to reject the third; adding the agglomeration bonus to trade did not increase LPE significantly. In Table 2, we see the NT treatment results in 133.6 % of the minimum possible foregone production cost outcome ($540). The estimated coefficient on TO is −0.078 ($p$ value = 0.054) indicating LPE is about $42 less for TO relative to NT, allowing us to reject $H_1$. The estimated coefficient on TAB takes a value of $-0.053$($p$value $= 0.038$) and reduces LPE by about $28.62 relative to the NT policy, allowing us to reject $H_2$. A comparison of the impacts of TAB on LPE relative to the TO baseline results in no significant difference ($p$value $= 0.65$), we fail to reject $H_3$. As expected, TSARs reduces the cost of conservation. Adding the agglomeration bonus to TSARs does not have a significant impact on the cost of foregone productivity relative to a TSARs without agglomeration bonus policy. Result 1 summarizes our findings.

**Result 1** *For Lost Production Efficiency, the TSARs works—it lowers costs by minimizing lost production. Allowing landowners to trade set-aside requirements reduces the foregone productivity opportunity cost of conservation relative to a policy discouraging trade. Adding an agglomeration bonus did not increase foregone productivity costs significantly.*

*Biological Efficiency.* For BE, Table 2 shows the NT treatment achieves 40 %, the TO treatment 58, and 84 % for the TAB treatment. The null hypotheses of equal means are

$$H_4: BE_{NT} = BE_{TO},$$
$$H_5: BE_{NT} = BE_{TAB},$$
$$H_6: BE_{TAB} = BE_{TO}.$$

We reject all three nulls at the 1 % level for comparisons between NT and TAB, TO and TAB, and NT and TO (see Table 2, in which implied $p$ values are near zero). The introduction of a TSARs policy and the subsequent market in conservation improves BE. Adding an additional incentive mechanism, the agglomeration bonus, designed to coordinate conservation efforts within the landscape and create contiguous habitat reserve further improves BE. The improvement in BE between NT and TO treatments is largely a result of the experimental construct. If the spatial allocation of low development valued land was less correlated, so that trade results in an offset in connectivity, it is conceivable that no differences in BE would be evident between the NT and TO treatments. Result 2 summarizes our findings.

**Result 2** *For Biological Efficiency, the TSARs works, but it works better with the agglomeration bonus. In our experimental context, the low valued land is spatially correlated, allowing trade in set-aside requirements creates a net gain in Biological Efficiency. Combining TSARs with an agglomeration bonus improves Biological Efficiency.*

*Rent Efficiency.* Recall rent efficiency is best characterized as a measure of the ability of landowners to comprehend the treatment mechanism and to extract rents. Table 1 shows RE is 99, 96, and 90 % in the NT, TO, and TAB treatments. We test three null hypotheses:

$$H_7 : RE_{NT} = RE_{TO},$$
$$H_8 : RE_{NT} = RE_{TAB},$$
$$H_9 : RE_{TAB} = RE_{TO}$$

Table 2 presents the regression results, in which we reject all three nulls at the 1 % significance level. RE is greatest in the NT treatment in which economic efficiency requires people to conserve their low cost land. Once trade was introduced, where potential gains from trade increase the size of the pie, RE decreased. Though some gains were realized as evidenced by the decrease in LPE, landowners were unable to extract all of the rents. RE deteriorated further with the introduction of the TAB treatment. Now the portion of earnings attributed to gains from trade is less than half the total gains resulting from this two part incentive scheme (59 % of gains can be earned prior to trade with the efficient spatial allocation of TSARs). We summarize:

**Result 3** *For Rent Efficiency, complexity compromises the performance of both the TSARs and the TSARs with agglomeration bonus treatments. The addition of a market, which requires people to interact in mutually beneficial ways to extract maximum earnings, results in net social gains. However, the market also increases the money left on the table. The percent of rents not captured increases when the agglomeration bonus is added to a TSARs policy.*

### 4.3 Market Outcomes

We now turn to an examination of the market outcomes for TO and TAB treatments. We compare aggregate outcomes relative to predicted outcomes for the two treatments for two measures of market accuracy: (1) price-accuracy (PA)—captures the percentage of observed prices that fall within the predicted interval; and (2) quantity accuracy (QA)—the ratio of actual TSARs traded relative to predicted trades.[14] We examine each in turn.

[14] Recall the predicted quantity traded in the TO treatment is 14. Acquisition of TSARs was to the landowner 2. Landowners 1 and 3 should have sold 5 brown out cell requirements (TSARs) and the landowner 4 should

**Table 3** Frequency of price

| | TO[a] | | | | TAB | | | |
|---|---|---|---|---|---|---|---|---|
| | 1–20 | 6–20 | 11–20 | 16–20 | 1–20 | 6–20 | 11–20 | 16–20 |
| < −$50.00 | 2 | 2 | | | | | | |
| −40.01 to −50.00 | 5 | 5 | | | | | | |
| **−28.00 to −40.00** | **248** | **248** | **225** | **138** | | | | |
| −20.00 to −27.99 | 18 | 13 | 13 | 9 | | | | |
| −10.00 to −19.99 | 11 | 2 | 2 | 2 | | | | |
| −0.01 to −9.99 | | | | | | | | |
| 0.00 | | | | | | | | |
| 0.01 to 9.99 | 9 | 9 | 2 | | | | | |
| **10.00 to 20.00** | 8 | 2 | 1 | | **118** | **100** | **81** | **40** |
| **20.01 to 30.00** | 3 | | | | **191** | **167** | **119** | **53** |
| **30.01 to 40.00** | 3 | | | | **148** | **136** | **120** | **75** |
| **40.01 to 60.00** | 9 | | | | **159** | **137** | **111** | **74** |
| > 60 | 10 | | | | 25 | 7 | | |
| N | 323 | 281 | 243 | 149 | 641 | 547 | 431 | 242 |
| % In predicted range = MPE | 76.8 | 88.3 | 92.6 | 92.6 | 96.1 | 98.7 | 100 | 100 |

Prices within the predicted range are highlighted in bold numbering
Frequencies represent individual TSARs sold within price range
[a] Omitted session 2 in which price converged towards zero but never entered negative space

*Price Accuracy*. For PA, Table 3 illustrates that 96 % of traded TSARs in the TAB treatment were transacted at a price within the predicted interval. For the TO treatment, only 77 % of TSARs were sold at prices within the predicted interval. We examine the differences in meeting market price expectations further by evaluating the observed average price by 5 round intervals (Table 4). Recall for TO, mutually beneficially trades occur when market price falls within the range from -$28 to -$40. Unexpectedly, the average price for TO in rounds 1-5 is positive with a large variance. For rounds 6-10, 11-15, and 16-20, average market price falls in the expected interval, with the variance surrounding the prices decreasing over time. In the TAB treatment, the predicted range of prices is $10 to $60. Average market prices fall within the predicted interval in each set of 5 round increments. As landowners gain experience, the variance of price falls. In addition, by rounds 15-20, for both the TO and TAB treatments, the average price is centered in the predicted price interval suggesting gains from trades are evenly distributed. We summarize the result as:

**Result 4** *For Price Accuracy, we see greater accuracy for TSARs with the agglomeration bonus than without.*

*Quantity Accuracy (QA)*. QA is 39.1 % for the TO treatment for all rounds and 53 % for all rounds in the TAB treatment (Table 5). If we consider QA as landowners gain experience with the market, the TO treatment increases to 74.6 % for rounds 16 - 20 and the TAB treatment increases to 79 % in rounds 16 - 20. In Table 6, quantity traded is presented in

Footnote 14 continued
have sold 4 TSARs. Predicted market price is all whole integers in the interval of −$28.00 to −$40.00{−$28, −29, …, −39, −40}. For the TAB treatment, predicted quantity was 15, with the Landowner 2 acquiring 5 TSARs from each of the other participants. Predicted market price is {$10, 11, …, 59, 60}.

**Table 4** Average price of TSARs by treatment

| | TO[a] | TAB |
|---|---|---|
| Rounds 1–5 | $41.55 | $53.68 |
| | (66.91) | (53.78) |
| | L = −20.00 | L = 10.00 |
| | H = 200.00 | H = 250.00 |
| Rounds 6–10 | −31.87 | 36.94 |
| | (20.40) | (16.00) |
| | L = −72.00 | L = 20.00 |
| | H = 10.00 | H = 105.00 |
| Rounds 11–15 | −33.85 | 30.90 |
| | (8.30) | (11.44) |
| | L = −39.00 | L = 10.00 |
| | H = 10.00 | H = 50.00 |
| Rounds 16–20 | −33.45 | 34.02 |
| | (4.48) | (11.44) |
| | L = −39.00 | L = 10.00 |
| | H = −10.00 | H = 50.00 |

Standard deviations in parenthesis
[a] Omitted session 2 in which price converged towards zero but never entered negative space

**Table 5** Frequency of quantity traded per round

| | TO[a] | | | | TAB | | | |
|---|---|---|---|---|---|---|---|---|
| | 1–20 | 6–20 | 11–20 | 16–20 | 1–20 | 6–20 | 11–20 | 16–20 |
| 0 | 7 | 5 | 1 | | 5 | 1 | | |
| 1 | 3 | 2 | 0 | | 2 | 1 | | |
| 2 | 6 | 3 | 1 | | | | | |
| 3 | 5 | 1 | 1 | | 3 | 1 | | |
| 4 | 9 | 7 | 2 | | 4 | 1 | | |
| 5 | 11 | 8 | 7 | 4 | 16 | 12 | 4 | 1 |
| 6 | 1 | 1 | 1 | | 3 | 2 | 1 | |
| 7 | 2 | 2 | 1 | 1 | 3 | 1 | | |
| 8 | | | | | 6 | 4 | 2 | 2 |
| 9 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | |
| 10 | 4 | 4 | 4 | 1 | 23 | 22 | 21 | 9 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 12 | 4 | 4 | 4 | 3 | 1 | | | |
| 13 | | | | | 2 | 2 | 2 | 2 |
| **14** | **5** | **5** | **5** | **4** | | | | |
| **15** | | | | | **8** | **8** | **7** | **5** |
| 16+ | | | | | 1 | 1 | 1 | 1 |
| N | 60 | 45 | 30 | 15 | 80 | 60 | 40 | 20 |
| Average | 5.47 | 6.36 | 7.07 | 9.93 | 7.95 | 9.03 | 10.65 | 11.85 |
| % of Predicted = MQE | 39.1 | 45.4 | 50.5 | 71.0 | 53 | 60.2 | 71 | 79 |

Quantities within the predicted range are highlighted in bold numbering
[a] Omitted session 2 in which price converged towards zero but never entered negative space

**Table 6** Average quantity of TSARs traded per round by treatment

| | TO | TO[a] | TAB |
|---|---|---|---|
| Rounds 1–5 | 2.9 | 2.8 | 4.7 |
| | (1.94) | (1.66) | (3.42) |
| | L = 0 | L = 0 | L = 0 |
| | H = 7 | H = 5 | H = 12 |
| Rounds 6–10 | 2 | 2.53 | 5.8 |
| | (2.15) | (2.20) | (3.41) |
| | L = 0 | L = 0 | L = 3 |
| | H = 7 | H = 7 | H = 10 |
| Rounds 11–15 | 5.75 | 6.67 | 9.45 |
| | (4.13) | (3.95) | (2.68) |
| | L = 0 | L = 0 | L = 5 |
| | H = 14 | H = 14 | H = 15 |
| Rounds 16–20 | 10.45 | 9.93 | 11.85 |
| | (3.90) | (3.65) | (4.18) |
| | L = 5 | L = 5 | L = 5 |
| | H = 18 | H = 14 | H = 25 |

Standard deviations in parenthesis
[a] Omitted session 2 in which price converged towards zero but never entered negative space

five round increments. We observe per round trade in TSARs to increase on average as individuals gain experience in the market in both the TO and TAB treatments. In addition, the variation in quantity traded also increases with experience, suggesting that perhaps some groups are responding to the market incentives as anticipated while other groups either are not responding or are still struggling to gain an understanding of the market incentives.

Turning back to Table 5, we compare QA across treatments for varying intervals of the experiment. We use a two-population difference in means test to test the hypothesis that the average number of units traded as a percentage of predicted is different when an agglomeration bonus is added to the TSARs. Our results indicate differences do exist for rounds 1–5 ($t = -1.78$; $p$ value = 0.082), and for rounds $6 - 10$($t = -3.98$; $p$value $< 0.01$), and rounds 11–15 ($t = -2.86$; $p$value $< 0.01$). However, for rounds 16–20 no differences exist (t = −0.50; $p$ value = 0.62). The implication is the mixture of agglomeration bonus and TSARs increases the ability of the market to allocate TSARs to capture market efficiencies in early trading. But as landowners gain market experience, we see that trading is statistically equivalent between the TO and TAB treatment. We summarize our findings as:

**Result 5** *For Quantity Accuracy (QA), we see greater accuracy in TSARs with the agglomeration bonus than without in the early rounds. But as landowners gain market experience, we see no difference in QA.*

## 4.4 Conservation Implications

We now dig deeper into what our results mean for cost-effective conservation with TSARs based on the opportunity cost of conservation (OC), provision of core habitat (K), and landscape connectivity (M). Recall OC is the sum of foregone productivity and subsidy payments on conserved parcels.[15] We measure K based on Eqs. (2)–(4)—we consider two edge effect

[15] OC does not address other additional costs such as administrative costs, monitoring and enforcing agreements, creating the infrastructure to facilitate trades, opportunity costs of habitat destruction, and other costs

**Table 7** Descriptive statistics

| | Optimal[a] | NT | TO | TAB |
|---|---|---|---|---|
| Foregone productivity | $570 | 709.00 | 681.25 | 694.87 |
| | | (31.57) | (68.94) | (80.30) |
| Subsidy | | | | 1207.38 |
| | | | | (133.76) |
| Opportunity cost | | 709.00 | 681.25 | 1902.25 |
| | | (31.57) | (68.94) | (117.15) |
| Patches | 1 | 8.01 | 5.19 | 2.30 |
| | | (3.45) | (3.07) | (0.75) |
| Edge | 18 | 54.10 | 43.18 | 29.88 |
| | | (7.14) | (11.33) | (4.62) |
| Shared borders | 31 | 12.95 | 18.36 | 25.22 |
| | | (3.57) | (5.64) | (2.32) |
| Area ($\tau = 0.10$) | 18.24 | 14.99 | 15.94 | 17.13 |
| | | (0.55) | (0.99) | (0.43) |
| Area ($\tau = 0.25$) | 15.75 | 7.48 | 9.85 | 12.82 |
| | | (1.37) | (2.48) | (1.08) |
| Connectivity | 110 | 44.64 | 61.20 | 84.99 |
| | | (7.36) | (20.79) | (10.43) |
| N | | 80 | 80 | 80 |

[a] The value of the metrics if the optimal $4 \times 5$ connected parcel matrix in the bottom left corner is placed in conservation

($\tau$) scenarios: *small habitat loss* ($\tau = 0.10$); *and 2) large habitat losses* ($\tau = 0.25$). Define M by the aggregate of Moore Neighborhoods, where $r = 1$. We now define our ideal cost-effective conservation target. The desired habitat is the $4 \times 5$ matrix in the SW corner of Fig. 1c with 31 shared borders and 18 exposed edges. The minimum opportunity cost is OC = \$570. Ideal core habitat area is K = 18.24 for small edge effects and K=15.75 for large. Ideal landscape *connectivity* is M = 110. Now we consider how well our landowners did at meeting this upper benchmark.

*Opportunity Cost. The ideal opportunity cost is* \$570. From Table 7, we see the unconditional average OC is \$709, \$681.25, and \$1,902.25 for the NT, TO, and TAB treatments. All policies exceed the ideal, but allowing for trade decreased OC relative to no trade. Adding an agglomeration bonus to trade increases OC significantly. From the GLS model in Table 8, we see the conditional results are the same—trade decreases OC by \$27.75 and the bonus increases OC by \$1,221.00 (\$1,193.25 relative to the NT treatment).

*Core Habitat. Recall ideal core habitat area is* K = 18.24 *or* 15.75 *for small or large edge effects.* We find under both scenarios—TSARs increase core habitat, and the agglomeration bonus further helps this effect relative to no-trade. Consider the details. For the small edge effect, Table 8 shows the benchmark NT treatment yielded about 75 % (14.99 of 20) of the core habitat, K. The TO treatment increases K to 15.94 (6.3 % increase), primarily due to the spatial cost correlation of low developed land in the landscape. K is further increased to 17.13 (14.2 % increase) in the TAB treatment. For the large edge effects, we see similar results, except the agglomeration bonus had a relatively bigger impact: K is 7.48 in the NT

Footnote 15 continued
associated with rent seeking behavior. These costs can vary significantly across incentive mechanisms (See Parkhurst and Shogren 2003).

**Table 8** GLS analysis on cost-effective conservation measures: two-way random effects

| Variable | OC | K($\tau = 0.10$) | K($\tau = 0.25$) | M |
|---|---|---|---|---|
| Constant | 709.00*** | 14.99*** | 7.48*** | 44.64*** |
| | (285.30) | (0.212) | (0.53) | (3.84) |
| TO | −27.75 | 0.95*** | 2.38*** | 16.56*** |
| | (403.45) | (0.291) | (0.728) | (5.17) |
| TAB | 1193.25 | 2.14*** | 5.34*** | 40.35*** |
| | (403.45) | (0.291) | (0.728) | (5.17) |
| LM test | 63.79 | 241.40 | 241.4 | 149.63 |
| | ($p < 0.001$) | ($p < 0.001$) | ($p < 0.001$) | ($p < 0.001$) |
| $R^2$ | 0.98 | 0.61 | 0.61 | 0.58 |
| N | 240 | 240 | 240 | 240 |

Standard errors in parentheses
*** Significant at the 1 % level, ** Significant at 5 % level

**Table 9** GLS analysis edge effect on core: two-way random effects

| Variable | K($\tau = 0.05$) | K($\tau = 0.10$) | K($\tau = 0.15$) | K($\tau = 0.20$) | K($\tau = 0.25$) |
|---|---|---|---|---|---|
| Constant | 17.49*** | 14.99*** | 12.49*** | 9.98*** | 7.48*** |
| | (0.106) | (0.212) | (0.318) | (0.42) | (0.53) |
| TO | 0.48*** | 0.95*** | 1.43*** | 1.90*** | 2.38*** |
| | (0.146) | (0.291) | (0.437) | (0.583) | (0.728) |
| TAB | 1.07*** | 2.14*** | 3.21*** | 4.27*** | 5.34*** |
| | (0.146) | (0.291) | (0.437) | (0.583) | (0.728) |
| LM test | 241.40 | 241.40 | 241.40 | 241.40 | 241.40 |
| | (p < 0.001) | (p < 0.001) | (p < 0.001) | (p < 0.001) | (p < 0.001) |
| $R^2$ | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 |
| N | 240 | 240 | 240 | 240 | 240 |

Standard errors in parentheses
*** Significant at the 1 % level, ** Significant at 5 % level

treatment, 9.85 (31.8 % increase in TO), and 12.82 (71.4 % increase) in TAB. See Table 9 for core habitat areas when edge effects are at 0.05, 0.10, 0.15, 0.20 and 0.25.
*Connectivity. Ideal landscape connectivity is M = 110.* From Table 7, we see M = 44.64 in NT, 61.20 in TO, and 84.95 in TAB. In addition, connectivity is more consistent in the TAB treatment relative to the TO treatment—the standard deviation in the TAB treatment is half that of the standard deviation in the TO treatment. From Table 8 we see M = 44.64 for NT. For TO, M increases to 61.20, a 36.6 % increase relative to NT. For TAB, we see a 90.4 % increase in M over the NT treatment (M = 84.99) and a 41.2 % increase relative to the TO treatment. All coefficients are statistically different from 0 at 1 % significance level. We summarize our results as:

**Result 6** *Given the ideal cost-effective conservation target and relative to command and control, we find the TSARs works to lower opportunity costs (OC) and increase core habitat (K) and connectivity (M). Adding the agglomeration bonus has mixed results—adding the* *agglomeration bonus significantly increases both core habitat and landscape connectivity but at the price of higher opportunity cost.*

Based on Result 6, the open question we address but do no answer completely is when is it cost-effective to add the agglomeration bonus to the TSARs policy. Addressing this question requires a few bold steps. First, we must define the cost-benefit comparison. Assuming the tax revenues that fund the agglomeration bonus are imposed on the entire population who benefit from the provision of the public good, adding the agglomeration bonus to TSARs provides a Pareto improvement if the social value $\mathrm{Y(V(K, M; \lambda))}$ of greater K and M exceeds the higher OC.

$$\mathrm{Y_{TAB}(V(K, M; \lambda)) - Y_{TO}(V(K, M; \lambda)) \geq OC_{TAB} - OC_{TO}}, \text{ for } \tau \geq 0$$

Second, given our experimental design we add numbers to this cost-benefit comparison for small and large edge effects. The marginal effect of adding an agglomeration bonus of \$50 to the TSARs is an increase in K of 7.5 % (1.19) when the edge effect was 10 and 30.2 % (2.97) with an edge effect of 25 %. The marginal effect on M of adding an agglomeration bonus of \$50 to the TSARs policy is an increase of 38.9 % (23.79). The marginal cost of adding the bonus to TSARs is an increase of 179.2 % (\$1,221). These results suggest, for our experimental setting, TSARs with an agglomeration bonus is preferred if:

$$Y\,(V(17.13, 84.98; \lambda)) - Y\,(V\,(15.94, 61.20; \lambda)) \geq \$1,221, \text{ when } \tau = 0.10,$$
$$Y\,(V(12.82, 84.98; \lambda)) - Y\,(V\,(9.86, 61.20; \lambda)) \geq \$1,221, \text{ when } \tau = 0.25.$$

A global response beyond the immediate experience of our experimental design demands explicit specifications of survivability and benefit functions. Specifications are likely problem- and context-specific (Saura and Pascual-Hortal 2007; Calabrese and Fagan 2004; Söndgerath and Schröder 2002; Weikard 2002). We acknowledge this limitation, and are wary of speculating further.

## 5 Concluding Comment

The success of tradable pollution permit programs to meet air quality standards for regional air pollutants at minimum cost has encourage policy makers and academics to find ways to create marketable instruments that can be readily applied to land uses (see e.g., Stavins 1998). Limits do exist, however, to straightforward transfers of standard tradable air pollution permit policy to habitat conservation. Marketable instruments to affect land use need to address two challenges explicitly: insufficient participation in thin conservation markets, and meeting the cost effective conservation landscape design resulting from spatial heterogeneity in development opportunity cost and habitat quality due to habitat location.

We have examined two institutions in the lab which could realistically address these challenges—tradable set-aside requirements (TSARs), and TSARs combined with an agglomeration bonus. As in any experiment, we indulge in artificial isolation. But we take our cue from several measures of bioeconomic efficiency and market accuracy heretofore mostly disregarded when spatial interdependencies among landowners predominate policy questions. If, before now, these measures have been neglected or implicitly treated as system parameters, we have changed the parameters into new variables, which created a new set of parameters at least one step removed. When compared across numerous measures of bioeconomic efficiency and market accuracy, our experimental results suggest TSARs work given asymmetric landowners, habitat quality connectivity, high spatial cost correlation, and all in spite of an opportunity set for conservation that includes millions of possible combinations of 20 conserved parcels. Combining TSARs with an agglomeration bonus improves habitat connectivity significantly but at a greater cost to the regulator.

Thanks to this mind-boggling array of possible combination of sites to set aside, biodiversity outcomes and economic payoffs can frequently be only indirectly and imperfectly inferred. We have not modeled the process by which participants in our experiment picked or sorted through these numerous combinations. Nevertheless, we conjecture, consistent with the network formation model of Bloch and Jackson (2007), that the bonus part of the TSAR-bonus combination in our experiment provided participants landmarks and direction posts because it embodied the multilateral features (positive externalities) of bilateral TSAR trades and because it made the sum of developmental opportunity costs and regulator outlays for bonuses contingent on realized site connectivity (Mezzetti 2004).

We have explored the human response to two tradable market instruments designed to overcome insufficient participation in thin markets and to conserve a contiguous conservation landscape in a context free environment. Our research shows promising results within the framework of our experimental design—monotonically increasing productive values from SW to NE, and a desired contiguous conservation patch located within one individual's landholdings. The performance of the TSARs and TSARs with an agglomeration bonus to achieve conservation goals in different spatial contexts is an open question, one worthy of future research. In addition, similar to an agglomeration bonus subsidy mechanism, the performance of a TSARs with agglomeration bonus policy may be influenced by the spatial configuration of desired habitat (Parkhurst and Shogren 2007; Drechsler et al. 2010), transaction costs (Banerjee et al. 2011) and side payments (Wätzold and Drechsler 2013), network size (Banerjee et al. 2012), information provision (Banerjee et al. 2014), and the impact of repeated interactions (Warziniack et al. 2007) and bidding iterations (Reeson et al. 2011).

Further, TSARs with or without an agglomeration bonus have greater flexibility than traditional TDR policies or conservation banking. TSARs overcome the low demand for development opportunities in many conservation settings that market institutions experience. Allowing neighboring landowners to connect parcels by transferring mitigation requirements reduces the opportunity cost of mitigation. In addition, a TSARs with agglomeration bonus policy could be adapted to complement current state and federal conservation programs such as the conservation reserve program. Current subsidies could be transformed to create interdependencies between conserved parcels and the assignment of TSARs could ensure all landowners share the burden of conservation across the landscape. By tempering landowners' resistance to preserving biodiversity habitat, market institutions can encourage conservation of natural features of "the unbought graces of life" (Burke 1791).

## References

Adler J (2008) Money or nothing: the adverse environmental consequences of uncompensated land use control. Boston College Law Rev 49(2):301–366

Albers H, Ando A, Batz M (2008) Patterns of multi-agent land conservation: crowding in/out, agglomeration, and policy. Resour Energy Econ 30(4):492–508

Banerjee S, Kwasnica A, Shortle J (2012) Agglomeration bonus in small and large local networks: a laboratory examination of spatial coordination. Ecol Econ 84:142–152

Banerjee S, de Vries FP, Hanley N (2011) The agglomeration bonus in the presence of private transaction costs. In: Paper presented at the 13th BIOECON conference, 11–13 September, Geneva

Banerjee S, de Vries FP, Hanley N, van Soest D (2014) The impact of information provision on aggloemration bonus performance: an experimental study on local networks. Am J Agric Econ. doi:10.1093/ajae/aau048

Bean M (1998) The endangered species and private land: four lessons learned from the past quarter century. Environ Law Rep 28:10701–10710
Boyd J, Cabellero K, Simpson D (2000) The law and economics of habitat conservation: lessons from an analysis of easement acquisitions. Stanf Environ Law J 19:209–236
Bloch F, Jackson M (2007) The formation of networks with transfers among players. J Econ Theory 133:83–110
Burke E (1791) Letter to a member of the national assembly. J. Dodsley, London
Calabrese J, Fagan W (2004) A comparison-shopper's guide to connectivity metrics. Front Ecol Environ 2(10):529–536
Conant J (1951) Science and common sense. Yale University Press, New Haven, CT
Crawford V (1998) A survey of experiments on communication via cheap talk. J Econ Theory 78:286–298
Crocker T (1966) The structuring of atmospheric pollution control systems. In: Wolozin H (ed) The economics of air pollution. W.W. Norton, New York, pp 61–87
Drechsler M, Wätzold F, Johst K, Shogren J (2010) An agglomeration payment for cost-effective biodiversity conservation in spatially structured landscapes. Resour Energy Econ 32(2):261–275
Drechsler M, Wätzold F (2009) Applying tradable permits to biodiversity conservation: effects of space-dependent conservation benefits and cost heterogeneity on habitat allocation. Ecol Econ 68(4):1083–1092
Feng H (2007) Green payments and dual policy goals. J Environ Econ Manage 54(3):323–335
Ferraro P (2008) Asymmetric information and contract design for payments for environmental services. Ecol Econ 65(4):810–821
Ferraro P, Kiss A (2002) Direct payments to conserve biodiversity. Science 298:1718–1719
Fox J, Nino-Murcia A (2005) Status of species conservation banking in the United States. Conserv Biol 19:996–1007
Goldman R, Thompson B, Daily G (2007) Institutional incentives for managing the landscape: inducing cooperation for the production of ecosystem services. Ecol Econ 64(2):333–343
Hanley N, Banerjee S, Lennox G, Armsworth P (2012) How should we incentivize private landowners to 'produce' more biodiversity? Oxf Rev Econ Policy 28(1):93–113
Hennessy D, Lapan H (2010) Buying ecological services: fragmented reserves, core and periphery national park structure, and the agricultural extensification debate. Nat Res Model 23(2):176–217
Hof J, Bevers M (1998) Spatial optimization for managed ecosystems. Columbia University Press, New York
Langpap C (2004) Conservation incentives programs for endangered species: an analysis of landowner participation. Land Econ 80(3):375–388
Langpap C (2006) Conservation of endangered species: can incentives work for private landowners? Ecol Econ 57(4):558–572
Latacz-Lohmann U, Van der Hamsvoort C (1997) Auctioning conservation contracts: a theoretical analysis and an application. Am J Agric Econ 79:407–418
Lewis D, Plantinga A (2007) Policies for habitat fragmentation: combining econometrics with GIS-based landscape simulations. Land Econ 83:109–127
Lewis D, Plantinga A, Wu J (2009) Targeting incentives for habitat fragmentation. Am J Agric Econ 91:1080–1096
Lewis D, Plantinga A, Nelson E, Polasky S (2011) The efficiency of voluntary incentives policies for preventing biodiversity loss. Resour Energy Econ 33(1):192–211
Madsen B, Carroll N, Moore-Brands K (2010) State of biodiversity markets report: offset and compensation programs worldwide. http://www.ecosystemmarketplace.com/document/acrobat/sbdmr.pdf Retrieved from March 10, 2013
Madsen B, Carroll N, Kandy D, Bennett G (2011) Update: state of biodiversity markets. Forest Trends, Washington, DC. http://www.ecosystemmarketplace.com/reports/2011_update_sbdm
Martín-López B, Montes C, Benayas J (2008) Economic valuation of biodiversity conservation: the meaning of numbers. Conserv Biol 22(3):624–635
Mezzetti C (2004) Mechanism design with interdependent valuations: efficiency. Econometrica 72(5):1617–1626
Mills D (1980) Transferable development rights markets. J Urban Econ 7:63–74
Nelson E, Polasky S, Lewis D, Plantinga A, Lonsdorf E, White D, Bael D, Lawler J (2008) Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. Proc Nat Acad Sci 105:9471–9476
Parkhurst G, Crocker T (2002) Incentive design for conserving optimal biodiversity habitat. Working paper, Weber State University
Parkhurst G, Shogren J (2003) An evaluation of incentive mechanisms for conserving habitat. Nat Res J 43:1093–1149

Parkhurst G, Shogren J, Bastian C, Kivi P, Donner J, Smith R (2002) Agglomeration bonus: an incentive mechanism to reunite fragmented habitat for biodiversity conservation. Ecol Econ 41:305–328
Parkhurst G, Shogren J (2007) Spatial incentives to coordinate contiguous habitat. Ecol Econ 64:344–355
Parkhurst G, Shogren J (2008) Smart subsidies for conservation. Am J Agric Econ 90:1192–1200
Polasky S, Nelson E, Camm J, Csuti B, Fackler P, Lonsdorf E, Montgomery C, White D, Arthur J, Garber-Yonts B, Haight R, Kagan J, Starfield A, Tobalske C (2008) Where to put things? Spatial land management to sustain biodiversity and economic returns. Biol Conserv 141:1505–1524
Polasky S, Nelson E, Pennington D, Johnson K (2011) The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of minnesota. Environ Res Econ 48(2):219–242
Pruetz R, Standridge N (2009) What makes transfer of development rights work? J Am Plan Assoc 75:78–87
Reeson A, Rodriguez L, Whitten S, Williams K, Nolles K, Windle J, Rolfe J (2011) Adapting auctions for the provision of ecosystem services at the landscape scale. Ecol Econ 70(9):1621–1627
Robertson M, Hayden N (2008) Evaluation of a market in Wetland credits: entrepreneurial Wetland banking in Chicago. Conserv Biol 22:636–646
Russell B (2009) Human knowledge: its scope and value. Routledge Classics, Routledge, NY, NY (original version published in 1948)
Saunders D, Hobbs R, Margules C (1991) Biological consequences of ecosystem fragmentation: a review. Conserv Biol 5:18–32
Saura S, Pascual-Hortal L (2007) A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study. Landsc Urban Plann 83(2):91–103
Shogren J, Tschirhart J, Anderson T, Ando A, Beissenger S, Brookshire D, Brown G, Coursey D, Innes R, Meyer S, Polasky S (1999) Why economics matter for endangered species protection. Conserv Biol 13:1257–1261
Smith R, Shogren J (2002) Voluntary incentive design for endangered species protection. J Environ Econ Manage 43(2):169–187
Smith VL (2008) Rationality in economics: constructivist and ecological forms. Cambridge University Press, Cambridge, UK
Söndgerath D, Schröder B (2002) Population dynamics and habitat connectivity affecting the spatial spread of populations-a simulation study. Landsc Ecol 17(1):57–70
Stavins R (1998) What can we learn from the grand policy experiment? Lessons from $SO_2$ allowance trading. J Econ Perspect 12:69–88
Stoneham G, Chaudhri V, Ha A, Strappazzon L (2003) Auctions for conservation contracts: an empirical examination of Victoria's BushTender trial. Aust J Agric Res Econ 47(4):477–500
Thornes P, Simons G (1999) Letting the market preserve land: the case for a market-driven transfer of development rights program. Contemp Econ Policy 17:256–266
Tischendorf L, Fahrig L (2000) On the usage and measurement of landscape connectivity. Oikos 90:7–19
United States Fish and Wildlife Service (USFWS), 2012. Conservation banking: incentives for stewardship. http://www.fws.gov/endangered/esa-library/pdf/conservation_banking.pdf. Retrieved from December 2, 2013
Warziniack T, Shogren J, Parkhurst G (2007) Creating contiguous forest habitat: an experimental examination on incentives and communication. J For Econ 13:191–207
Wätzold F, Drechsler M (2013) Agglomeration payment, agglomeration bonus or homogeneous payment? Res Energy Econ 37:85–101
Weikard H (2002) Diversity functions and the value of biodiversity. Land Econ 78(1):20–27
Werling B, Dickson T, Isaacs R, Gaines H, Gratton C, Gross K, Landis DA (2014) Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc Natl Acad Sci 111:1652–1657
Wissel S, Wätzold F (2010) A conceptual analysis of the application of tradable permits to biodiversity conservation. Conserv Biol 24:404–411