Conservation Strategies in Contested Environments:

Dynamic Monte Carlo Simulations and a Bolivian case study*

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Abstract

What are the most effective conservation strategies for achieving environmental objectives? We model conservation as an iterative, strategic contest, introducing a novel framework that simulates dynamic interactions between conservationists ("Greens") and developers ("Farmers") competing to claim plots of land with heterogeneous agricultural and environmental values. Using a comparative statics analysis of Monte Carlo simulations, we evaluate the environmental benefits, additionality and welfare implications of alternative siting strategies, including targeting the most environmentally valuable land, targeting the most at-risk land (blocking development), and targeting 'hot spots' of high value and high risk. Our rich, nonlinear framework yields several striking and counterintuitive insights. Notably, blocking development consistently under-performs other strategies, with low conservation outcomes and high welfare losses, and does not generally result in higher additionality. In addition, reduced leakage does not uniformly improve performance; under certain conditions, it may even amplify welfare losses. A Bolivian case study underscores these insights - we find evidence of Farmer behavior consistent with our model and a tendency of conservation strategy towards maximizing environmental benefits. Consistent with the Bolivian experience, our simulation analysis suggests that, in environments with weak legal enforcement capabilities, high leakage, and profit-maximizing farmers, the Maximize Environment strategy achieves overall maximum conservation outcomes at minimum welfare loss. Together, the simulations and case study suggest that a narrow focus on additionality may, in some cases, hinder the achievement of optimal long-term environmental outcomes.

Key words: Conservation strategies, Additionality, Monte Carlo simulation

JEL classifications:

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1 Introduction

Vital ecosystem services and numerous species are increasingly threatened by global land-use changes (Ceballos et al., 2015; Tilman et al., 2017; IPBES, 2019; Almond et al., 2022). In response, more than 190 countries have committed to protecting 30% of the Earth's land and ocean by 2030—the "30×30" goal of the Kunming–Montreal Global Biodiversity Framework agreed upon in 2022 at the 15th Convention on Biological Diversity in Montreal. Although over 300,000 terrestrial and marine protected areas safeguard more than 16% of Earth's landmass and 8% of its oceans, achieving the 30×30 target requires nearly doubling terrestrial protection and quadrupling marine protection, demanding an acceleration of conservation efforts.

However, targeting conservation investments efficiently poses substantial financial and logistical challenges. Recent estimates by The Nature Conservancy suggest that while current global conservation spending ranges from USD 124–143 billion per year, meeting conservation targets may require approximately USD 845 billion annually (Deutz et al., 2020). Moreover, biodiversity hotspots—covering about 2.5% of Earth's land and home to roughly 2 billion people—account for nearly 35% of the ecosystem services that vulnerable populations depend on . The intense competition between conservation and development in these areas makes it imperative to allocate constrained conservation funds in the most cost-effective manner.

Despite this urgency there is no clear consensus on the optimal conservation strategy for achieving environmental objectives. Early studies in conservation biology often framed protected-area selection as a problem of maximizing species coverage, largely ignoring heterogeneity in land costs and ecological threats (e.g. Margules et al., 1988). Subsequent work introduced cost and threat dimensions; for example, Abbitt et al. (2000) argued for a "hot-spot" approach that prioritizes areas with both high environmental benefit and high threat from conversion, while Ando et al. (1998) demonstrated that, among U.S. counties, remote sites—even with lower ecological quality—yield greater cost-effectiveness in species preservation.

In practice, many conservation initiatives have embraced the hot-spot approach (Balmford et al., 2000; Wünscher and Engel, 2012; Lu et al., 2023), yet several studies indicate that global patterns of protected areas are driven primarily by factors such as remoteness and low population density rather than explicit environmental preferences (Baldi et al., 2017; Pfaff et al., 2015; Sims, 2014). This suggests that, in practice, de facto conservation targeting may be more aligned with the cost-minimizing perspective of Ando et al. (1998).

More recently, the integration of conservation funding with carbon markets has led to an increasing emphasis on "additionality " — the extent to which conservation outcomes exceed the "business as usual" (BAU) trajectory (Wunder, 2015; Delacote et al., 2024). Projects with high additionality are, by definition, located in areas at the greatest risk of development. However, the emphasis on additionality introduces its own set of challenges by channeling conservation efforts toward lands near agricultural or urban frontiers (Engel et al., 2008; Aspelund and Russo, 2023), where clashes with development interests are inevitable.

This longstanding tension between development and environmental agendas is not new. Throughout history societies have set aside forests, mountains, and other landscapes for religious, cultural, or exclusive elite use (Verschuuren et al., 2010), even as local communities have resisted efforts to monopolize these resources (Redpath et al., 2013; Young et al., 2005). In medieval England, for instance, the establishment of royal hunting reserves—such as the New Forest created in 1079 by William the Conqueror—required draconian enforcement measures that sparked significant conflict between the monarchy and commoners (NewForestCommoner, 2021; Hudson, 2012). Over time, many of these areas were reclaimed by local populations as development pressures grew (Morrison, 2014).

Contemporary cases, such as in Bolivia, mirror these historical dynamics. Figures 7a and 7b trace the increases in both protected areas and anthropogenic land use in Bolivia over time; it is clear from the historical record that new land is being brought into both development (e.g. for agriculture, urban or industrial use) and conservation (in protected areas) simultaneously. Indeed, from the early creation of Sajama National Park in the 1930s to the rapid expansion of protected areas following the 1992 Rio Earth Summit, Bolivia's conservation landscape reflects a continuous tug-of-war between pro-development policies (e.g., agribusiness expansion, resource extraction, and infrastructure projects) and pressures from civil society and international norms for ecological stewardship. Although protected areas were once predominantly located in remote regions, recent developments in road construction, oil exploration, and shifting agricultural practices have increasingly exposed even these areas to development pressure; in section 4 we further explore the Bolivian experience to illustrate the nature of land use competition in an environmentally rich but economically poor setting.

The challenges faced by conservationists in Bolivia are not unique - competition between divergent long-term land use objectives is a common feature in many countries. Numerous studies document political and physical conflicts between conservationists and developers, with institutions like the International Union for Conservation of Nature (IUCN) emerging in 1948 to amplify and provide a unified conservation voice (Phillips, 2004). In this adversarial context – where additionality-focused strategies entail higher economic and political costs – a critical question arises: are conservation strategies that focus on additionality cost-effective in achieving superior long-term environmental outcomes?

Traditional academic research has modeled conservation either as an optimal allocation problem from the perspective of a social planner balancing environmental benefits and socio-economic needs (e.g. Ando et al., 1998; Delacote et al., 2024), or via cooperative game theoretic models that result in conservation agreements with financial compensation, tradable land rights, or multi-stakeholder governance structures (e.g. Ferraro and Simpson, 2002; Engel et al., 2008). Yet, as we argue above, empirical evidence suggests that conflict is intrinsic to many land-use decisions; indeed dual-objective projects, which aim to promote equity and human development alongside conservation, often achieve less effective environmental outcomes (Delacote et al., 2014; Amin et al., 2019).

Thus rather than assuming a single planner or a cooperative bargaining framework, this paper develops a sequential land claim game to evaluate optimal conservation strategies in an environment of adversarial competition. Our approach takes seriously the iterative and adversarial nature of conservation, exploring the patterns of environmental and welfare outcomes that may emerge from divergent long-term interests, or when formal agreements may not be feasible due to institutional weakness. Motivated by the observation that conservation site selection is frequently determined by local and national political competition between non-overlapping interests, we develop a dynamic game in which two groups—the Greens (conservationists) and the Farmers (developers)—compete to claim parcels of land, each with known environmental and agricultural values. We then use Monte Carlo simulations to explore how alternative conservation strategies perform in terms of conservation outcomes, additionality, and social welfare under different assumptions about Farmer behavior and leakage levels.

We view this approach as a complement to, rather than a substitute for, more unitary social planner or cooperative game-theoretical models. To our knowledge, this is the first study to compare alternative conservation strategies side-by-side within a dynamic framework with heterogeneous land values that allows for nonlinear interactions. Previous work by Newburn et al. (2006) employed dynamic programming and Monte Carlo simulations to contrast strategies that account for land cost and conversion threat heterogeneity in Sonoma County, California, but without modeling explicit, nonlinear interactions between developers and conservationists or deviations from the social welfare maximizing land use pattern. Delacote et al. (2024) study alternative siting decisions of a single planner for dual-objective conservation projects, but their optimization approach assumes full information and smooth trade-offs between conservation and development. In contrast, our two-player adversarial framework with randomly assigned (though potentially correlated) land values and complex heterogeneity allows for dynamic nonlinearities and explores outcomes emerging from uncooperative interaction.

The remainder of the paper is organized as follows. Section 2 describes our simulated framework and the classification of conservation strategies and formalizes the set up. Section 3 presents the main simulation results. In section 4 we examine the Bolivian experience more closely, comparing our theoretical Farmer and Green strategies with the actual sequence of agricultural and protected area expansion and reflecting on insights from our analytical framework. Finally, Section 5 concludes. We include further robustness and heterogeneity exercises in the Appendix; in section A2 we explore outcomes when the grid is intially populated with agricultural and environmental values that are positively correlated; section A3 explores the performance of strategies when enforcement of protected areas in weak in areas of high threat (a negative correlation between agricultural and environmental values); and section A4 simulates a situation where Farmers have considerably more resources and/or political power than conservationists.

2 Simulation Framework

As discussed above, we explore the outcomes from decisions to conserve or develop land that are inherently dynamic, iterative, and politically contested, modelled as adversarial competition between conservationists and developers. To capture this complexity, we propose a Monte Carlo simulation framework that models the behaviour of two teams: the Greens (conservationists) and the Farmers (developers) who each follow a fixed strategy. We then compare the land use patterns resulting from different combinations of Green and Farmer strategy under different levels of leakage.

The Grid

We begin by randomly populating a grid of land “plots” (grid cells) with two attributes: a conservation value and an agricultural value. These values represent the net present social benefit of conserving a plot or developing it, respectively. The grid can be initialized to simulate a range of ecological and geographic scenarios by varying the correlation between conservation and agricultural values; in our initial analysis here we assume a correlation of zero, but in the Appendix sections A2 and A3 we explore outcomes for a positive correlation of 0.3 and a negative correlation of -0.3, respectively. The grid serves as a pragmatic tool; its structure does not encode spatial relationships, meaning that cells distant on the grid may correspond to adjacent plots in reality, and vice versa. We assume that plots with higher agricultural values are inherently more attractive for development.

Both plot values are interpreted as comprehensive measures that embed dynamic externalities and other intrinsic characteristics affecting their suitability for conservation or development. For example, while global protected areas have been shown to reduce forest loss on average (Yang et al., 2021), their effectiveness is highly heterogeneous (Leverington et al., 2010; Joppa and Pfaff, 2010; Geldmann et al., 2019; Duncanson et al., 2023; Delacote et al., 2024). In our framework, such heterogeneity is incorporated directly into the conservation value assigned to each plot. Thus we can use a negative correlation between agricultural and environmental values to simulate a context where it is legally more difficult to ensure conservation outcomes on land that has high development potential.

Claims and Rounds

After the grid is populated, a fixed number of claims—equal to the number of grid cells—are divided between the two teams. One claim secures one plot and in each round the teams then take turns spending their claims to secure plots. By varying the number of rounds (for a grid size of 100 the maximum number of rounds is 50), we can adjust the granularity of the game.

In our baseline we allow for 50 rounds in which each team spends at most one claim per round. However, it is possible to allow each team to claim a different number of plots per round by varying the allocation of claims and the number of rounds, thereby simulating relative differences in economic or political power. For example in the Appendix section A4 we explore outcomes under an unequal division of power in which Farmers are initially allocated 70% of the claims.

Leakage

In the context of the simulation, “leakage” is a term that describes the general equilibrium effectiveness of conservation projects (Green claimed plots) in terms of quantity of plots. If Greens claim a plot that Farmers desired in their business as usual (BAU) plan, if there is 100% leakage Farmers can develop another plot elsewhere (either in or out of their BAU set), so the conservation project has only increased conservation in one location but decreased it in another. On the other end of the continuum, 0% leakage means that if the Greens block the Farmers from claiming a BAU plot, the total number of plots that can eventually be allocated to agriculture decreases by one plot.

We introduce alternative leakage scenarios by reducing the Farmers’ remaining claims at varying rates when the Greens claim plots that the Farmers would have targeted under their preferred ’business-as-usual’ (BAU) land-use pattern. Thus, when leakage levels are 100% there are no deductions and Farmers can spend all their initial claims; if a plot that the Farmers would prefer is captured by the Greens, the Farmers simply claim an alternative plot. On the other end of the continuum, with 0% leakage, one Farmer BAU plot lost to the Greens translates to a one-claim deduction of any remaining unspent Farmer claims. In between, for example with 25% leakage, every four BAU plots claimed by the Greens result in a loss of one unspent Farmer claim. We examine leakage levels of 100%, 75%, 50%, 25%, and 0%.

Game Play

In our simulations, each team may adopt one of several strategies that are outlined below in sections 2.1.2 and 2.1.3. Farmer strategies include Naïve Profit Maximiser and Strategic Profit Maximiser and their strategy determines a fixed preferred BAU set of plots that is determined at the start of play. Green strategies include Maximize Environment, Block Farmers (Maximize Additionality), Hot Spot, Maximize Difference, and Random. On each grid, we simulate every possible combination of Green and Farmer strategies across different levels of leakage. This experiment is repeated 500 times with a new randomly generated grid in each repetition.

Game conclusion

The game concludes when both teams have exhausted their claims. If leakage¡100% any remaining unclaimed plots are automatically assigned to the Greens in the last round and we then compute several outcomes: (a) the final total conservation score (the sum of environmental values for plots held by the Greens); (b) the final degree of additionality achieved by the Greens (the difference between their actual conservation score and the score they would have obtained had the Farmers claimed all their BAU plots); and (c) the final percentage total welfare loss (from the deviation of the final land use pattern from the social welfare–maximizing allocation). In order to visually differentiate the mechanisms through which strategy and leakage interact we report both the final average outcome scores for every strategy and leakage combination and the dynamic trajectories that the outcomes follow throughout the game.

The assignment of unclaimed plots to Conservation only in the last round is done not because this timing is ‘realistic’ but rather because we want to clearly distinguish between conservation gains from the strategy and leakage combination itself (what we call the *Pure Strategy* effect, defined below), and conservation gains from the residual left-over plots (what we call the *Displacement-Leakage* effect, also defined below), which are determined by different mechanisms. More specifically, at different levels of leakage the set of available plots to choose from at any given point changes, so different strategies can lead to different dynamic trajectories. By allocating all the residual unclaimed plots in the last round we can visually separate this more subtle *Pure Strategy* mechanism from the more mechanical *Displacement-Leakage* increase in final Conservation score from residual unclaimed plots, which may also be different across different strategies.

2.1 Formal Setup

We now outline the game simulation framework more formally. We first generate a 10 × 10 grid of plots, each with a randomly assigned environmental value and an agricultural value. Let P represent the set of land plots, where $P = \{p_{ij}\}$, a 10×10 grid with 100 plots. Each plot p_{ij} is associated with two values:

$$e_{ij} : \text{the environmental value of plot } p_{ij}, \text{ where } e_{ij} \geq 0$$

$$a_{ij} : \text{the agricultural value of plot } p_{ij}, \text{ where } a_{ij} \in \mathbb{R}$$

A positive a_{ij} implies suitability for agriculture, while a negative value implies unsuitability.

The two land attributes, e_{ij} and a_{ij}, are initialized using a bivariate random number generation process designed to create two values whose correlation can be determined by the user to simulate various underlying ecosystems. Specifically, each pair of land attributes (e_{ij}, a_{ij}) is drawn from a Gaussian copula:

$$(z_e, z_a) \sim \mathcal{N}\left(\mathbf{0}, \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}\right)$$

where z_e and z_a are standard normal variables, and ρ denotes the desired correlation coefficient between environmental and agricultural values. These are then transformed into uniform variables: $u_e = \Phi(z_e)$ and $u_a = \Phi(z_a)$, where $\Phi(\cdot)$ denotes the cumulative distribution function (CDF) of the standard normal distribution, mapping each z to $u \in [0, 1]$. Finally, u_e and u_a are linearly rescaled to the interval $[0.1, 10.0]$ to produce:

$$e_{ij} = 0.1 + 9.9 \cdot u_e$$

$$a_{ij} = 0.1 + 9.9 \cdot u_a$$

This procedure ensures that the marginal distributions of e_{ij} and a_{ij} are uniform on $[0.1, 10.0]$, while preserving the desired rank correlation ρ between them.

It is important to note that the choice of a grid structure is purely practical — there is no spatial information in the grid. The framework can map to any geographical arrangement or size distribution of plots. We consider the values to be the net present value, including any dynamic externalities, if the plot were protected (for the environmental value) or developed (for the agricultural value).

Guided by the observed sequential evolution of agricultural land and protected areas (for example depicted in Figure 1), we simulate the dynamic decisions of two ‘teams’, the Farmers and the Greens, competing over a set number of periods to claim plots of land for agriculture or conservation.

Let T_f and T_g represent the two teams, Farmers and Greens, respectively. Each team $T \in \{T_f, T_g\}$ has an initial allocation of claims C_T, where: $C_f + C_g = 100$, i.e. the total number of plots. By varying the allocation of claims between the Greens and Farmers, we simulate differing degrees of political power.

The simulation runs for R rounds. In each round r, Farmers (team T_f) move first, followed by Greens (team T_g). Let C_T^r denote the number of claims team T can use in round r. If the game is played over R rounds, then:

$$C_T^r = C_T/R$$

where C_T is the total number of claims allocated to team T. For example, if $R = 50$, both teams claim 1 plot per round, and if $R = 25$, they claim 2 plots per round.

Let $S_f^r \subset P$ and $S_g^r \subset P$ denote the sets of plots claimed by Farmers and Greens in round r, respectively. The total set of plots claimed by each team after round r is:

$$S_f^{\leq r} = \bigcup_{k=1}^{r} S_f^k \quad \text{and} \quad S_g^{\leq r} = \bigcup_{k=1}^{r} S_g^k$$

A plot p_{ij} can only be claimed once, so $S_f^{\leq r} \cap S_g^{\leq r} = \emptyset \ \ \forall t$.

2.1.1 Leakage

Let S_f^{BAU} represent the set of plots that the Farmers would claim under the 'business as usual' (BAU) scenario if they were allowed to use all their claims without any interference from the Greens. During the game, if the Greens claim a plot that is part of the Farmers' BAU set S_f^{BAU}, then the Farmers must deviate from their business-as-usual desired trajectory. If conservation efforts face 100% leakage, then the Farmers can simply claim an alternative plot elsewhere in the grid that may or may not be in S_f^{BAU}. Thus in the baseline case when there is 100% leakage, both teams spend all their initial claims, resulting in all plots $P = \{p_{ij}\}$ being allocated by the end of the game.

We then vary the degree of leakage, denoted as Leakage $\in [0, 1]$ by reducing the Farmers' remaining unspent claims proportionally for every plot $p_{ij} \in S_f^{BAU}$ claimed by Greens, such that for example:

- For Leakage = 0.5, Farmers lose 1 unspent claim for every 2 plots in S_f^{BAU} claimed by Greens.
- For Leakage = 0.0, Farmers lose 1 unspent claim for every 1 plot in S_f^{BAU} claimed by Greens.

The game concludes when both teams have exhausted their claims, or when no further plots are eligible for claim. If Leakage < 100% and the Greens have claimed plots in the Farmers' BAU set, there may be some residual unclaimed plots at the end of the game, $p_{ij} \notin (S_F^R \bigcup S_G^R)$ and these are automatically assigned to the Greens in the final round.

2.1.2 Farmer Strategies

Farmers choose plots following two possible simulated strategies:

1. **Naive Profit Maximizer:** Farmers claim plots based solely on the highest agricultural value, ignoring the environmental value:

$$S_f^r = \max\left(a_{ij}\right)$$

2. **Strategic Profit Maximizer:** Farmers recognize that the Greens may want to claim good agricultural plots if they are also environmentally valuable, so they consider the environmental value as well. They may choose plots with slightly lower agricultural value but higher environmental value to prevent environmentalists from claiming them in the next round. Specifically, Farmers sort the plots by environmental score in declining order and consider plots with scores below the cut-off based on the Greens' claims allocation to be 'safe' plots that the Greens are unlikely to claim. The Farmers then prioritize the remaining 'risky' plots, leaving the safe plots (that may have a higher agricultural score) to be claimed later in the game.

$$S_f^r = \begin{cases} \max(a_{i,j}^{risky}) & \text{if } |a_{i,j}^{risky}| \neq 0, \\ \max(a_{i,j}^{safe}) & \text{if } |a_{i,j}^{risky}| = 0 \end{cases}$$

2.1.3 Conservation Strategies

In each round, Greens evaluate each available plot and choose the plot that maximizes a weighted function of e_{ij} and a_{ij}:

$$S_g^r = \max f(e_{ij}^{\alpha}, a_{ij}^{\beta})$$

where coefficients α and β are respective weights of the conservation and agricultural scores that correspond to different alternative strategies as described below.

1. **Maximize Environmental Score:** Conservationists claim plots with the highest environmental scores. This corresponds to: $\alpha = 1$ and $\beta = 0$:

   $$S_g^r = \max(e_{ij})$$

2. **Target Hot Spots** Conservationists claim plots with both high environmental scores and high agricultural scores. The default is $\alpha = 1$ and $\beta = 1$:

   $$S_g^r = \max(e_{ij} \times a_{ij})$$

   These weights α and β can be adjusted to shift the emphasis between conservation value and development threat.

3. **Block Farmers:** Conservationists claim plots with the highest agricultural scores to block farmers from claiming them. This corresponds to $\alpha = 0$ and $\beta = 1$:

   $$S_g^r = \max(a_{ij})$$

   This approach reflects the idea from Delacote et al. (2024), where under high-quality institutions, conservationists benefit from targeting plots with high development pressure (high a_{ij}), in their case leading to the greatest additionality.

   On the other hand, in weak institutional settings where conservation efforts are less likely to succeed in the face of development pressure, the Delacote et al. optimal siting choice is that with the *lowest* development potential. In our framework this would map to a strategy where the Greens target the plots with the lowest agricultural scores first, which is not a strategy we have modelled (but could do. . .).

4. **Maximize Difference:** Conservationists claim plots where the difference between environmental and agricultural values is greatest:

$$S_g^r = \max(e_{ij} - a_{ij})$$

5. **Random Protection:** Conservationists claim plots at random.

$$S_g^r = rand(e_{ij})$$

2.1.4 Outcomes

We then conduct a comparative statics analysis by running Monte Carlo simulations in which a grid is populated with environmental and agricultural scores according to the specified parameters. Each farmer strategy is run against all Green strategies on the same grid, ensuring comparability. This is repeated 500 times, with the grid randomly repopulated each time, and the average of the following outcomes is recorded.

1. **Final Conservation Score** The final conservation score is the sum of the environmental values in the plots claimed by the Greens during the game, plus any remaining unclaimed plots at the end that are left undeveloped:

$$Conservation\ Score_{Green} = \sum_{p_{ij} \in S_g^{\leq R}} e_{ij} + \sum_{p_{ij} \notin (S_g^R \cup S_f^R)} e_{ij}$$

   The final conservation score for each strategy combination and level of leakage can be further decomposed into:

   (a) **A Pure Strategy Effect** (PSE) which reflects the inherent quality of the conservation targets selected by the strategy. The PSE may vary also with leakage to the extent the degree of leakage affects the set of available plots in each round and thus possibly the environmental quality of the strategy's targets:

$$PSE = \sum_{p_{ij} \in S_g^{\leq R}} e_{ij}$$

   (b) **A Displacement-Leakage Effect** (DLE) is the additional conservation benefit realized due to the combination of effective targeting of Farmer BAU plots and incomplete leakage:

$$DLE = \sum_{p_{ij} \notin (S_g^R \cup S_f^R)} e_{ij}$$

2. **Additionality** Additionality is measured as the Actual total conservation score achieved by the Greens minus the conservation score the Greens would have obtained had the Farmers been allowed to claim all the plots they wanted under their 'business as usual' (BAU) scenario.

   Let S_f^{BAU} represent the set of plots that the Farmers would claim under the BAU scenario. Conversely, let S_g^{BAU} represent the set of plots the Greens would be left with under the BAU scenario. We define the BAU and Actual conservation outcomes as:

$$Conservation_{BAU} = \sum_{p_{ij} \in S_g^{BAU}} e_{ij}$$

$$Conservation_{Actual} = \sum_{p_{ij} \in S_g^{\leq R}} e_{ij} + \sum_{p_{ij} \notin (S_g^R \cup S_f^R)} e_{ij}$$

   Then Additionality is calculated as $Conservation_{Actual} - Conservation_{BAU}$

3. **Total Welfare Loss** The total welfare loss (%) is the percentage decline from the maximum total welfare that could possibly be achieved to the actual total welfare achieved.

   Let W_{max} represent the maximum total welfare that could be achieved under the optimal land use pattern where each plot is allocated to its highest use value:

$$W_{max} = \sum_{p_{ij} \in P} \max(e_{ij}, a_{ij})$$

   Let W_{actual} represent the actual sum of use values based on the final plot allocation:

$$W_{actual} = \sum_{p_{ij} \in S_f} a_{ij} + \sum_{p_{ij} \in S_g} e_{ij}$$

   Then the welfare loss percentage is:

$$\text{Welfare Loss}(\%) = 100 \cdot \frac{W_{max} - W_{actual}}{W_{max}}$$

3 Monte Carlo Simulation Results

Our baseline results reported here explore the outcomes of all Green and Farmer strategy combinations for different levels of leakage with equal initial allocation of claims and zero correlation between environmental and agricultural values. In further robustness simulations reported in the Appendix we allow for (A.1) a correlation of 0.3 between the environmental and agricultural values of each plot; and (A.2) unequal allocation of claims to simulate a greater degree of Farmer economic or political power.

3.1 Conservation Outcomes of Green Strategies

At the end of the day, the primary outcome that Conservationists should be most concerned with is the total amount of Conservation (Environmental quality) achieved with their budget. Thus, we first examine how the different possible Green strategies perform when it comes to conservation outcomes.

3.1.1 Green strategies' Conservation outcomes and Naïve Farmers

Table 1 reports the final Conservation scores decomposed into the *Pure Strategy* and the *Displacement-Leakage* effects for the three primary Green strategies playing against the two Farmer strategies at three levels of leakage (0%, 50%, and 100%). The values reported in Table 1 are graphically displayed in Figure 1a which graphs the final scores of all five Green strategie, and Figure 1b which displays the dynamic trajectories of the primary three Green strategies.

As leakage is reduced, the Farmers lose the ability to replace their desired business as usual (BAU) plots that have been claimed by the Greens, and the Greens are allocated all remaining unclaimed residual plots at the end of the game, increasing their total Conservation score (but not necessarily their additionality, since it is unlikely the left-over plots are in the Farmer BAU set - something we discuss further below in section 3.2). This can be seen in the Dynamic Trajectory plots of Figures 1b where each Green strategy – leakage level dynamic trajectory is unique (the *Pure Strategy* effect) but with differing 'jumps' in the last round as the total score is augmented with the environmental values of remaining unclaimed plots (the *Displacement-*

Leakage effect).

Playing against Naïve Farmers, the Hot Spot strategy returns the highest final Conservation scores across all levels of leakage, while the Maximize Environment strategy produces the second-highest environmental benefits for all but the lowest levels of leakage. We can see from Fig. 1b that the *Pure Strategy* effect of Maximize Environment outperforms that of the Hot Spot earlier in the game by focusing solely on environmental values. The *Pure Strategy* effect of the Hot Spot strategy, on the other hand, sacrifices some early conservation gains to block development in high-development high-conservation value plots, but we see that this approach allows for gains later in the game when the Hot Spot strategy claims plots that would otherwise have been lost to development. Thus, as the game progresses, the *Pure Strategy* effect of Hot Spot eventually surpasses that of Maximize Environment. Then, in the last round, the *Displacement-Leakage* effect of Hot Spot is considerably higher than that of Maximize Environment, due also to the partial emphasis on claiming more Farmer BAU plots.

Another interesting feature of the Hot Spot strategy's *Pure Strategy* effect is that it produces lower conservation scores under 0% leakage than under higher levels of leakage. While counterintuitive, this can be understood because the Hot Spot strategy is equally weighting environmental and agricultural scores, so when there has been more leakage in earlier rounds, the Farmers have had more chances to claim plots with relatively higher agricultural scores and towards the end of the game the remaining plots that are attractive to the Hot Spot strategy will on average have higher environmental scores. In other words, under zero leakage the remaining high-agricultural value plots may attract the Hot Spot strategy away from plots with better conservation value, leading to a nonlinear and heterogenous *Pure Strategy* effect under different levels of leakage. However, the final Hot Spot Conservation score remains higher at lower leakage levels due to the contribution of the *Displacement-Leakage* effect, reflecting the larger number of unclaimed plots in the final round.

Of the three primary Green strategies playing against Naïve Farmers, the Block Farmers approach yields the lowest final conservation scores at all but the lowest level of leakage. At zero leakage, however, the final conservation score of the Block Farmers strategy actually exceeds that of Maximize Environment; this outcome is entirely due to the *Displacement-Leakage* effect, which is especially high at low levels of leakage for the Block Farmers strategy (especially playing against Naïve farmers) as it is the most effective at displacing Farmer BAU plots. However the *Pure Strategy* effect of the Block Farmers strategy is always below that of the Maximize Environment strategy, and the final Block Farmers score only exceeds it in the zero leakage case due to the *Displacement-Leakage* effect.

The differentiation of the *Pure Strategy* and the *Displacement-Leakage* effects of each Green strategy, along with the impact on each of the level of leakage, suggests that in practice the ultimate success of the different Green strategies may depend on the relative effectiveness of conserving protected land actively claimed by the Greens (*Pure Strategy* component) compared to the effectiveness of leakage enforcement – the ability to inhibit Farmers from expanding elsewhere when blocked from their BAU trajectory (*Displacement-Leakage*). Under a realistic scenario where protecting Green-claimed land is relatively more feasible than achieving zero-leakage, the *Pure Strategy* component may become considerably more important than the *Displacement-Leakage* component. In the limit we face a 100% leakage scenario and the Block Farmers strategy performs no better than Random at zero correlation between agricultural and environmental values.

3.1.2 Green strategies' Conservation outcomes and Strategic Farmers

Strategic Farmers are willing to target slightly lower value agricultural plots if they believe they are at risk of being claimed by the Greens, leaving less-at-risk high-agricultural value but low environmental value plots to be claimed later in the game. We can see in Table 1 and Fig. 2a that when confronting Strategic Farmers, the ranking of two top-scoring Green strategies is reversed: in this case Maximize Environment is strictly dominant, followed by Hot Spot. The Block Farmers strategy in this case comes last and is strictly dominated by all other possible Green strategies, including 'Random.'

We can observe in Fig. 2b the success of the Maximize Environment strategy in this case is almost entirely due to its superior *Pure Strategy* effect; when Farmers also target some high-environmental value plots, any deviation in focus by a Green strategy in claiming the top environmental plots carries a higher risk of losing them. At the same time, since the Farmer BAU set contains more environmentally high value plots, Maximize Environment also has a more successful Displacement-Leakage effect than the other strategies.

3.2 Additionality of Green Strategies

As discussed in the Introduction, a growing trend in Green Finance and empirical evaluations of conservation projects is to require evidence of additionality – that the project resulted in a conservation pattern that is different from and superior to the conservation under the counterfactual, e.g. that would have been expected had development followed its business-as-usual (BAU) trajectory. Here we explore the Additionality of each Green strategy.

3.2.1 Green Strategies' Additionality and Naïve Farmers

Figures 3a and 3b present the static final additionality scores of all five Green strategies across different leakage levels and dynamic trajectories of the primary three strategies, respectively, playing against Naïve Farmers. The pattern of final Additionality in Fig. 3a mirrors that of the final Conservation scores, since Additionality is defined as the actual conservation score achieved less the score the Greens would have obtained had the Farmers claimed all their BAU plots, which itself is fixed across all Green strategies.

However, the dynamic trajectory plots in Fig. 3b show that the path of additionality to those final scores is highly nonlinear and varies considerably at different levels of leakage. Since Additionality is only increased when a Greens claim a plot that was originally in the Farmer BAU set, and the remaining unclaimed plots at the end of the game at lower levels of leakage are never Farmer BAU plots, we do not see any final jump in the additionality scores in the last round as we did with the conservation scores.

Unlike the Conservation score, where differences in the *Pure Strategy* effect across leakage levels were relatively subtle, Fig. 3b shows that leakage is a critical determinant of final additionality as at higher levels of leakage the Farmers can later erode early gains. In the limit with 100% leakage the Block Farmer strategy essentially achieves no additionality at all.

3.2.2 Green Strategies' Additionality and Strategic Farmers

Figures 4a and 4b present the static final and dynamic trajectories of Additionality with Strategic Farmers. While the patterns of the final Additionality scores again mirror those from the Conservation scores, the levels of Additionality when playing against the Strategic Farmers is higher than when playing against Naïve Farmers because these Farmers include high-conservation value plots in the BAU set, so the additionality premium for the Greens for claiming Farmer BAU set plots is higher.

When playing against Strategic Farmers Maximize Environment strictly dominates all other strategies in achieving additionality at all levels of leakage, followed by the Hot Spot strategy. The Block Farmers strategy is strictly dominated by all strategies by a large margin; it performs even worse when Farmers are strategic as it does worse at targeting strategic farmer BAU plots by incorrectly assuming that Farmers are only going for high agricultural value plots.

3.3 Some Thoughts on Conservation Outcomes and Additionality of Green Strategies

Several general observations from sections 3.1 and 3.2 are worth discussing. First, although ex ante the 'block farmers' strategy might seem likely to maximize additionality, even if it doesn't maximize conservation, within our framework this is clearly not the case. This can be understood because the environmental and agricultural scores are uncorrelated and the game is iterative, so by targeting prime agricultural land, the Greens risk claiming plots with relatively low environmental value. When there is a high degree of leakage, once the Greens claim a plot in the Farmer's BAU set, Naïve profit maximizing Farmers will claim the next best agricultural plot, which may or may not have high environmental value; when it does, this further reduces the additionality the Greens can achieve. If the Farmers are Strategic and target plots with high conservation value, then the Block Farmers strategy is even costlier to the Greens.

As in the case with the Total Conservation score, as leakage is reduced and Farmers lose the ability to replace their desired business as usual (BAU) plots that have been claimed by the Greens, the additionality potential of the Block Farmers strategy increases. However, for levels of leakage greater than zero, and/or if Farmers claim plots more strategically, the Block Farmer strategy is generally either the worst or the penultimate worst strategy (after 'random') at achieving additionality.

Mirroring the total score outcomes, the two best-performing Green strategies in terms of

Additionality - Hot Spots and Maximize Environmental Score – each exhibit distinct advantages depending on the Farmers' strategy. As with the total Conservation score, against Strategic Farmers the Maximize Environment strategy performs better than Hot Spots for final additionality. Strategic Farmers include high-environmental-value plots in their BAU set, making these plots more likely to be claimed by Greens following the Maximize Environmental Score strategy. As leakage decreases, the Maximize Environmental Score strategy further benefits from reducing Farmer claims with each claim of a Farmer BAU plot, increasing the number of residual plots that default to the Greens at the end of the game. This dynamic makes Maximize Environmental Score the dominant strategy for Greens when competing against Strategic Farmers.

Finally, the results presented in sections 3.1 and 3.2 raise an interesting paradox for the Greens. Although the total Conservation achieved is greater when Farmers are Naïve, the measured Additionality is greater when playing against Strategic Farmers. In a broader sense, then, to the extent then that Greens are rewarded for greater Additionality this creates an incentive to target regions where farmers are attempting to preemptively claim prime environmental land, raising the prospect of conflict between the two interest groups.

3.4 Social Welfare loss of Green strategies

So far, we have concentrated on analyzing the environmental outcomes from alternative Green conservation strategies. However, the effects on overall social welfare are also salient, for both social planners and, in practice, possibly for long-run Green strategy itself in as much as the political cost of a Green strategy may ultimately play a role in the continued feasibility of conservation and leakage enforcement. Because we know the true social value of agriculture (development) or conservation for each plot on the grid, we are able to calculate the maximum social welfare that could be achieved from the socially optimal land use pattern. By comparing this maximum social welfare with the actual social welfare achieved under each Green strategy-Farmer strategy-Leakage combination, we can directly calculate the social welfare loss associated with different Green strategies.

3.4.1 Social Welfare loss of Green strategies and Naïve Farmers

Figures 5a and 5b present the graphical simulation results of total welfare loss and the dynamic trajectory of welfare loss, respectively, of differing Green strategies at differing levels of leakage with Naïve profit maximizing Farmers.

Across all levels of leakage the Maximize Environment returns the lowest degree of Welfare loss of all strategies, getting the closest to achieving the maximum possible social welfare. The Hot Spot strategy is a close second, also generating only a small social welfare loss. In contrast, the Block Farmers strategy results in the land use pattern with a much higher deviation from the social welfare maximizing outcome.

Fig. 5a reveals a surprising insight about the relationship between leakage and social welfare. Reduced leakage somewhat reduces the high welfare losses from the Block Farmers strategy, as expected, because at lower leakage levels the Farmers' lose claims, and among the unclaimed plots that are allocated to Greens in the final round are some plots that should optimally be conserved, reducing the total welfare cost of this strategy.

However reduced leakage counter-intuitively increases the welfare costs of the Maximize Environment strategy, and generates a U-shaped relationship between leakage and welfare loss for the Hot Spot strategy. This can be understood because without leakage some farmer's BAU plots with low environmental scores are more likely to be unclaimed and thus allocated to the Greens at the end of the game, increasing misallocation. We can see this pattern in the dynamic trajectory plot of Fig. 5b; the *Pure Strategy* effect on welfare loss of Maximize Environment and Hot Spot is not affected much by the level of leakage except towards the end of the game, but the Displacement-Leakage effect generates a jump up in loss, with larger losses for lower levels of leakage, that drives the nonlinear final pattern.

3.4.2 Social Welfare loss of Green strategies and Strategic Farmers

Figures 6a and 6b explore the welfare loss of alternative Green strategies when facing strategic Farmers. In this case the Maximize Environment strategy still strictly dominates the other strategies, producing the lowest loss in social welfare across all leakage levels. The Block Farmer strategy similarly also produces the highest level of welfare loss at all levels of leakage.

However, the final welfare loss and the dynamic trajectory of the Hot Spot strategy looks quite different when playing against Strategic Farmers, displaying a striking nonlinearity both temporally as the game progresses and across different levels of leakage. Temporally, as the game unfolds, the *Pure Strategy* of the Hot Spot strategy initially finds plots with high values for both agriculture and conservation, with moderate disparities between them; for these plots, any 'flipping' of the optimal land use (e.g. an optimally agricultural plot claimed by the Greens and allocated for conservation) generates only a small fall in social welfare. As the game progresses the remaining pool increasingly comprises plots where there is a greater difference between agricultural and environmental values; flipping these plots generates greater losses in social welfare.

Furthermore, because Strategic Farmers tend to claim plots with higher environmental values earlier in the game, the set of available plots later will become increasingly dominated by those with both larger gaps and higher agricultural values. When the Greens then flip these plots the welfare loss is relatively high. Then, if the Farmers are constrained from claiming these later in the game because of low leakage, the welfare loss is even further increased. All together this dynamic leads to a nonlinear cumulative welfare loss trajectory: a relatively flat increase in the early rounds, a steep mid-game rise as the difference between agricultural and environmental values in the remaining plots widens, and then another abrupt jump in the final round, particularly under 0% leakage.

Finally, as we can see in Fig 6b, although the Maximize Environment Strategy still has the lowest welfare loss, towards the end of the game we again see that lower leakage levels lead to higher welfare losses, and this counterintuitive relationship is even more pronounced when playing against Strategic Farmers. We observe this positive leakage-welfare loss relationship in both the *Pure Strategy* as well as the Displacement-Leakage components; the result arises because, without leakage, plots with low environmental scores and higher agricultural scores are less likely to be claimed during the game and are instead more likely to be allocated to Greens in the final rounds, increasing misallocation and thus total welfare loss.

Overall, with both Naïve and Strategic Farmers, we observe that the social welfare costs of the Maximize Environment and Hot Spot strategies are the lowest, but also that in both cases the welfare losses are *increasing* as leakage falls at lower levels of leakage. In all cases the social welfare costs of Block Farmers are considerably higher, with some moderation as leakage levels fall.

4 Case Study: Conservation Strategies in Bolivia

As a large, geographically diverse developing country with both extremely high levels of biodiversity and an urgent need to improve living standards, Bolivia provides an interesting case study on how protected areas and agricultural expansion have competed for space over the last several decades.

4.1 A short history of protected areas in Bolivia

Bolivia provides an insightful case study of the dynamic and contested nature of conservation decisions. With an extraordinary level of biodiversity and significant pressure for economic development, the history of Bolivian conservation efforts illustrate well the trade-offs and strategic interactions that our simulated framework addresses. Protected Areas (PAs) in Bolivia span national, state, and municipal jurisdictions, varying widely in size, purpose, and effectiveness, but have in common a restriction on the type and extent of development that may take place. As illustrated in figure 7b and detailed in Appendix table A5.1, since 1939 the total land area under Protected Area status has gradually increased from zero to 35.4 million hectares, 32% of the national territory[1]. Figure 7 reveals that PA expansion in Bolivia has proceeded at least 3 times faster than agropastoral expansion since 1985 (30 million hectares for conservation versus 8 million hectares for agropastoral expansion).

Formal conservation efforts began in 1939 with the creation of Sajama National Park to protect the endangered Polylepis forests around Bolivia's highest peak. Shortly thereafter, in 1942, the Tuni Condoriri National Park was established to safeguard critical water supplies for El Alto and La Paz. However, conservation activity remained sparse until the mid-1960s, when protected areas such as TIPNIS, Manuripi, and Eduardo Avaroa were established, marking the first substantial extension of Bolivia's protected lands into regions with significant biodiversity value.

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[1] Bolivia is among 35 countries in the world that have already reached the 30x30 goal of the CBD.

The late 1980s and 1990s constituted a “golden age” of Bolivian conservation, fueled largely by international funding through mechanisms like the pioneering 1987 Debt-for-Nature swap and extensive international support from NGOs. Major protected areas established during this period—including Amboró, Madidi, Carrasco, and Kaa-Iya del Gran Chaco—targeted regions with exceptionally high environmental values but often lower immediate agricultural threats, consistent with a strategy focused primarily on maximizing environmental benefits.

By contrast, the economic expansion from the early 2000s through around 2015 significantly reshaped conservation dynamics. Protected area establishment slowed markedly during this period due to greater economic incentives for agricultural and extractive development. At the same time, the new PAs that were established were often placed within or near the agricultural frontier, as is apparent in the Supplementary video 8 and as we illustrate below in figure 12, where we see that the agricultural potential of newly protected areas in the early 2000s is relatively high. The Laguna Concepción State-Level Wildlife Reserve, established in 2002, is a good example. Laguna Concepción is a natural lagoon designated a Ramsar Site, recognizing it as a wetland of international importance, but it is located in the center of Bolivia’s Santa Cruz State near the heart of agricultural expansion in the country. Despite its Protected Area status, conservation of the Laguna has been a struggle, with significant agricultural and livestock encroachment by Mennonite colonies into the western and northern sectors, threatening the fragile ecosystem (Navia, 2022).

Following the economic downturn of the late 2010s and the subsequent pandemic crisis (2020–2023), Bolivia again intensified conservation efforts, rapidly designating new protected areas—particularly at the municipal level; the year 2019 saw the establishment of more than 4.2 million hectares of newly Protected Areas and the pandemic crisis of 2020-2023 coincided with the creation of 2.4 million hectares of primarily municipal protected areas.

4.1.1 Data

In order to map the expansion of Protected Areas in Bolivia to our theoretical Green conservation strategies we combine annual (1985-2023) pixel-level land use data from Mapbiomas MapBiomas Bolivia Project (2024) and a detailed geo-referenced database of all Protected Areas in Bolivia, including type and year of establishment from SDSN Bolivia (SDSN Bolivia, 2025).

A times series of Bolivian GDP per capita is from Our World in Data (Our World in Data, 2025).

In order to estimate the potential conservation values of land areas either designated as Protected Areas or put into agricultural production we take advantage of a high-resolution map of the value of ecosystem services from Andersen et al. (2024). The map, reproduced in figure 9b, is expressed in *potential* annual dollar values per hectare (USD/ha/year) from the benefits of conservation, including provisioning values (timber, non-timber forest products, hunting and fishing, water), regulation values (biodiversity conservation, carbon sequestration, local climate regulation, pollination, and water treatment), and cultural values (tourism and recreation). Conservation values range from the lowest in the arid region of the southwestern Bolivian Altiplano, to the highest in the dense Amazon jungle in the north and the biodiversity-rich mountainous valley regions between the highlands and the lowlands.

In order to estimate the Agricultural value of land we generate estimates of net agricultural potential per hectare, presented in figure 9a, following the methodology from Andersen et al. (2023). Agricultural potential varies greatly across Bolivia due to differences in topography, soil quality, and climate, with the most profitable regions being those with climates appropriate for the production of high value crops, like fruits and berries[2]. To generate the map, we use detailed pixel-level geographical data on slope, soil quality, precipitation, and temperature distribution to develop a high-resolution Production Cost Factor. Combining this with information on the most common crop (or livestock), average yields, and prices in each municipality to generate pixel-level estimates of agricultural potential[3].

4.2 Strategy Analysis

Our high resolution time series land use data combined with potential conservation and agricultural values allows us to map the evolution of the new land allocated to either agriculture or conservation as well as measure the 'payoffs' and opportunity costs, mirroring as much as pos-

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[2] In practice, the private profitability of agriculture depends not only on agricultural potential but also on local infrastructure and proximity to markets, which are not reflected in these numbers. Nevertheless, the map provides an estimate of relative agricultural values.

[3] While the original map in Andersen et al. (2023) uses information on Protected Area status and infrastructure such as distance to roads to generate the Production Cost Factor estimates, for our purposes we have produced estimates that use only geo-physical conditions

sible the structure of the strategy simulation discussed above. Figure 10 graphs the evolution of GDP per capita in Bolivia.

Supplementary video 8 shows the dynamic expansion of agricultural land and Protected Areas from 1985 to 2024. Figures 11a and 11b show the average potential conservation and potential agricultural values of the land newly allocated to either agriculture or conservation (via Protected Area status), respectively, for each year from 1985 to 2023.

Figure 12 consolidates this information and combines it with data on the area increment (figures 7a and 7b) in 5-year increments. The area of new land allocated to Protected Areas is indicated by the height of upwards bars, while new land allocated to Agriculture is show by the downwards bars. Each bar has both green and brown shades to indicate the average conservation and agricultural potential, respectively, of the newly allocated land - darker shades represent higher average values and lighter shades represent lower average values. For example, figure 12 shows that in 1986-1990 almost 4 million ha was allocated to Protected Area status, and just over 1 million ha was converted to agricultural land. Comparing the potential agricultural values (shades of brown) we can see that the land allocated to agriculture is a darker brown (higher potential) than that allocated to conservation. Comparing the potential conservation values (shades of green) we see that the average conservation value of land allocated for Protected Area status is much higher (darker) than that allocated to agriculture. Thus, overall the period 1986-1990 displays land use patterns consistent with Greens maximizing conservation and Farmers maximizing agricultural profits, with minimal loss of social welfare.

In fact, figure12 suggests that throughout the sample period Farmers seem to display Naive Profit Maximizing behavior - in each 5-year period Farmers target the highest agricultural-potential land, which also happens to have relatively low to medium conservation quality. The revealed Green strategy is more complex. From the heights of the upwards (Conservationists) bars in figure 12 and the GDP per capita trends from figure 10, we can see that Bolivia has historically expanded its protected area network most effectively during economic downturns, when there is less extractive pressure, more reliance on international conservation funds, and greater political willingness to use conservation as a development tool. However, during economic booms, such as that in the early 2000 to 2015, protected areas faced greater political resistance and less support. However the type of land targeted for protection seems also to have changed over time. In the early years before 1995 conservation appears to have been following a Maximize Environment strategy, however the targeting was not quite as accurate between 1996-2000, and during the early part of the millennium, from 2001-2005 Green Strategy is consistent with a Hot Spot strategy. This can also be seen in the Supplementary video 8 where new Protected Areas during this period are often sited within areas that already have significant agricultural expansion. From 2006 onwards the strategy reverts to Maximize Environment, though not as effectively targeted in the last five-year period.

The failure of Protected Area status at Laguna Concepción to prevent human encroachment and ecosystem degradation (Navia, 2022) suggests that in practice realized environmental values may be negatively correlated with agricultural values due to weak legal enforcement of protected areas in the face of increased development pressure. Thus in the Appendix section A3 we explore the performance of Green strategies when there is a weak enforcement, i.e. a negative correlation between agricultural and environmental values. The results in figures A3.1a and A3.1b show that in this case the conservation performance of the Maximize Environment *Pure Strategy* effect may be even stronger than in the zero-correlation case. In addition, as would be expected, the *Displacement-Leakage* effect becomes a much larger determinant of the final conservation outcome of the Block Farmer strategy - but since it seems unlikely that legal enforcement of protected areas would be weak while effective suppression of leakage would be strong, we view this particular combination as unrealistic.

In sum, we find that the broadly Maximize Environment strategy that Bolivian conservationists have mostly followed since 1939 is most likely the optimal strategy, both for achieving the best conservation outcomes and for facilitating economic development and social welfare maximization. In particular, when legal protections are relatively weak, leakage is likely high, and Farmers are naive profit maximizers - the Bolivian case - the Maximize Environment strategy stands out in our Monte Carlo simulations as the strategy with the strongest conservation performance (of the *Pure Strategy* effect) and lowest social welfare costs. However, the additionality of Maximize Environment is never as high as the Hot Spot strategy, highlighting an interesting paradox revealed in the simulations - that under some realistic scenarios maximizing additionality does not guarantee the highest overall conservation outcomes.

5 Discussion

What are the most effective conservation strategies for achieving environmental objectives? We model conservation as an iterative, strategic contest, introducing a novel framework that simulates dynamic interactions between conservationists (Greens) and developers (Farmers) competing to claim land plots with heterogeneous agricultural and environmental values. Using dynamic Monte Carlo simulations, we provide comparative statics analyses evaluating the environmental benefits, additionality, and welfare losses associated with various strategies for siting protected areas—including targeting high-threat hot spots, maximizing environmental benefits, and blocking development—across different developer behaviors and leakage levels.

The framework allows us to differentiate between a *Pure Strategy* effect of each Green strategy, reflecting the relative conservation quality of the Green-claimed plots in each round, and a *Displacement-Leakage* effect, reflecting the ability of a particular Green strategy to target Farmer BAU plots and thus, under leakage ¡100%, potentially reduce Farmer claims and leave some plots unclaimed (and thus conserved). While both effects contribute to the final conservation and welfare scores, separating them clarifies how, in practice, varying degrees of enforcement—of protected status on the one hand, and leakage control on the other—may influence the ultimate outcomes.

Several surprising insights emerge from our simulations. First, the 'Maximize Conservation Score' and 'Hot Spot' strategies consistently yield the highest total conservation scores, though their relative effectiveness depends critically on the behavior of Farmers. Second, strategies explicitly aimed at blocking development consistently underperform, producing lower conservation outcomes, greater welfare losses, and even lower additionality compared to alternatives. Third, reduced leakage does not uniformly improve outcomes; under certain conditions, it paradoxically amplifies welfare losses, especially when conservation strategies target plots with substantial discrepancies between agricultural and environmental values.

In practice, if conserving officially protected areas is relatively more feasible than preventing development from encroaching into unclaimed land, the *Pure Strategy* component may become considerably more important than the *Displacement-Leakage* component. In these cases, the *Pure Strategy* of the Maximize Environment, and to a slightly lesser extent the Hot Spot strategy, stand out for their superior performance in generating high conservation outcomes at relatively low welfare cost. Under 100% leakage, the Block Farmers strategy performs no better than Random, despite its intuitive appeal, and incurs significantly higher welfare costs.

To facilitate broader engagement with these findings, we have developed an interactive, browser-based version of the game that mirrors the simulation framework introduced in this paper. Users can can play the role of either conservationist Greens or developer Farmers to explore the dynamic effectiveness of alternative strategies for different ecosystems and levels of institutional quality. A link to the game and user manual is provided in Appendix A1.

In addition, our case study of Bolivia illustrates how this framework can be applied to better understand conservation strategy in practice. Bolivian Farmers appear to consistently follow naive profit-maximizing behavior, while conservation strategy has varied over time. We observe several decades in which conservation practice aligns with a Maximize Environment strategy, while other periods reflect a Hot Spot or Block Farmers approach. In terms of sheer area protected, conservation expansion has been more successful during economic downturns when agricultural pressures subsided, international funding increased, and political will aligned. Whether these shifts were driven by economic conditions or other institutional factors remains a promising avenue for future research.

The case study also reveals how development pressure can undermine the effectiveness of protected status—exemplified by Laguna Concepción—suggesting that realized conservation values may be negatively correlated with agricultural values. Our simulations under such negative correlation confirm that the Pure Strategy performance of the Maximize Environment approach may be even more robust in such settings. In environments with weak legal enforcement, high leakage, and profit-maximizing farmers—conditions consistent with Bolivia—the Maximize Environment strategy achieves the strongest conservation outcomes. In contrast, while Hot Spot strategies may yield higher additionality, they do not necessarily lead to higher overall conservation. This highlights a strategic paradox: a singular focus on additionality can incur substantial welfare costs and may fail to deliver the highest environmental gains in the long run.

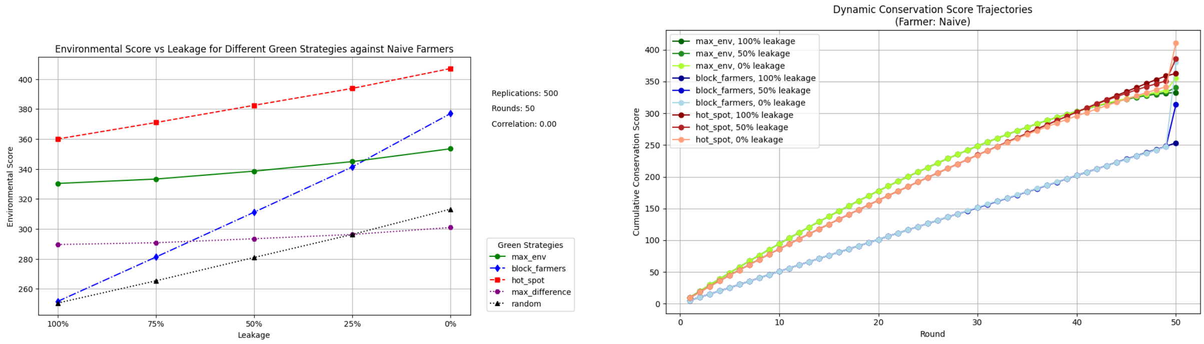
Our analysis also has methodological implications for the empirical evaluation of conservation policies. Causal inference studies should interpret short-run conservation impacts in actively contested regions primarily as reflections of the Pure Strategy effect. By contrast, evaluating long-term conservation effectiveness—incorporating both strategic targeting and displacement dynamics—requires a broader research design and longer time horizon than typically employed in current evaluations.

6 Tables

Table 1: Conservation Scores Under Different Strategies and Leakage Levels: The *Pure Strategy* and *Displacement-Leakage* Effects

Farmer Strategy	Green Strategy	Leakage Level (%)	*Pure Strategy* Effect	*Displacement-Leakage* Effect	Final Conservation Score
naive	Max Environment	0	337	17	354
naive	Max Environment	50	333	6	339
naive	Max Environment	100	331	0	331
naive	Block Farmers	0	252	126	378
naive	Block Farmers	50	252	60	312
naive	Block Farmers	100	252	0	252
naive	Hot Spot	0	344	63	408
naive	Hot Spot	50	354	29	383
naive	Hot Spot	100	361	0	361
strategic	Max Environment	0	301	34	336
strategic	Max Environment	50	294	12	306
strategic	Max Environment	100	290	0	290
strategic	Block Farmers	0	142	7	148
strategic	Block Farmers	50	142	3	144
strategic	Block Farmers	100	142	0	142
strategic	Hot Spot	0	237	22	259
strategic	Hot Spot	50	241	11	252
strategic	Hot Spot	100	244	0	244

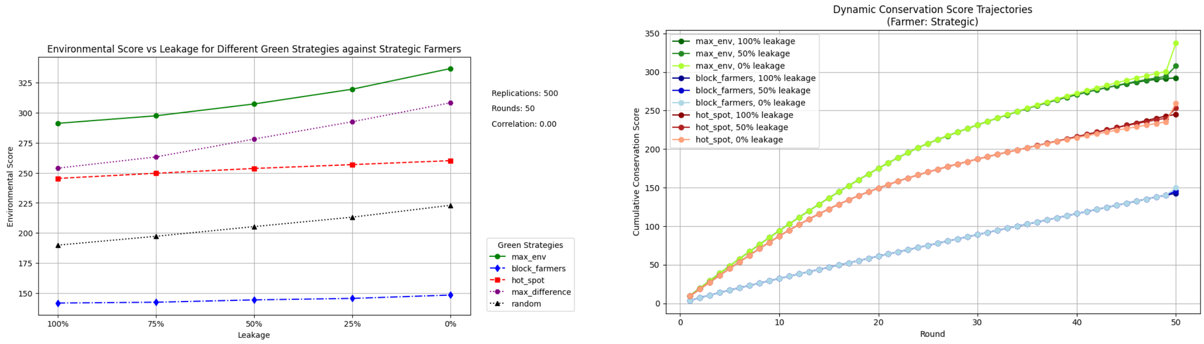
7 Figures



(a) Final Conservation Scores

(b) Dynamic Trajectories

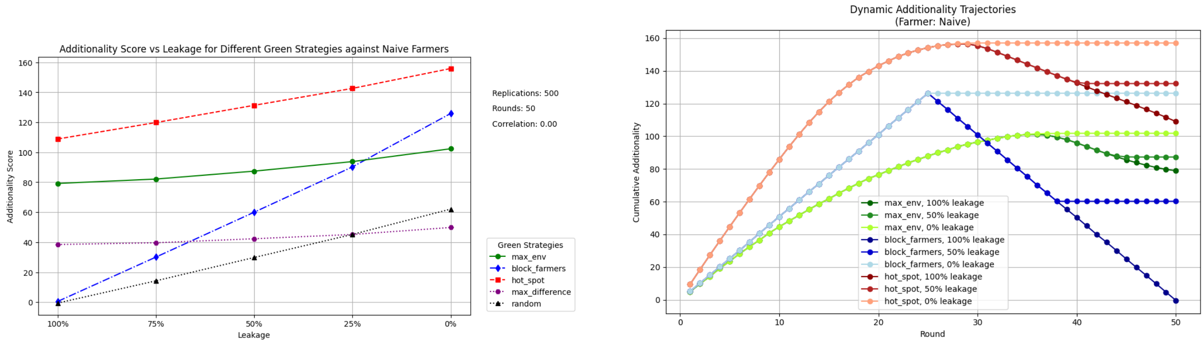
Figure 1: Green Strategies and Naive Farmers: Conservation Scores



(a) Final Conservation Scores

(b) Dynamic Trajectories

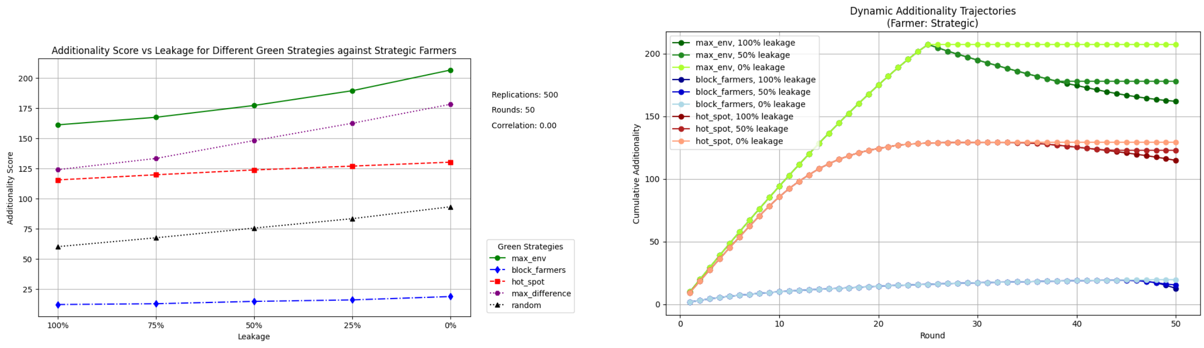
Figure 2: Green Strategies and Strategic Farmers: Conservation Scores



(a) Final Total Additionality

(b) Dynamic Trajectories

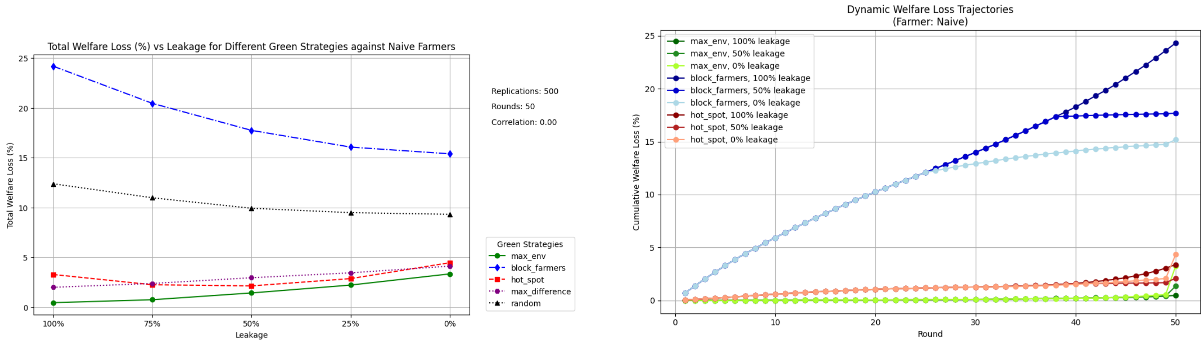
Figure 3: Green Strategies and Naive Farmers: Additionality



(a) Final Total Additionality

(b) Dynamic Trajectories

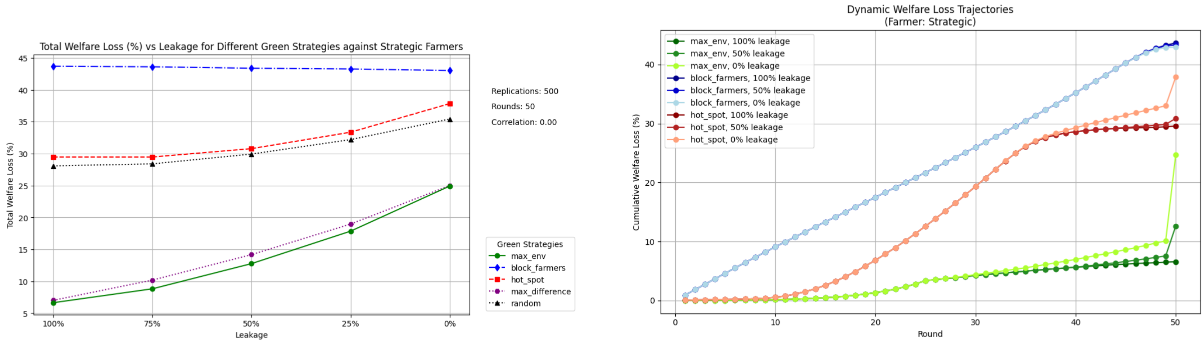
Figure 4: Green Strategies and Strategic Farmers: Additionality



(a) Final Social Welfare Loss(%)

(b) Dynamic Trajectories

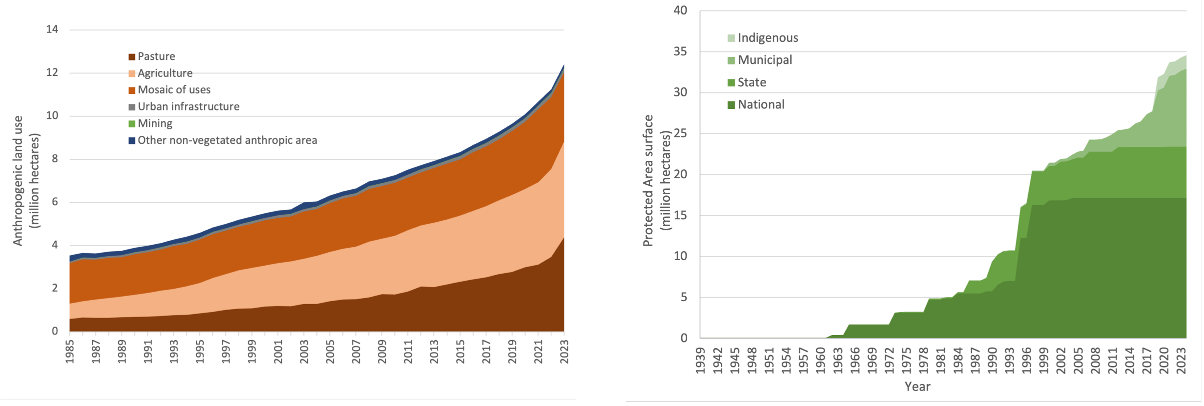
Figure 5: Green Strategies and Naive Farmers: Social Welfare Loss(%)



(a) Final Social Welfare Loss(%)

(b) Dynamic Trajectories

Figure 6: Green Strategies and Strategic Farmers: Social Welfare Loss(%)

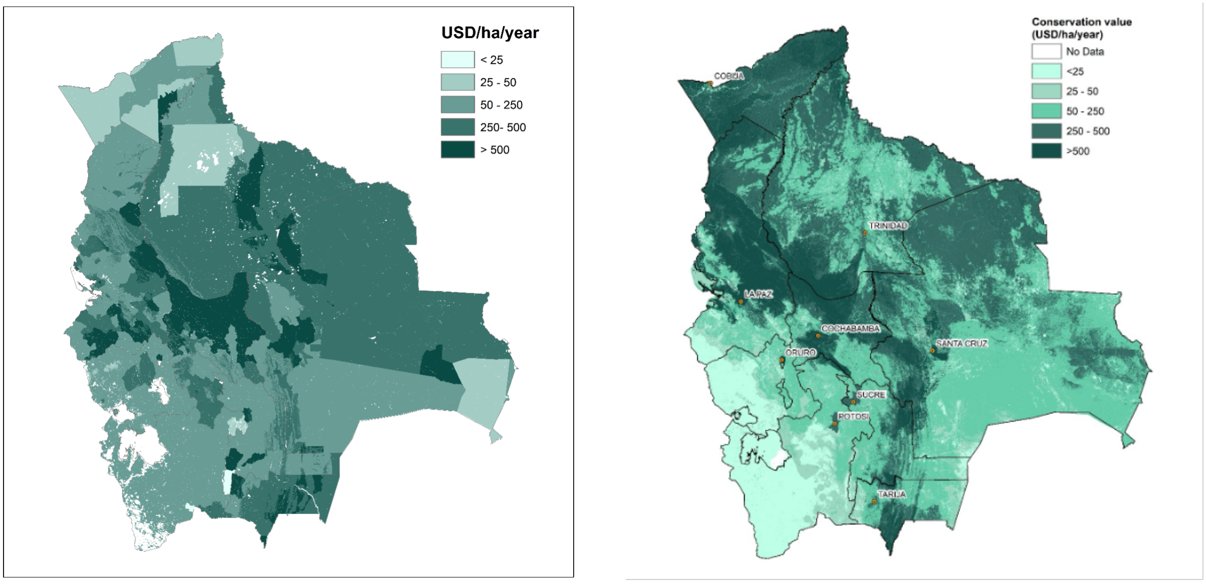


(a) Cumulative Anthropogenic Land Use

(b) Cumulative Protected Areas

Figure 7: Cumulative Land Use in Bolivia, 1930-2023

Figure 8: Supplementary Video: Dynamic expansion of Agricultural and Protected Area Land, 1985-2024
(Click the button to view the video).



(a) Potential Agricultural Values

(b) Potential Conservation Values

Figure 9: Potential Agricultural & Conservation values (annual USD per ha)

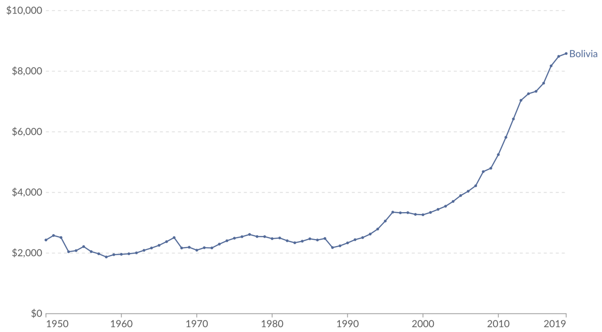
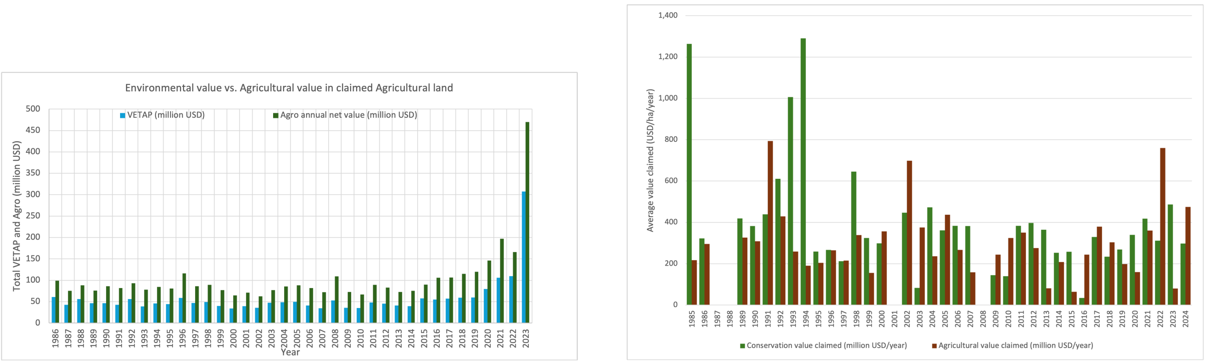


Figure 10: Bolivian GDP per capita, 1950-2019
(constant 2017 USD adjusted for cost of living)



(a) New Agricultural Land, by year

(b) New Protected Areas, by year

Figure 11: Potential Agricultural & Conservation Values of New Agricultural and Protected Land, (annual USD per ha)

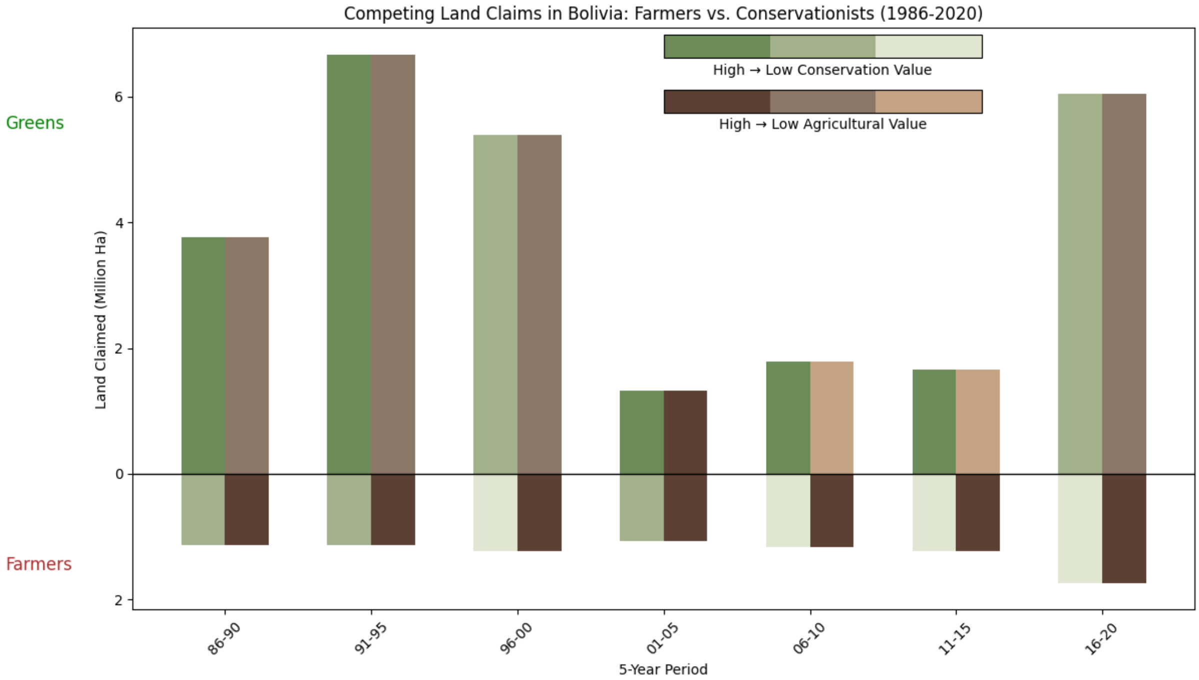


Figure 12: Agricultural & Conservation Potentials and Area of New Land allocated to Agriculture and Conservation, 5-year increments

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Appendix

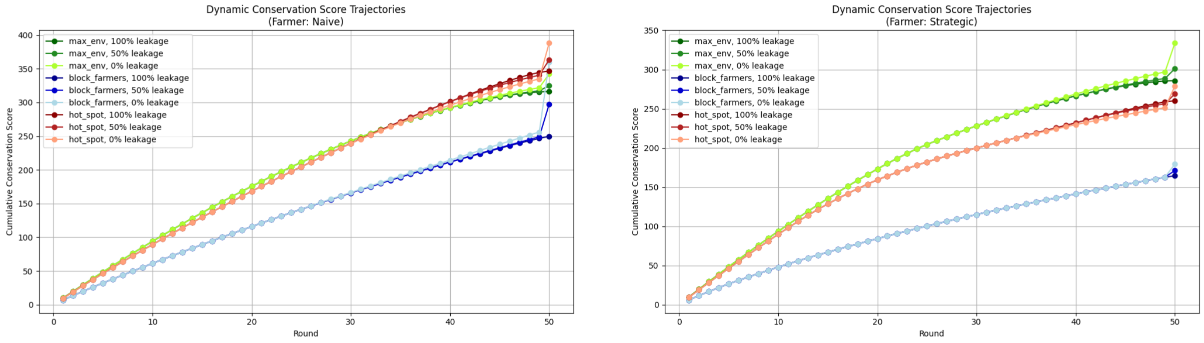
A1 Supplementary Interactive Conservation Strategies Game

An interactive version of the Conservation Strategy Game based on the simulation framework developed here is available for free use in web browsers or as a downloadable standalone app here: `https://dmweinhold.github.io/Conservation-Strategy-Game-Page/`. The game supports a variety of user-defined configurations and displays conservation scores, additionality, and welfare outcomes upon completion.

A2 Positive Correlation between Agricultural and Conservation Values

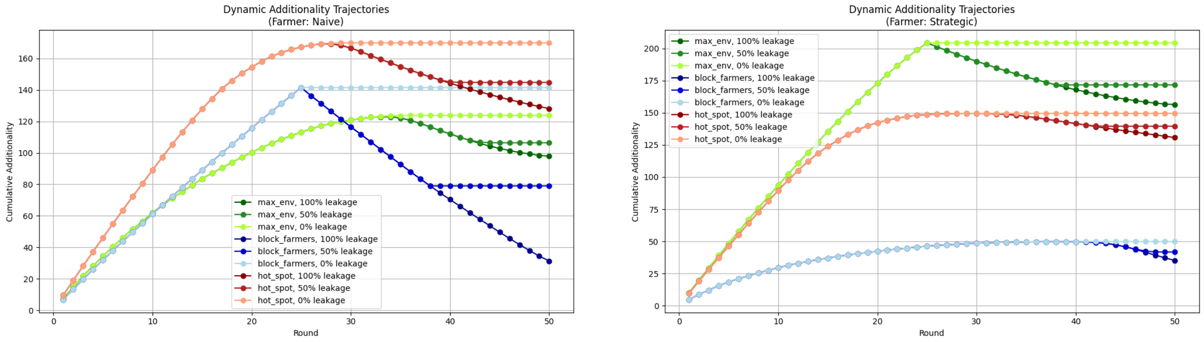
Our case study of Bolivia suggests that agricultural and conservation potentials in practice may be positively correlated. Thus, below we plot the dynamic trajectories of outcome variables for different combinations of strategies when the grid is initialized with a positive correlation of 0.30 between Conservation values and Agricultural values (500 replications and 50 rounds).

Overall, with a positive correlation between agricultural and environmental values, we observe that conservation scores tend to be lower across all strategies, but the additionality scores of the Hot Spot and Block Farmers strategies tend to be slightly higher. The dynamic trajectory patterns are broadly similar, with the Conservation values of the Hot Spot *Pure Strategy* effect slightly stronger than in the zero correlation case.



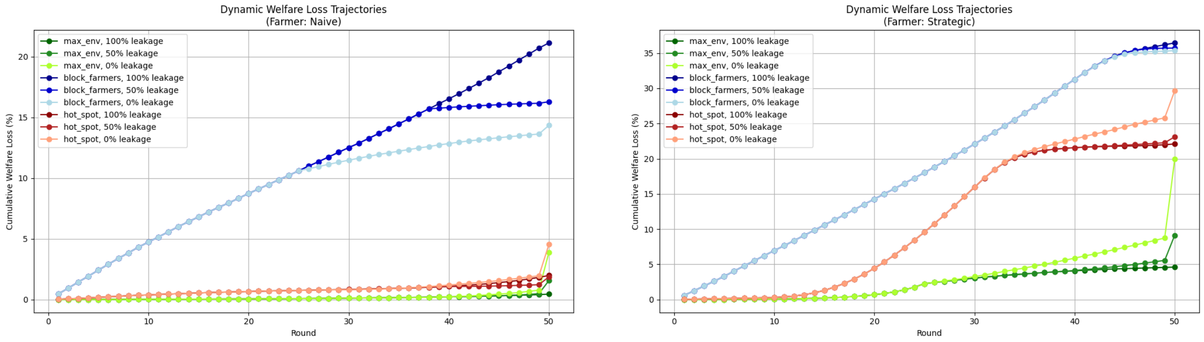
(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A2.1: Conservation Scores for $\rho = 0.3$



(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A2.2: Additionality for for $\rho = 0.3$



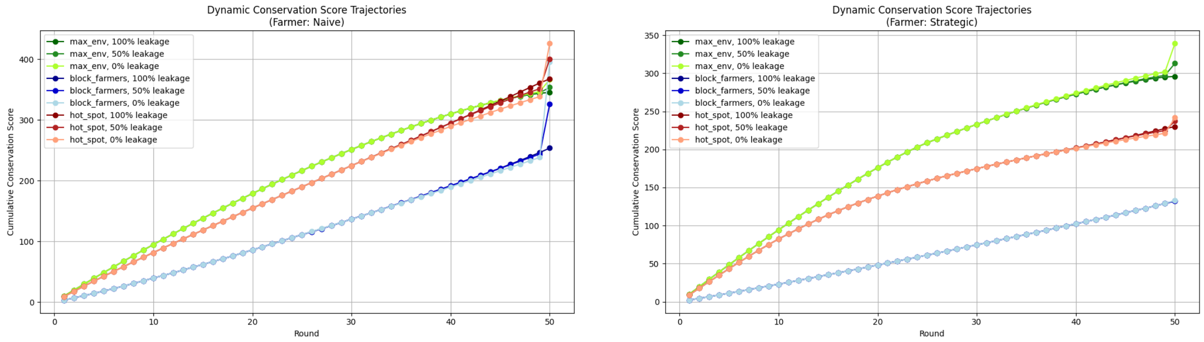
(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A2.3: Social Welfare Loss(%) for for $\rho = 0.3$

A3 Negative Correlation between Agricultural and Conservation Values

Our case study of Bolivia suggested that enforcement of protected status may be more challenging in areas under high threat of development, as illustrated by the experience of Laguna Concepción. In order to simulate this relationship we initialize the grid with a negative correlation between Agricultural and Environmental values - in those plots most desirable to the Farmers, realized Environmental values are lower due to increased difficulty of enforcement. Note that this approach explicitly differentiates between the effectiveness of leakage control (the *Displacement-Leakage* effect), which is still explored in the simulation by allowing for different levels of leakage, and a *Pure Strategy* effect when protection effectiveness is systematically reduced in Green claimed land of high agricultural value.

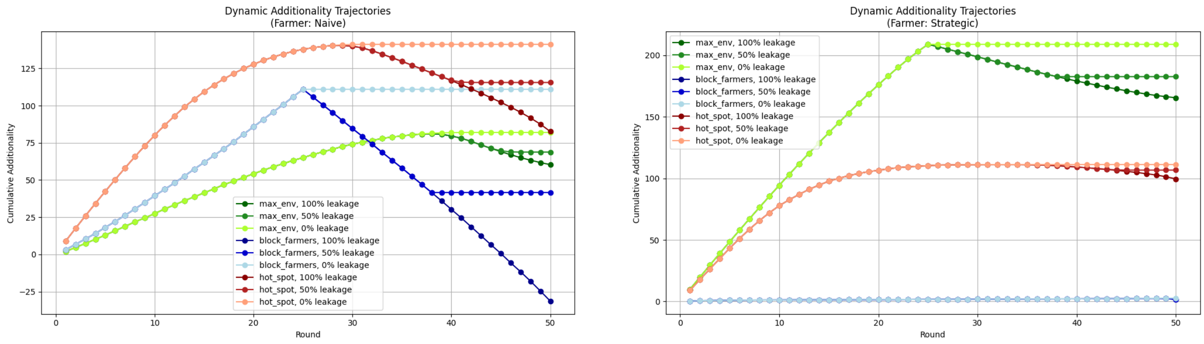
Thus, below we plot the dynamic trajectories of outcome variables for different combinations of strategies when the grid is initialized with a negative correlation of -0.30 between Conservation values and Agricultural values (500 replications and 50 rounds). Overall, with a negative correlation between agricultural and environmental values, the dynamic trajectory patterns are broadly similar, with the Conservation values of the Maximize Environment *Pure Strategy* effect slightly stronger than in the zero correlation case.



(a) Green Strategies and Naive Farmers

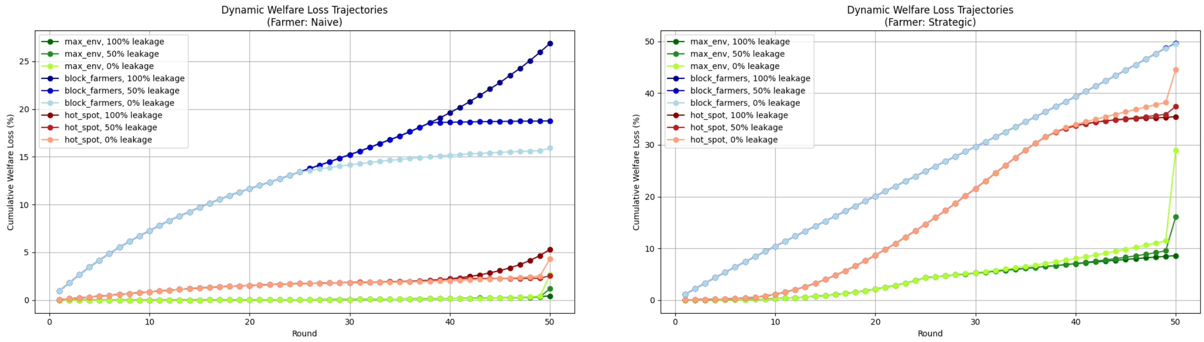
(b) Green Strategies and Strategic Farmers

Figure A3.1: Conservation Scores for ρ = -0.3



(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A3.2: Additionality for for ρ = -0.3



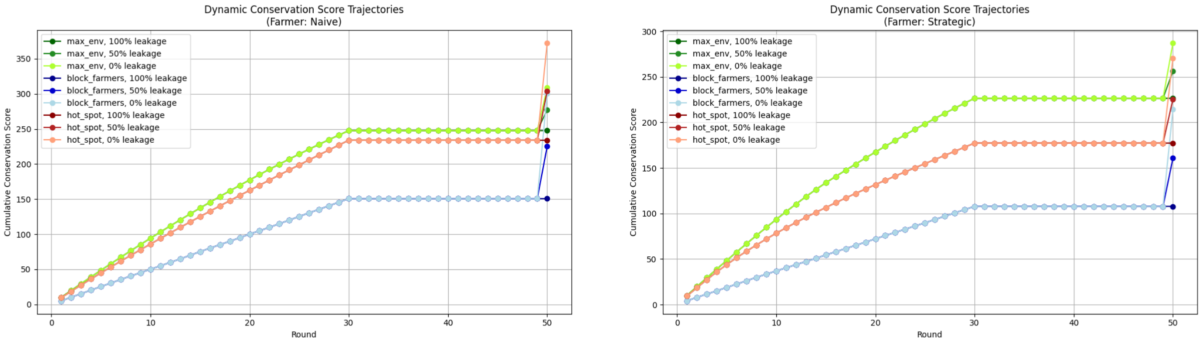
(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A3.3: Social Welfare Loss(%) for for ρ = -0.3

A4 Political Allocation in Favour of Farmers

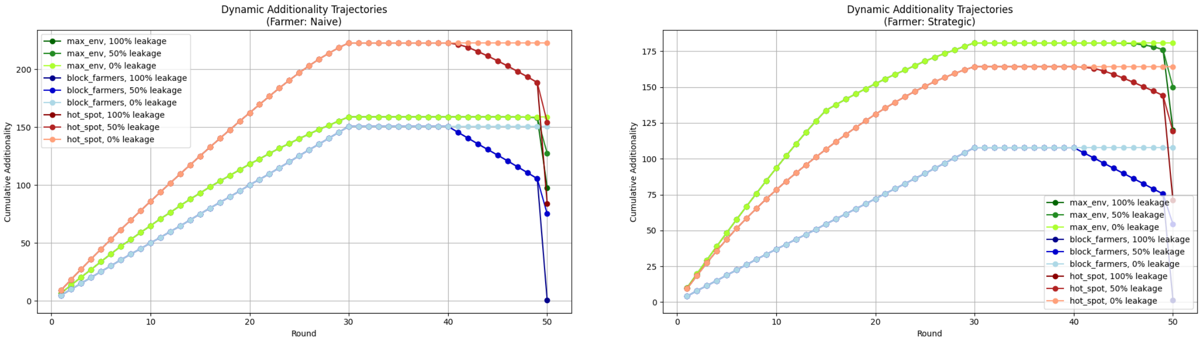
Here we allocate 70% of the initial claims to the Farmers, exploring how the different Green strategies perform when conservation faces an economic or political disadvantage.

We present the dynamic trajectory paths below, and the final score is represented by the outcome in round 50. Since in the political allocation considered the Farmers will have excess claims and spend those to claim additional plots in the last round (while the Greens are allocated any remaining unclaimed plots), then in this scenario there are significant last-round adjustments to the final score across all three outcomes considered.



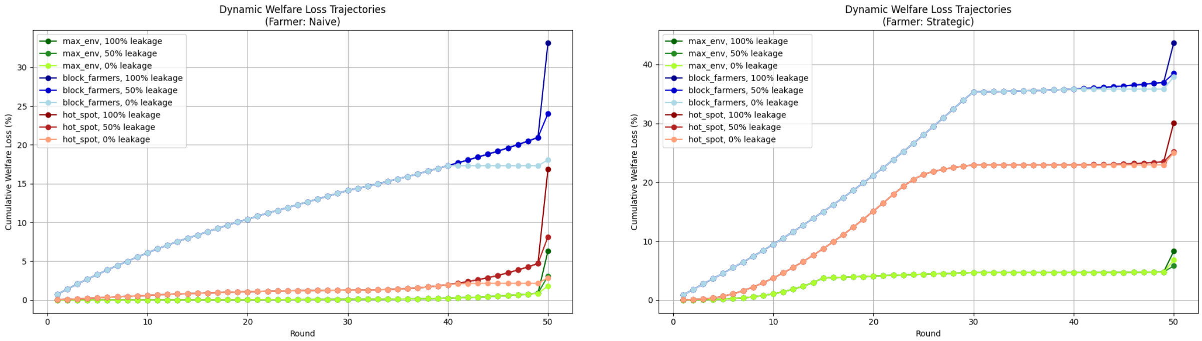
(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A4.1: Conservation Scores for Political Allocation to Farmers = 70%



(a) Green Strategies and Naive Farmers (b) Green Strategies and Strategic Farmers

Figure A4.2: Additionality for Political Allocation to Farmers = 70%



(a) Green Strategies and Naive Farmers

(b) Green Strategies and Strategic Farmers

Figure A4.3: Social Welfare Loss(%) for Political Allocation to Farmers = 70%

A5 List of Bolivian Protected Areas

Table A5.1: List of Bolivian Protected Areas

Name	**Category**	**Administrative Level**	**Year Established**	**Area (ha)**
Sajama	National Park	National	1939	94,372
Cerro Tapilla	Fiscal Reserve	State	1940	1,064
Tuni Condoriri	Natural Park	State	1942	9,046
Mirikiri	Protection Area	State	1945	752
Tunari	National Park	National	1962	326,078
Flavio Machicado Viscarra	Wildlife Sanctuary	State	1963	66
Isiboro Sécure	National Park and Indigenous Territory	National	1965	1,291,120
Las Barrancas	National Park	State	1966	225
Mallasa	Natural Park	Municipal	1972	303
Manuripi	Amazonian Wildlife National Reserve	National	1973	746,044
Eduardo Avaroa	Andean Fauna National Reserve	National	1973	683,066
Yura	Natural Immobilization Reserve	State	1974	96,885
Huancaroma	Natural Reserve	State	1975	36,647
Noel Kempff Mercado	National Park	National	1979	1,598,470
Huaripampa	Natural Park	Municipal	1980	1,550
Estación Biológica del Beni	Biosphere Reserve and Biological Station	National	1982	134,335
Valle de la Luna y Cactario	Natural Monument	Municipal	1982	47
Amboró	Integrated Natural Management Area	National	1984	186,941
Amboró	National Park	National	1984	439,552
Gran Jardín de La Revolución	Natural and Landscape Heritage	Municipal	1985	291
Iténez	Natural Park and Integrated Natural Management Area	State	1986	1,432,270
Tariquía	National Flora and Fauna Reserve	National	1989	247,764
Torotoro	National Park	National	1989	16,689
Laguna Alalay	Environmental Protection Area	Municipal	1989	311
Santa Cruz La Vieja	Historical National Park	Municipal	1989	79,384
Santa Cruz La Vieja	Natural Park	State	1989	17,173
Llica	Natural Park	State	1990	74,630
Eva Eva Mosetenes	Watershed Protection Zone	State	1990	252,362
Yacuma	Natural Park	State	1990	219,609
Ríos Blanco y Negro	Natural Reserve	State	1990	1,421,380
Lomas de Arena	Regional Park	State	1991	14,071

Continued on next page

Table A5.1 (Continued)

Name	Category	Administrative Level	Year Established	Area (ha)
Bosquecillo de Pura Pura	Natural Park	Municipal	1991	318
Carrasco	National Park	National	1991	686,426
Área de Protección del Pino del Cerro	Protection Area	Municipal	1991	4,709
Pedro Ignacio Muiba	Regional Park	State	1991	71,542
Cordillera de Sama	Biological Reserve	National	1991	106,823
Chapare	Immobilization Reserve	Municipal	1992	6,885
Pilón Lajas	Biosphere Reserve and Indigenous Territory	National	1992	403,044
Cotapata	Integrated Natural Management Area	National	1993	40,032
Cotapata	National Park	National	1993	22,398
Muela del Diablo y Cerro Pachajalla	Natural and Landscape Heritage	Municipal	1994	983
Cicatrices de Meandros Antíguos del Río Ichilo	Natural Reserve	State	1995	23,844
Kaa-iya del Gran Chaco	Integrated Natural Management Area	National	1995	1,484,280
Kaa-iya del Gran Chaco	National Park	National	1995	1,914,170
Madidi	Integrated Natural Management Area	National	1995	600,061
Madidi	National Park	National	1995	1,268,920
Curichi La Madre	Integrated Natural Management Area	Municipal	1995	50
Lago San José	Natural Reserve	Municipal	1995	16,471
Lago San José	Natural Reserve	Municipal	1995	1,491
Lago Tumichucua	Natural Park	Municipal	1995	2,856
Kenneth Lee	Scientific, Ecological, and Archaeological Reserve	State	1996	435,251
Otuquis	Integrated Natural Management Area	National	1997	161,700
Otuquis	National Park	National	1997	838,521
San Matías	Integrated Natural Management Area	National	1997	2,909,970
El Palmar	Integrated Natural Management Area	National	1997	59,895
Chuchini	Wildlife Sanctuary	State	1998	4,969
Valle de las Ánimas Putupampa	Natural and Landscape Heritage	Municipal	1998	2,826
Cañon de Chuwaqueri	Tourist Natural Monument	State	1999	296
Bosque de Bolognia	Natural and Landscape Heritage	Municipal	2000	280
Cerro Aruntaya (23 de marzo)	Municipal Environmental Protection Area	Municipal	2000	11
Cerro Ticani	Natural Reserve	Municipal	2000	49
Cerros Challaloma Cóndor Samaña	Natural Monument	Municipal	2000	848

Continued on next page

Table A5.1 (Continued)

Name	Category	Administrative Level	Year Established	Area (ha)
Cerro Llucancari y Taraqui	Natural and Landscape Heritage	Municipal	2000	101
Cóndores Lakota	Natural and Landscape Heritage	Municipal	2000	11
Huallatani Pampa	Natural and Landscape Heritage	Municipal	2000	1,483
Huayllani	Natural and Landscape Heritage	Municipal	2000	8
Jonkhomarca	Municipal Eco-Pedagogical Space	Municipal	2000	93
Keyllumani	Municipal Eco-Pedagogical Space	Municipal	2000	33
Laguna Cota Cota	Natural and Landscape Heritage	Municipal	2000	2
Parque de Aranjuez	Municipal Environmental Protection Area	Municipal	2000	25
Parque Urbano Central	Natural and Landscape Heritage	Municipal	2000	111
Serranía de Chicani	Natural and Landscape Heritage	Municipal	2000	1,322
Serranías de Aruntaya	Municipal Ecological Conservation Area	Municipal	2000	68
Siete Lagunas	Natural and Landscape Heritage	Municipal	2000	130
La Cumbre (apacheta)	Natural Reserve	Municipal	2000	63
Cuchilla de Chuquiaguillo y Quebradas del río Callapa	Natural and Landscape Heritage	Municipal	2000	1
Valle de Tucavaca	Natural Reserve	Municipal	2000	260,904
Poopó	National Heritage and Natural Reserve	State	2000	129,083
Aguarague	Integrated Natural Management Area	National	2000	48,037
Aguarague	National Park	National	2000	62,889
Espejillos	Natural Monument	State	2000	1,250
Apolobamba	Integrated Natural Management Area	National	2000	470,902
Cerro San Pedro	Protected Natural Area	Municipal	2000	216
Lagunas Santa Bárbara y Brava	Water Management Area	Municipal	2002	1,649
Laguna Concepción	RAMSAR Site	State	2002	129,054
Laguna Yaguaru	Natural Reserve	Municipal	2002	1,183
Incasani Altamachi	Andean Fauna Reserve	State	2002	345,013
Curichi El Cuajo	Natural Immobilization Reserve	Municipal	2002	378
Bosquecillo y Serranía de Auquisamaña	Municipal Environmental Protection Area	Municipal	2002	95
Cotapachi	Natural Archaeological Monument	Municipal	2003	2,120

Continued on next page

Table A5.1 (Continued)

Name	Category	Administrative Level	Year Established	Area (ha)
Parque Ecológico Incachaca	Archaeological Site	Municipal	2003	345
El Cardón	Natural Park and Integrated Natural Management Area	National	2003	36,031
Cuenca del Río Bañado	Integrated Natural Management Area	Municipal	2004	109,808
Parabanó	Natural Reserve	Municipal	2004	37,278
Motacusito	Protected Area with Managed Resources	Municipal	2004	877
Microcuenca El Chape	Water Management Area	Municipal	2004	2,972
Laguna Esmeralda de Quirusillas	Natural Reserve	Municipal	2004	6,098
Iñao	Integrated Natural Management Area	National	2004	171,193
Iñao	National Park	National	2004	90,904
San Nicolás	Ecological Reserve	Municipal	2004	16,058
Norte de Tiquipaya	Wildlife Reserve	Municipal	2005	118,507
Bruno Racua	Natural Reserve	State	2005	74,153
Orquídeas del Encanto	Natural Reserve	Municipal	2005	2,841
Serranía Sararenda	Natural Heritage Conservation Unit	State	2005	144,419
Jardín de Cactáceas de Bolivia	Natural Reserve	Municipal	2005	26,079
San Rafael	Natural Reserve	Municipal	2006	66,645
Palmera de Sao	Natural Reserve	Municipal	2006	753
Bosque Encantado	Integrated Natural Management Area	Municipal	2006	9
Ruinas de Aranjuez	Integrated Natural Management Area and Pre-Columbian Archaeological Heritage	Municipal	2006	95
Bosque de algarrobos de Tiataco	Municipal Protected Area	Municipal	2006	21
San Agustín	Ecological Reserve	Municipal	2006	34,794
Serranía de El Tigre - Alto Madidi	Municipal Protected Area	Municipal	2006	47,535
Serranía de El Tigre - Alto Madidi	Municipal Protected Area	Municipal	2006	474
Río Maniquí	Natural Reserve	Municipal	2007	115,348
Churo Negro	Water Management Area	Municipal	2007	1,275
Pampas del Río Yacuma	Integrated Natural Management Area	Municipal	2007	485,997
Laguna Represa Zapocó	Water Management Area	Municipal	2007	2,019
Río Grande y Valles Cruceños	Integrated Natural Management Area	State	2007	738,330

Continued on next page

Table A5.1 (Continued)

Name	**Category**	**Administrative Level**	**Year Established**	**Area (ha)**
Serranía de Paramarani	Natural Immobilization Reserve	Municipal	2007	5,588
Lagarpampa	Integrated Natural Management Area	Municipal	2009	29,969
Muela del Diablo	Natural Monument	Municipal	2009	5,088
San Juan del Corralito	Ecological Sanctuary	Municipal	2010	30
Laguna Marfil	Integrated Natural Management Area	Municipal	2010	70,320
Microcuenca Las Arenas El Escondido	Integrated Natural Management Area	Municipal	2010	665
Pasorapa	Integrated Natural Management Area	Municipal	2010	177,890
Copaibo	Cultural and Natural Heritage Reserve	Municipal	2011	331,801
Ibaré - Mamoré	Natural Reserve	Municipal	2011	26,573
Las SerranÍas de Pokotaika	Protected Area of Natural Heritage	Municipal	2012	142
Humedales del Norte	Integrated Natural Management Area	State	2012	512,316
Monte Willca	Integrated Natural Management Area	Municipal	2012	3,649
Arenales Cochiraya	Cultural and Landscape Heritage	Municipal	2013	88
Ríos Tahuamanu y Orthon	Natural Reserve	State	2013	53,655
Torrenteras del Río Cárcel Mayu	Protected Area and Natural Heritage	Municipal	2013	65
Bosques de Aranjuez	Natural Park	Municipal	2013	95
Arocagua	Metropolitan Park	Municipal	2014	60
Serranía los Milagros	Integrated Natural Management Area	Municipal	2014	103,049
Preservación de Caminos del Inca Tacuri	Municipal Forestry and Preservation Area	Municipal	2014	60
Laguna Esmeralda de Quirusillas	Wildlife Sanctuary and Integrated Natural Management Area	Municipal	2014	8,348
Ecoparque Encantado	Natural Monument	Municipal	2014	3,815
Thalackocha	Integrated Natural Management Area	Municipal	2014	11,021
La Cordillera Crucero La Tranca	Wildlife Sanctuary and ANMI	Municipal	2014	11,646
Grandes Lagos Tectónicos de Exaltación	Integrated Natural Management Area	Municipal	2015	477,066
Curichi Las Garzas	Wildlife Natural Reserve	Municipal	2015	1,238
Ivi Maraei	Integrated Natural Management Area	Municipal	2015	91,303
Acuático	Natural Park	Municipal	2015	78

Continued on next page

Table A5.1 (Continued)

Name	Category	Administrative Level	Year Established	Area (ha)
Arenales de Sora	Natural Reserve	Municipal	2015	351
Cabeza de la Víbora	Natural Park	Municipal	2015	< 1
Capachos	Natural Park	Municipal	2015	64
Cerro Cerrato	Natural Reserve	Municipal	2015	2
Cerro de San Pedro	Natural Reserve	Municipal	2015	96
Chusaqueri	Natural Reserve	Municipal	2015	41
Corazón de Jesús	Natural Reserve	Municipal	2015	< 1
El Cóndor	Natural Park	Municipal	2015	1
Tagarete	Natural Reserve	Municipal	2015	185
Rumy Campana I	Natural Reserve	Municipal	2015	19
Rumy Campana II	Natural Reserve	Municipal	2015	< 1
Sapo	Natural Park	Municipal	2015	< 1
Serranías de Oruro	Natural Reserve	Municipal	2015	108
Hampaturi	Natural Reserve	Municipal	2015	21,492
Héroes del Chaco	Historical and Wildlife Municipal Reserve	Municipal	2016	265,824
Paquió	Ecological Reserve	Municipal	2017	24,488
Laguna Sucuará	Wildlife Reserve	Municipal	2017	1,304
Bosque de Santa Rosa del Abuná	Integrated Natural Management Area	Municipal	2017	178,348
Santuario de Agua Chorrillos	Water Management Area	Municipal	2017	54
Gran Mojos	Natural Park and Integrated Natural Management Area	Municipal	2017	575,571
Cuenca Alta del Rio Parapeti Fernández - San Juan del Piray	Integrated Natural Management Area	Municipal	2017	117,600
Villa Abecia	Comprehensive Water Conservation Natural Management Area	Municipal	2018	34,668
Itachinini - Itiyuro	Community Water and Biodiversity Management Natural Area	Municipal	2018	97,449
Paisaje Turístico Biocultural del Lago Titicaca	Protected Landscape	Municipal	2018	1,991
Entre Ríos	Natural Reserve	Municipal	2018	144,707
Río Yaguarí	Natural Reserve	Municipal	2018	456
Pampa Tholar de las Vicuñas	Municipal Integrated Natural Management Area	Municipal	2018	58,513
Irenda	Water Management Area	Indigenous	2019	150,471
Tequeje-Tudaray	Natural Reserve	Municipal	2019	7,112
Serranía Santa Rosa	Comprehensive Water Management Natural Area	Municipal	2019	47,542
Las Lomas - El Recreo	Natural Heritage	Municipal	2019	95
Guajukaka	Life Area	Indigenous	2019	284,469

Continued on next page

Table A5.1 (Continued)

Name	Category	Administrative Level	Year Established	Area (ha)
Rhukanrhuka	Integrated Natural Management Area	Municipal	2019	452,158
Rhukanrhuka	Municipal Park	Municipal	2019	402,675
Bajo Madidi	Integrated Natural Management Area	Municipal	2019	1,618,060
Ñembi Guasu	Conservation and Ecological Importance Area	Indigenous	2019	1,203,330
Serranías del Mururata	Mountain Water and Forest Reserve	Municipal	2020	17,282
Bosque Amazónico de Manejo Integral Puerto Rico	Amazon Forest Integrated Management	Municipal	2020	204,091
Serranías de Igüembe	Integrated Natural Management Area	Municipal	2020	122,685
Bosque de Porvenir	Integrated Natural Management Area	Municipal	2020	30,645
Juan Chulo	Integrated Natural Management Area	Municipal	2021	1,605
Fuente de Vida	Integrated Natural Management Area	Municipal	2021	7,668
Cordillera de los Chichas - Mochara	Wildlife Sanctuary and Integrated Natural Management Area (ANMI)	Municipal	2021	36,304
Rincón del Tigre y Cajones	Integrated Natural Management Area	Municipal	2021	11,853
Río Piraí	Ecological Protection Park	Municipal	2021	1,575
Serranía San Lorenzo	Integrated Natural Management Area	Municipal	2021	55,270
Serranía de Incahuasi	Integrated Natural Management Area and Community Water and Biodiversity Management	Municipal	2021	28,632
Chuñuuma	Mountain Water and Forest Reserve	Municipal	2021	8,550
Río Negro	Water Reserve and Mountain Ecosystem Conservation	Municipal	2021	6,039
Bajo Paragua de Concepción	Natural Reserve	Municipal	2021	153,285
Guendá Urubó	Natural Heritage Conservation Unit	State	2021	44,428
Bajo Paragua de San Ignacio de Velasco	Natural Reserve	Municipal	2021	976,679
Guanay	Integrated Natural Management Area	Municipal	2021	112,532
Alto Beni	Integrated Natural Management Area	Municipal	2022	12,684
Alto Beni	Municipal Park	Municipal	2022	26,989

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Table A5.1 (Continued)

Name	Category	Administrative Level	Year Established	Area (ha)
Reserva de Vida Silvestre Laguna Concepción	Municipal Protected Area and Wildlife Reserve	Municipal	2022	818
Cuenca del Arroyo Bahía	Ecological Park	Municipal	2022	3,630
Quebracho Colorado	Integrated Natural Management Area	Municipal	2022	52,593
Gran Manupare	Integrated Natural Management Area	Municipal	2023	452,090
SCH1	Natural Immobilization Reserve	Municipal	2023	107
Mayaya	Municipal Park and Integrated Natural Management Area	Municipal	2023	43,496
Arroyo Guarichona	Integrated Natural Management Area	Municipal	2024	198,693
Puerta Amazónica Guanay	Conservation Area	Municipal	2024	23,120
Puerta Amazónica Guanay	Regeneration and Restoration Area	Municipal	2024	19,245
Dowara Kanda Tech Uyapi	Integrated Natural Management Area	Municipal	2024	24,018