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A Bioeconomic Analysis of Community Wildlife Conservation in Zimbabwe

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A Bioeconomic Analysis of Community Wildlife Conservation in Zimbabwe

Herbert Ntuli and Edwin Muchapondwa

Abstract

This paper uses a bioeconomic model to analyse wildlife conservation in two habitats adjacent to a national park by two types of communities in the context of Southern Africa. One community is made up of peasant farmers operating under a benefit-sharing scheme (CAMPFIRE) while the other is made up of commercial farmers practising game farming in a conservancy (the Save Valley Conservancy). Both communities exploit wildlife by selling hunting licenses to foreign hunters but with different levels of success. The park agency plays a central role by authorizing the harvest quota for each community. We formulate a bioeconomic model for the three agents, optimize the market problem for each agent and compare the outcomes with the social planner's solution. Our results show that the level of anti-poaching enforcement by the park agency is suboptimal, while anti-poaching effort exerted by the conservancy community achieves social optimality. CAMPFIRE communities exert more poaching effort than what the social planner would recommend. Our model shows that an improvement in community institutions might have a significant impact on growth of the wildlife stock through their role in constraining behaviour. Thus, institutional reforms in benefit-sharing schemes such as CAMPFIRE could result in the local community behaving like game farming communities such as the Save Valley Conservancy.

Key Words: bioeconomic, community wildlife conservation, CAMPFIRE, conservancy

JL Codes: Q20, Q57, Q28

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Herbert Ntuli and Edwin Muchapondwa*

1. Introduction

Integrated Conservation and Development Projects (ICDPs), commonly referred to as Community-Based Natural Resource Management (CBNRM), are central to future rural development in Southern Africa (Munthali 2007; and Thomson et al. 2013). Conceptually, CBNRM is a sound idea and seems likely to encourage conservation of wildlife resources and to improve the livelihoods of poor rural households if resources are exploited legally and commercially by local communities. Nevertheless, despite such arrangements, community wildlife conservation in the region still faces some serious challenges, one of them being illegal harvesting¹ of wildlife resources by local people living adjacent to protected areas (Murombedzi 1999; Fischer et al. 2011; and Gandiwa 2011).

This paper considers two communities that are involved in wildlife conservation under two different CBNRM arrangements in the same area in Zimbabwe, but are experiencing very different wildlife conservation outcomes. We use a bioeconomic model to evaluate the behaviour of various actors in order to propose institutional changes that might move individual decisions closer to the social optimum.

One example of CBNRM is the Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) in Zimbabwe, which was instituted by the government during the mid-1980s as a benefit-sharing scheme involving local communities. Previous studies have described the CAMPFIRE programme as a role model for CBNRM in Southern Africa (Murombedzi 1999; Logan and Moseley 2002; Muchapondwa 2003; and Balint and Mashinya

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¹ A distinction is made in this paper between commercial and subsistence poaching. Commercial poaching is presumed to be an open access business usually conducted by outsiders with the help of local communities, while subsistence poaching is mainly done for subsistence by the local communities themselves (Fischer et al. 2011). Local communities contribute to commercial poaching or illegal trophy hunting by supplying information to outsiders about the movements of wild animals in their wilderness area and sometimes provide escort services for a very small fee. The paper studies subsistence poaching by CAMPFIRE communities.

2006). The fundamental idea behind such initiatives is that benefits from wildlife conservation should strengthen the incentives of local people in such a way that they treat wildlife as a valuable asset (Songorwa 1999; Songorwa 2000; and Balint and Mashinya 2006). Viewed as an asset, wildlife has the potential to provide local communities with a hedge against agricultural risk associated with extreme weather conditions, by creating employment and generating revenues (Muchapondwa and Sterner 2012; and Poshiwa et al. 2013).

However, the CAMPFIRE programme has enjoyed very limited success over the entire course of its establishment. Poaching subsided only temporarily after its commencement, as neighbouring communities started to reap economic benefits from legal wildlife utilization, and then rebounded a few years later (Fischer et al. 2011). Both human-wildlife conflict (Gandiwa et al. 2013a) and poaching incidents (Gandiwa et al. 2013b) escalated during the fast-track land reform programme (FTLRP) in Zimbabwe, which spanned more than a decade starting in the year 2000. The FTLRP was also accompanied by severe economic hardships and human settlements encroaching on wildlife habitat. Thus, the CAMPFIRE programme experienced two major setbacks. The increase in poaching incidents seems to suggest that the CAMPFIRE programme failed to generate adequate incentives for local communities to conserve wildlife and that the FTLRP was disruptive, in the sense that it brought in settlers who were not interested in conservation. It is also hard to separate the economic incentives of CAMPFIRE from the general difficulties of the land reforms.

This phenomenon is not unique to Zimbabwe; it has occurred in many other countries in the Southern Africa region (Johannesen and Skonhoft 2005). To this end, scholars argue that the impact of benefit-sharing schemes such as CAMPFIRE is limited by possible dilemmas in the actual design of the scheme or trade-offs inherent in linking development and conservation objectives (Wells et al. 1999; Fischer et al. 2011; and Johannesen and Skonhoft 2014). These dilemmas are also closely intertwined with the nature of the community (i.e., the quality of local institutions that are in place) and the benefit-cost structure (incentives) associated with the property rights system.

A different CBNRM model takes the form of conservancies over privately-owned land (Kreuter et al. 2010). Conservancies have played a crucial role in protecting wildlife and biodiversity on private farmland outside of formal protected areas since their establishment in Southern Africa during the early 1970s. An example is found within the bounds of the Great Limpopo Trans-frontier Conservation Area, where private land is organized into private nature reserves or conservancies, e.g., the Save Valley Conservancy (SVC).

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It is the intention of most governments in the region to improve the living standards of poor rural households living adjacent to national protected areas through wildlife-based land reform. Given this, it is imperative to understand how different types of CBNRM regimes or conservation models work and to use this information not only to take appropriate action to enhance wildlife conservation in existing communal areas but also to undertake reforms to safeguard good stewardship practices in conservancies.²

This paper models two CBNRM communities in the vicinity of the Gonarezhou National Park (GNP) in Zimbabwe. We consider private game farms in the Save Valley Conservancy and the CAMPFIRE community. To a large extent, the conservancy performs much better than the CAMPFIRE communities with respect to biodiversity conservation and livelihoods because the CAMPFIRE communities lack incentives to conserve wildlife (Fischer et al. 2011; and Campbell and Shackleton 2001). This finding is supported by the increase in area under conservation and wildlife population on private land (Muir-Leresche and Nelson 2000). Moreover, the conservancy community exhibits characteristics that enhance CBNRM and coordinated decision-making for wildlife conservation (Krug 2001; and Kreuter et al. 2010).

Therefore, the main objectives of this paper are to develop a bioeconomic model of wildlife conservation; to apply the model to compare wildlife management and utilization in the CAMPFIRE and conservancy communities; and to suggest appropriate reforms that might encourage the CAMPFIRE community to move from a seemingly suboptimal regime to one that is optimal. Unlike previous studies, this paper seeks to establish the conditions under which a CAMPFIRE community can be incentivized to behave like the conservancy community, which is more successful in revenue generation and stewardship practice. Given the background above, three important questions arise: i) What are the significant differences between the two types of communities that interact with wildlife in Zimbabwe? ii) How and why do their differences affect revenue generation and stewardship practice? iii) Given the apparent superiority of conservancy outcomes in terms of livelihoods and conservation, how can we incentive CAMPFIRE communities to behave like the conservancy community, i.e., what reforms are necessary in CAMPFIRE for it to achieve equivalent outcomes?

² While there is no statutory definition of a conservancy in Zimbabwe, the working definition is: "Any number of properties, which are amalgamated into a single complex in order to enable more effective management, utilization and protection of the natural resources" (Fitzgerald 2012).

The rest of the paper is organised as follows. Section 2 analyses the similarities and differences between the CAMPFIRE and conservancy communities. Section 3 develops the bioeconomic model and computes estimates of some key parameters of the model, using data collected from communities around the Gonarezhou National Park (GNP) in Zimbabwe. Section 4 presents some comparative statics, including their policy implications, and discusses the results of the optimization problems and model simulation. Finally, Section 5 concludes.

2. CAMPFIRE versus the Conservancy Community

In Zimbabwe, community-based wildlife conservation takes place mainly under two different CBNRM arrangements: conservancies and the CAMPFIRE programme. According to Bell (1984), emphasis on formal protected areas shifted during the 1970s with the recognition that islands of protection were inadequate for maintaining spatially heterogeneous biodiversity. The Parks and Wildlife Act (1975) gave landowners property rights to wildlife on their land (Murombedzi 1999). In conservancies, private game farms have pulled down their fences and are managing wildlife as a common pool resource. Due to its fugitive character, wildlife is managed as a community, rather than on individual farms, in order to supply the required habitat size. Kreuter et al. (2010) identified groups of landowners within the bounds of the Great Limpopo Trans-frontier Conservation Area that have incorporated their properties into conservancies or private nature reserves, thereby expanding the management scale of common pool wildlife resources. Managing wildlife as a community allows the conservancy to enjoy economies of scale and individual farms to specialize in offering services and products that are in line with the resources found on their properties.

Upon independence, the government enacted a new law, the Parks and Wildlife Act of 1982, which gave birth to the CAMPFIRE programme. The law aimed to provide democratically elected rural district councils (RDCs) the appropriate authority for managing wildlife within their geographical boundaries. This new paradigm entails conferring on local communities, through their RDCs, (i) greater control over formerly public wildlife in communal areas in defined territories, (ii) enhanced capacities to add value to local wildlife, and (iii) specific financial rewards linked to the estimated conservation value of wildlife within their territories (Gadgil and Rao 1994; and Murombedzi 1999). Provided these commitments are forthcoming, the park agency steps back into the role of regulator and adviser, retaining the right to control wildlife harvesting quotas (Fischer et al. 2011).

Following the FTLRP, which resulted in some conservancies being invaded by peasant farmers, Zimbabwe has about eight conservancies (with over 100 registered private game farms)

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and 37 CAMPFIRE districts, managed by 37 RDCs that comprise 118 wards with over 121,500 households participating in wildlife conservation. The eight conservancies cover an area of 1,140,688 ha in total, while the CAMPFIRE wards cover approximately 2,478,000 ha in total. Comparing how communities under CAMPFIRE operate with the conservancy communities, we observe both similarities and striking differences. First, we characterize the CAMPFIRE community, followed by a characterization of the conservancy community in the SVC, and then summarize the major differences in a table. Although the paper utilizes the GNP area as a case study, the results would generally apply to other areas in Zimbabwe.

2.1 The CAMPFIRE Community

The CAMPFIRE projects are located on ancestral land that belongs to the whole community by traditional law. Part of the land is allocated to individual use rights for crop cultivation, while the remainder is allocated to communal use rights such as grazing and wildlife conservation. In addition to wildlife conservation, peasant farmers under CAMPFIRE grow crops and keep livestock as part of their livelihood activities. They also suffer losses from wildlife intrusion. The potential for crop cultivation is extremely low due to harsh climatic conditions, while the technology is predominantly subsistence in nature. This makes livestock rearing and wildlife conservation the most viable private investment options for CAMPFIRE communities living around the national park.

The CAMPFIRE programme aimed at giving local communities co-ownership of local natural resources so that they could generate income through leasing trophy hunting concessions, harvesting resources, game cropping and tourism activities (Fischer et al. 2011; and Balint and Mashinya 2006). However, this aim was not achieved, as the government has been reluctant to continue with the devolution of natural resource management (NRM) to the grassroots level (Murombedzi 1999). CAMPFIRE has only been able to devolve authority over natural resources from the central government to rural district councils. Murombedzi (1999) argues that, if the programme is to be effective, a further devolution of authority is required so that producer communities, those who live directly beside wildlife, are given full control of the natural resources on their land. This calls for policies that can result in greater devolution of managerial functions (e.g., quota setting, game cropping, patrols or monitoring and enforcement) and decision-making (e.g., harvesting, investment and how revenue is shared and utilized) into the hands of local communities, while the state maintains regulatory functions (Ntuli and Muchapondwa 2015).

Custody of wildlife falls in the hands of the Zimbabwe National Parks and Wildlife Authority (ZNPWA), which manages it on behalf of the state and allocates hunting quotas to other players in the industry, such as CAMPFIRE and the conservancy communities.³ The appropriation rights to wildlife under the CAMPFIRE programme fall into the hands of the Rural District Councils. This means that, to receive a harvesting quota, the CAMPFIRE communities need to apply for it through their respective RDCs. This puts the local communities at a disadvantage because the major decisions about how wildlife is managed and utilized, as well as how revenues from wildlife conservation are shared, rest in the hands of state apparatus. With the present arrangement, local communities are relegated to mere spectators or beneficiaries of wildlife conservation rather than important stakeholders. The current revenue sharing plan is such that the RDC gets 47% of wildlife income from each community, while 3% goes to the CAMPFIRE association, and the remainder (50%) goes to the producer community (Bond and Frost 2005).

Local communities operate under very close supervision from both the park agency and RDC. Because park authorities are unable to carry out anti-poaching enforcement either inside the national park or on communal land due to limited resources, local communities are now tasked to continue with the conservation work in their jurisdictions outside the formal protected areas. As a result, anti-poaching enforcement under most CAMPFIRE projects is very weak, because it is done by communities that lack incentives to conserve wildlife.⁴ The problem of information asymmetry is also rife between state authorities and CAMPFIRE communities, such that the park agency usually has less information about poaching activities in the area than does the community. Acquiring such information would involve costs for the agency. This puts the CAMPFIRE community in a better position to manage wildlife roaming outside the formal protected areas.

Local communities are supposed to satisfy a number of requirements in order to be recognized as conservation groups. For example, they are required to set aside land belonging to

³ In Zimbabwe, wildlife is the property of the state and no one community or individual owns it. This implies that the state has the authority to grant only appropriation rights (i.e., rights to use or rights to income) to certain individuals or communities, but not ownership rights (Murombedzi 1999).

⁴ Anti-poaching enforcement under the CAMPFIRE programme is not very effective because it is carried out on a part-time basis by either volunteers in the community (resource monitors) or the wildlife management committee, who usually face resource and time limitations, particularly during the agricultural season.

the community as a wildlife buffer zone or conservation land,⁵ to have a wildlife management committee (WMC) in place, to develop a constitution, to have a wildlife management plan (WMP) and to designate resource monitors, among other things. In a few areas, the RDC supplies game guards, but it is only in a very few cases that these guards are either armed or trained to execute such important assignments. For example, out of many CAMPFIRE communities around the GNP, the Mahenye CAMPFIRE community is the only one with trained and armed game guards (Ntuli and Muchapondwa 2015).

Due to the absence of an effective fence separating the national park from communal land, wildlife is free to traverse the community's conservation area. The community, however, does not carry out any meaningful investment that would encourage the wildlife stock to replenish, although there is some replenishment simply because wildlife can move freely between the communal land and the national park. Under CAMPFIRE, the link between returns to wildlife conservation and investment is not clear. For instance, the contribution by individual members of the community in terms of effort is uncertain. Hence, the idea of shares in the wildlife enterprise is not well defined. In reality, the CAMPFIRE community treats wildlife as a common pool resource and this automatically gives members of the community equal shares in the wildlife enterprise. As a result, this presents a situation which assumes that all members of the community contribute the same level in terms of their investments (e.g., labour inputs, conservation land and wild animals) so that even free-riders get equal shares on things such as labour inputs.

Wildlife harvesting under CAMPFIRE happens legally when the RDC engages the safari operator, who will in turn search for clients to utilize the quota on behalf of the RDC, and illegally by community members themselves to get rid of problem animals or for selfish reasons in order to maximize individual benefits. The safari operators link the RDC with the overseas market. The RDCs generate revenues by selling hunting licenses to safari operators in the area and share the proceeds with local communities. In this way, the safari operators act as a kind of middlemen, who then sell the licenses at a premium to the actual trophy hunters abroad at organized international events and also make the necessary arrangements for the clients to come.

⁵ It should be noted that the land allocated by local communities for conservation does not really expand the wildlife reserve because the land inside the reserve and the communal land are governed by different pieces of legislation.

Even though some clients may be professional hunters themselves, every kill must be made in the presence of a certified professional hunter who is registered according to the laws of Zimbabwe. If the animal being killed is on communal land, a representative from the RDC must be present. In cases where the safari operator lacks adequate knowledge about animal movements in the area, a community member is recruited to assist and to witness the kill. A registered professional hunter is there to make sure that the right kind of animal is killed (e.g., by law, female elephants must not be killed) and the animal is killed ethically.

2.2. The Conservancy Community

Some private game farms have pooled land (i.e., by dissolving their internal boundaries) and other resources and now manage wildlife as a common pool resource. This recognizes the fugitive character of wildlife and allows for economies of scale and specialization in activities that are most conducive to the type of resources present on individual farms. For example, some farmers might choose to specialize in wildlife conservation, while others combine conservation with agricultural activities, such as crop cultivation, cattle ranching and citrus, but on a limited scale. This paper considers the SVC due to its proximity to the GNP and the fact that the conservancy shares borders or interacts with neighbouring communities. Most importantly, the farmers in the SVC are operating as a community, just as in CAMPFIRE projects.

The establishment of the SVC was meant to rectify the ecological imbalances and environmental degradation caused by excessive cattle ranching during the 1920s, which subsequently forced wildlife to the outskirts of the valley. As a matter of policy, it was suggested that decreasing the number of cattle and introducing the original wildlife back to the area would help to restore the natural balance. Because of this intervention, the environment slowly recovered. Many of the indigenous plants and vegetation have been rehabilitated and the area has been successfully restocked with wildlife. The SVC was formed by combining 24 adjoining farms measuring about 3200 km². It is involved in intensive protection of rhinos, private game safaris, limited hunting concession and multi-species research. Farmers in the conservancy receive most of their income from high-quality and low-density tourism, including accommodation for travellers. It supports local communities by supplying jobs, allowing them to sell their arts and crafts, and improving and upgrading the Save Valley area. There is also a 330 km electric fence surrounding the conservancy to protect the wildlife and the environment.

The appropriation rights to wildlife fall in the hands of the conservancy. Unlike in the CAMPFIRE areas, labour inputs and capital contributions by individual private game farms, as well as provisioning rules, are well defined. With the removal of fences, each farm contributed to

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the common pool resources in terms of land and wild animals. The contributions of land were noted and converted into shares, which are in turn used to allocate the hunting quota given to the conservancy as a whole. The conservancy is charged with making sure that the wild animal population reaches a threshold needed for sustainable trophy hunting, which will in turn benefit the whole group. If the wild animal population is reduced significantly or falls below some agreed level, all members contribute to make sure that the animals reach the intended threshold. The group is also responsible for maintaining roads and other infrastructure, animal counting and anti-poaching enforcement. Anti-poaching enforcement under the conservancy is very effective because well-trained and armed game guards patrol the area at regular intervals. The SVC also generates revenue through tourism activities.

The conservancy community operates with minimal state interference because it is on private land. This gives the conservancy autonomy to make important decisions such as investments. The conservancy pays tax and levies to the government and to the RDC, and applies for a harvesting quota as a community directly from the ZNPWA every year. Just as in communal areas, wildlife is harvested both legally and illegally in the conservancy. The legal trophy hunting activities in both the SVC and CAMPFIRE communities are guided by quota allocations. Illegal harvesting in the conservancy is also carried out by the adjacent communities. Because local communities constantly suffer from wildlife intrusion and are marginalized by the law to the extent that the benefits from wildlife conservation are negligible, they have greater incentives to poach.

The conservancy community sells its products to overseas markets and sometimes engages safari operators because they are more specialized in this type of business. Representatives from the conservancy travel overseas to attend organized international events where they advertise their products to interested clients. To a large extent, the clients who eventually utilize the quota under CAMPFIRE and the private game farming community are the same. In addition to getting a small margin from selling hunting quotas, farmers in the SVC also generate substantial income through the provision of accommodations, specific guns requested by the trophy hunter and fees paid each day the farm owner is traveling with the client until a kill is made.

Table 1 below gives a summary of the key differences and similarities between the two communities.

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Communal farmers in CAMPFIRE projects	Private game farms in the conservancy
- Degree of state interference is high	- Minimum state interference
 Operating on communal land 	 Operating on private land
 Appropriation rights belongs to RDC 	 Appropriation rights fall in the hands of the conservancy
- Contributions/shares are not well defined	 Contributions and shares are well defined in terms of provision rules
 Anti-poaching enforcement is done by community/unpaid volunteers who lack incentives 	 Anti-poaching enforcement is done by trained and armed game guards
 Marketing is done by safari operators on behalf of local communities 	 Marketing activities are carried out at both individual farm level and as a group Income is generated from non-consumptive tourism

Table 1: Summary of Key Differences and Similarities Differences

Similarities

- Same geographical region and located adjacent to GNP
- Similar activities (i.e., agricultural production and wildlife conservation)
- Wildlife in Zimbabwe is property of the state and no one individual or group owns it
- Wildlife is managed as a Common Property Resource (CPR) due to the absence of internal boundaries
- Anti-poaching enforcement is done at group level
- The clients who eventually utilize the quota are the same
- Income from trophy hunting

Source: Survey data 2013

The differences in characteristics between the CAMPFIRE community and the conservancy could be responsible for driving the discrepancies in outcomes between the two communities. The next section will model only the key attributes that we think matter for conservation and welfare, and for the CAMPFIRE communities to catch up. This paper argues that, because both communities are involved in wildlife conservation, they should potentially be able to achieve good results. For instance, both communities should be able to register a positive growth in the stock of wildlife as poaching subsides over time.

3. The Bioeconomic Model

The analysis focuses on comparing conservation and welfare outcomes for two different communities involved in wildlife management adjacent a formal protected area: the CAMPFIRE community gets part of the proceeds from wildlife conservation which are distributed to them as

cash transfers, while the conservancy community manages wildlife and generates revenues directly through hunting and tourism activities. There are three agents: the park agency, the conservancy and the CAMPFIRE community. We formulate optimization problems for each agent representing the baseline scenarios in terms of wildlife management (stock size and antipoaching enforcement), and wildlife utilization (harvesting effort and subsistence poaching effort). We then compare the outcomes with those of the social planner and suggest reforms required to induce the CAMPFIRE community to behave like the conservancy community, which produces better conservation and welfare outcomes.

We adopt the standard assumption of a homogenous community where decisions are made at a group level, i.e., a community can choose to put effort into either poaching or antipoaching enforcement, depending on how it weighs the benefits and costs from wildlife conservation. This is a plausible assumption given the nature of decision-making we observe. Local communities use traditional institutions, which normally involve the chief or village headmen, where they meet under a tree and make decisions together as a group. Even though rebellion often occurs in the community, social norms help ensure the prevalence of a certain course of action by all members of the community. The conservancy community has committees and boards in place that make the crucial decisions on behalf of the group.

We assume that agents are managing a single wildlife species (e.g., African elephant) whose stock size is denoted by X_i , where the subscript $\{i = 0, 1\}$ denotes a patch of land. We agree that the issue of relative sizes of the park and various communities is an important consideration, but we do not think that our key results are dependent on relative size. Given the ineffectiveness of the fence between the park and communal lands, we assume that wildlife on that patch is managed as one stock. Intuitively, one could envisage the stock leaving the national park and roaming on communal land during the agricultural season (being attracted by crops) and returning to the protected areas after the season. Let X_0 denote the stock of wildlife shared by the park agency and CAMPFIRE communities and X_1 the stock managed by the conservancy. The following additional implicit assumptions apply: $X_i(t) \ge 0$, $X_i(0)$ at time t=0 is given and $X_i(\infty) < \infty$, i.e., the stock of wildlife will not explode or grow toward infinity as time tends toward infinity because of the carrying capacity of the habitat. Please refer to the appendix for a summary of definitions of symbols and the functional forms used in this paper.

No hunting takes place inside the national park, but it is allowed in areas outside the park. Therefore, in the absence of natural growth, X_0 potentially shrinks when the stock roams on communal land and is allowed to recover when it returns to the protected areas. Assuming a

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particular biomass at a specific point in time, $X_i(t)$, the stock grows according to natural growth $F(X_i, \cdot)$ and shrinks due to trophy hunting h_i and poaching $\psi_i(\cdot)$.

Stock dynamics of wildlife roaming on communal land

$$\dot{X}_0 = F(X_0, L) - h_0 - \psi_0(L, T_0^p)$$
.....(2)

Stock dynamics inside the conservancy

$$\dot{X}_1 = F(X_1, T_1^e) - h_1 - \psi_1(T_1^e, T_1^p)....(3)$$

where *L* is anti-poaching effort exerted by the park agency, T_1^e denotes anti-poaching effort exerted by the conservancy, T_0^p represents the poaching effort employed by the CAMPFIRE community and T_1^p represents the poaching effort of the local communities bordering the conservancy. We assume that the growth function depends not only on stock size, but also on anti-poaching effort, which facilitates growth of the wildlife stock. The natural growth function obeys the usual conditions:

$$\frac{\partial F(X_i, \cdot)}{\partial X_i} > 0, \frac{\partial^2 F(X_i, \cdot)}{\partial X_i^2} \le 0, \frac{\partial F(X_0, L)}{\partial L} > 0 \text{ and } \frac{\partial F(X_1, T_1^e)}{\partial T_1^e} > 0$$

In addition, we assume that $F(0, \cdot) = 0 = F(K, \cdot)$, so that there is no growth if the stock size either is zero or reaches the carrying capacity of the resources system (Fischer et al. 2011).

Unlike Fischer et al. (2011), who emphasized poaching by outsiders but with assistance from the local community and anti-poaching enforcement by a few successful CAMPFIRE communities, we emphasize subsistence poaching activities by the majority of CAMPFIRE communities living adjacent to protected areas. Our approach is in line with Johannesen and Skonhoft (2014). Accordingly, we assume that it is only the park agency that carries out anti-poaching enforcement both inside the park and in the communal areas adjacent to the protected area. The conservancy is responsible for anti-poaching effort in its area. The CAMPFIRE community perpetrates poaching on communal land, while poaching inside the conservancy is carried out by the non-CAMPFIRE communities living adjacent to the SVC – this is motivated by the need to defray costs from the nuisance effect of wildlife (Johannesen and Skohoft 2014), for selfish reasons, i.e., hunting for meat and trophies (Marks 1984; Barrett and Arcese 1998; and Fischer et al. 2011) and also to protest the establishment of conservancies in areas viewed as traditionally belonging to local communities (Wels 2000).

Poachers do not take into consideration the impact of their actions on the future stock of wildlife. It is natural to assume that the poaching function increases with poaching effort and decreases with anti-poaching enforcement by the park agency and conservancy community, i.e.,

$$\psi_0(L,0) = 0, \frac{\partial \psi_0(\cdot)}{\partial T_0^p} > 0 \text{ and } \frac{\partial \psi_0(\cdot)}{\partial L} < 0$$
$$\psi_1(T_1^e,0) = 0, \frac{\partial \psi_1(\cdot)}{\partial T_1^p} > 0 \text{ and } \frac{\partial \psi_1(\cdot)}{\partial T_1^e} < 0$$

The second-order derivatives are such that the poaching function is concave with respect to poaching effort and convex with respect to anti-poaching effort. The marginal productivity of poaching effort decreases with anti-poaching enforcement.

$$\frac{\partial^2 \psi_i(\cdot)}{(\partial T_i^p)^2} \le 0, \frac{\partial^2 \psi_0(\cdot)}{\partial L^2} \ge 0, \frac{\partial^2 \psi_1(\cdot)}{\partial (T_1^e)^2} \ge 0, \frac{\partial^2 \psi_0(\cdot)}{\partial T_0^p \partial L} = \frac{\partial^2 \psi_0(\cdot)}{\partial L \partial T_0^p} < 0 \text{ and } \frac{\partial^2 \psi_1(\cdot)}{\partial T_1^e \partial T_1^p} = \frac{\partial^2 \psi_1(\cdot)}{\partial T_1^p \partial T_1^e} < 0$$

It is assumed that there is no relationship between the stock of wildlife in the conservancy and in the national park because the conservancy is enclosed such that wildlife cannot move across borders.⁶ The conservancy purchased live animals only once, when it was established, in order to boost its wildlife stock, and thereafter restocking ceased. By contrast, the stock of wildlife on communal land is linked to the population of wild animals in the national park due to the absence of an effective fence. Thus, the wildlife stock on communal land replenishes itself because of its relationship with the park (i.e., wildlife is ordinarily harvested when roaming on communal land and recovers when it returns to the national park).

Currently, property rights in wildlife belong to the state, both inside and outside the national park (Child 1996; and Murombedzi 1999). Therefore, both the CAMPFIRE communities and the conservancy landowners have only use rights to wildlife. From this perspective, land tenure ceases to be an important variable in this analysis. For purposes of this model, we can assume that the property rights in wildlife "belong" to the park manager.

The park agency is responsible for allocating hunting quota h_i to other players in the wildlife sector. Let h_1 and h_0 be the quota allocated to the conservancy and CAMPFIRE

⁶ Of course, in exceptional cases, the conservancy can purchase live animals from the national park when restocking is required due to exogenous forces like severe drought or floods.

communities respectively. In practice, this could be implemented as $h_i = \overline{h_i} + \varepsilon_i$, where average quota is adjusted on the basis of overall impressions about the community's conservation effort, rather than the actual stock size, because the park agency usually lacks vital information such as animal counts and trophy quality in the study area.⁷

The state has the right to grant appropriation authority (this includes both the right to use and right to income) to any individual or community (Murombedzi 2003). In the case of the CAMPFIRE programme, the state gave the appropriation rights to the RDC instead of the local communities directly. Therefore, the RDC collects the revenues and makes the decisions about how the proceeds from wildlife conservation are allocated. The RDC generates wildlife income by selling hunting licenses to safari operators who, in turn, sell the licenses at a premium (*s*) to clients from overseas. The RDC's gross wildlife income is given by the following expression:

$$W = W(h_0) = (P^* - s)h_0 \dots (4)$$

The parameter (*s*) can be interpreted as a premium charged by the safari operator above the fee paid to the RDC and includes his time spent looking for clients, time spent with clients during the actual hunting sessions, his skills, guns, etc. P^* is the fixed price per unit of harvest paid by the trophy hunters, and is exogenous to the communities because there is a competitive environment in the wildlife sector, such that no single community can influence the trophy price. Moreover, the fact that Zimbabwe is only one of the many countries offering sport-hunting opportunities motivates the price-taking assumption (Fischer et al. 2011). A fraction of the income ($0 < \tau < 1$) goes into the hands of local communities, while the remainder $(1-\tau)$ is retained by the RDC. Hence, the community receives

The CAMPFIRE community is involved in different production activities, for example, agricultural production, poaching, anti-poaching enforcement and selling hunting licenses.

⁷ In practice, CAMPFIRE communities have generally complained that the quota does not change much and seems irresponsive to stock dynamics. This perception could be true, as quotas for selective or trophy hunting do not change much (Muchapondwa 2003). For simplicity, we assume the fixed quotas rule $h_i = h_i$, which reflects the behaviour of an agency that is understaffed and does not dare take new initiatives (Fischer et al. 2011).

Because the property rights of the park manager are not effectively enforced on communal land, the local people are not effectively prevented from illegally harvesting wildlife.

Both communities allocate a fixed amount of effort $(\overline{T_i})$ between the two activities, namely agricultural production (T_i^a) and wildlife activities (i.e., either anti-poaching enforcement or illegal harvesting). Assuming a binding time constraint, we have:

where the superscripts $\{j = p, e\}$ represent poaching effort T_0^p by the CAMPFIRE communities and anti-poaching enforcement T_1^e exerted by the conservancy.

For a fixed size of agricultural land and hence neglecting the possible loss of wildlife habitat through agricultural expansion (Johannesen and Skonhoft 2014), the agricultural yield function in the absence of wildlife damage depends on effort when all other variable inputs are assumed to be fixed. The agricultural technology is given by:

$$A_i = A_i(T_i^a) = A_i(\overline{T_i} - T_i^j) \dots (7)$$

The agricultural production function satisfies the usual concavity assumptions, i.e., A(0) = 0, A'(.) > 0 and $A''(.) \le 0$.

More wildlife means more nuisances, so that damages are proportional to the amount of wildlife (Carlson and Wetzstein 1994; and Hueth et al. 1998), i.e.,

 $D_i \propto X_i \Longrightarrow D_i = \beta X_i \dots \dots \dots \dots \dots (8)$

where $\beta \ge 0$ is a fixed constant and $D \in [0,1]$. Ideally, β captures the nuisance effect of the wildlife stock (see also Zivin et al. 2000). If the quantity of crops not damaged is $1 - D_i = 1 - \beta X_i$, then the net crop benefits are given by

$$Q_{i} = A_{i}(T_{i}^{a}) - A_{i}(T_{i}^{a})\beta X_{i} = A_{i}(\overline{T_{i}} - T_{i}^{j})[1 - \beta X_{i}]....(9)$$

3.1 The Park Agency's Problem

We assume that the park agency gets most of its income from non-consumptive tourism and budget allocation from the state, but not from selling hunting licenses, because trophy hunting is not permitted inside the national park. The park agency employs a small fraction of its anti-poaching effort *L* outside the national park so that there is a small probability of being caught, $\theta_0(\cdot)$, if the community decides to harvest wildlife illegally. We assume further that the probability of detection is a function of poaching effort and anti-poaching effort of the park agency. The probability of being detected when hunting illegally is assumed to be an increasing function of the time spent hunting illegally, as well as the level of law enforcement exerted by the park agency, i.e., $\partial \theta_0(\cdot)/\partial T_0^P > 0$ and $\partial \theta_0(\cdot)/\partial L > 0$. In addition, we have $\theta_0(L,0) = \theta_0(0,T_0^P) = 0$. The marginal probability of detection increases with the level of antipoaching effort $\partial \theta_0(\cdot)/\partial L T_0^P > 0$.

The park agency receives four types of benefits: i) budget from the state, \overline{M} ; ii) revenue from benign tourism $R(X_0)$; iii) the public goods value of wildlife $G(\cdot)$; and iv) proceeds from poaching fines $\theta_0(\cdot)c_0$ imposed on detected perpetrators. It is assumed that G(0) = 0, $G'(\cdot) > 0$, and $G''(\cdot) \le 0$. The total cost of managing the park is given by v_0L , where v_0 is the fixed cost per unit of anti-poaching effort. The park agency chooses hunting quotas to allocate to different communities and the level of anti-poaching effort to employ, which is split according to the land sizes inside and outside the park. The agency maximizes net benefits subject to stock dynamics of wild animals shared by the park agency and CAMPFIRE community, the stock of wildlife roaming the conservancy, the budget constraints and the participation constraints of the two communities, where the discount rate is given by $\delta > 0$.

$$\begin{aligned} &\underset{\{L,h_0,h_1\}}{\operatorname{Max}} \pi_0(L,h_0,h_1) = \int_{t=0}^{\infty} [G(X_0,X_1) + R(X_0) + \overline{M} + \theta_0(L,T_2^{\ p})c_0 - v_0L]e^{\delta t} dt.....(10) \\ &St: \quad \dot{X}_0 = F(X_0,L) - h_0 - \psi_0(L,T_0^{\ p}) \\ &\dot{X}_1 = F(X_1,T_1^{\ e}) - h_1 - \psi_1(T_1^{\ e},T_1^{\ p}) \\ &v_0L \leq \overline{M} \text{ [Budget constraint - assumed to hold with equality]} \\ &(P^* - s)h_0 \geq \overline{U}_0 \text{ [Participation constraint for local community - assumed to hold with equality]} \\ &P^*h_1 \geq \overline{U}_1 \text{ [Participation constraint for private game farms - assumed to hold with equality]} \end{aligned}$$

As in Mukanjari et al. (2013) and Johannesen and Skonhoft (2014), the park agency bases its decision on inter-temporal considerations because it has the property rights to wildlife on both

public and private land, and chooses both an optimal amount of effort toward anti-poaching activities and optimal quotas to give to CAMPFIRE communities and the conservancy. However, before park managers can calculate the quota, they need to know the wildlife stock in each community. The current value Hamiltonian is given by:

$$H(.) = G^{PA}(X_0, X_1) + R(X_0) + \overline{M} + \theta_0(L, T_0^P)c_0 - v_0L + \lambda[F(X_0, L) - h_0 - \psi_0(L, T_0^P)] + \mu[F(X_1, T_1^P) - h_1 - \psi_1(T_1^P, T_1^P)] + \Lambda_0[\overline{M} - v_0L] + \Lambda_1[\overline{U_1} - P^*h_1] + \Lambda_2[\overline{U_0} - (P^* - s)h_0].....10(a)$$

with h_1 , h_0 and L as the control variables; X_i as state variables; $\lambda > 0$ and $\mu > 0$ as shadow prices⁸ for the shared stock X_0 and the stock inside the conservancy X_1 respectively; and Λ_i as Lagrange multipliers. The following expressions can be obtained from the first-order condition:

$$\frac{\partial \theta_0(L, T_0^p)}{\partial L} c_0 + \lambda \frac{\partial F(X_0, L)}{\partial L} = v_o(1 + \Lambda_0) + \lambda \frac{\partial \psi_0(\cdot)}{\partial L} \dots 10(b)$$

According to Equation 10(b) above, the park agency employs anti-poaching effort until the benefits of stopping crime and growing the shared stock X_0 equals the value of reduced poaching plus the marginal cost of employing anti-poaching enforcement. Equations 10(c) and 10(d) tell us that the park agency allocates hunting quotas until the shadow price of the stock equals the market value.

$$\mu = -\Lambda_1 P^* \dots 10(c)$$

 $\lambda = -\Lambda_2 (P^* - s) \dots 10(d)$

The portfolio conditions (Equations 10(e) and 10(f) below) indicate that the sum of the wildlife gain and the net stock effect resulting from maintaining one unit of wildlife must be equal to the marginal benefit of harvesting and putting the proceeds into the bank.

$$\dot{\lambda} + \frac{\partial G(\cdot)}{\partial X_0} + \frac{\partial R(X_0)}{\partial X_0} + \lambda \frac{\partial F(\cdot)}{\partial X_0} = \delta \lambda.....10(e)$$
$$\dot{\mu} + \frac{\partial G(\cdot)}{\partial X_1} + \mu \frac{\partial F(\cdot)}{\partial X_1} = \delta \mu......10(f)$$

⁸ The shadow price measures the approximate decrease in the present value of net benefits resulting from a unit decrease in the wildlife stock.

On the assumption of the functional forms reported in the appendix, the market equilibrium levels of anti-poaching effort by the park agency and the respective stocks of wildlife roaming inside the national park and on communal land and in the conservancy can be computed from the first-order conditions given above. The steady-state off-take of wildlife can be solved for by substituting the optimal wildlife stock and anti-poaching effort into the harvesting function. For comparison purposes, all solutions to the maximization problems presented in this analysis are shown at the end of this section.

3.2 The Conservancy Community

The private game farms employ T_1^a in agricultural production and anti-poaching effort T_1^e in order to grow the wildlife stock. Benefits enjoyed by the private game farms come from agricultural production $A_1(\cdot)$, selling hunting licenses h_1 , revenues from tourism activities $R(\cdot)$ and proceeds from poaching fines $\theta_1(\cdot)c_1$ imposed on detected perpetrators on their land. Anti-poaching enforcement is costly, with v_1 as the fixed cost per unit of anti-poaching effort. It is assumed that revenue from non-consumptive tourism $R(X_1)$ increases with the stock of wildlife; that is, R(0) = 0, $\partial R(\cdot) / \partial X_1 > 0$ and $\partial^2 R(\cdot) / \partial X_1^2 < 0$.

The decision to be made by the conservancy community is how much anti-poaching effort T_1^e to invest in, while taking the off-take as given, because this is determined by the park agency through quota allocation h_1 . Because the conservancy community has appropriation rights (legal rights to exploit wildlife), they have a long-term view and therefore take the stock dynamics into consideration. For simplicity, we assume that the discount rate used by the park agency is the same as the discount rate used by the conservancy community and the social planner. Thus, the conservancy community's net benefits from agriculture and wildlife conservation are given by:

$$\begin{aligned} &\underset{\{T_{1}^{e}\}}{\text{Max}} \pi_{1}(T_{1}^{e}) = \int_{t=0}^{\infty} [P_{a}A_{1}(\overline{T_{1}} - T_{1}^{e}) + P^{*}h_{1} + R(X_{1}) + \theta_{1}(T_{1}^{e})c_{1} - v_{1}T_{1}^{e}]e^{\hat{\alpha}}dt.....11\\ &St: \quad \dot{X}_{1} = F(X_{1}, T_{1}^{e}) - h_{1} - \psi_{1}(T_{1}^{e}, T_{1}^{P})\\ &h_{1} \leq \overline{h_{1}} \text{ [Harvesting cannot exceed quota]}\\ &\overline{T_{1}} = T_{1}^{a} + T_{1}^{e}\end{aligned}$$

The production activities inside the conservancy are constrained by stock dynamics, the hunting quota and labour effort. The current value Hamiltonian is given by:

$$H(.) = P_a A_1(\overline{T_1} - T_1^e) + P^* h_1 + R(X_1) + \theta_1(T_1^e)c_1 - v_1T_1^e + \mu[F(X_1, T_1^e) - h_1 - \psi_1(T_1^e, T_1^P)] + \Omega_1[\overline{h_1} - h_1].....11(a)$$

The first-order condition with respect to anti-poaching effort is therefore given by:

Equation 11(b) tells us that the conservancy community will employ T_1^e until the benefit of catching a poacher and the value of growing the stock of wildlife as a result of a marginal increase in effort equals the value of losing agricultural harvest as a result of employing antipoaching enforcement, the marginal cost of anti-poaching enforcement and the value of reduced poaching. In other words, the conservancy community allocates time toward anti-poaching activities until the loss from agriculture and anti-poaching equals the value of the growth in stock plus marginal benefits from collecting fines. According to 11(c), the conservancy community will maintain the stock of wildlife at a level that equates the return from trophy hunting and tourism activities with the return from alternative investments.

$$\dot{\mu} + \frac{\partial R_1(\cdot)}{\partial X_1} + \mu \frac{\partial F(X_1, T_1^e)}{\partial X_1} = \delta \mu.....11(c)$$

On the assumption of the functional forms shown in the appendix, the market equilibrium levels of anti-poaching effort by the conservancy community can be computed from the first-order conditions. The optimal wildlife stock is the same whether computed by the park agency or conservancy.

3.3 The CAMPFIRE Community

We assume that the CAMPFIRE community takes both stock size and legal off-take h_0 as given. This is consistent with the behaviour we discovered in the survey, which suggests that community institutions are not strong enough to be proactive in conservation. The local community allocates its fixed endowment of labour effort \overline{T}_0 between two production activities, namely agriculture T_0^a and poaching T_0^p , with η_0 as the fixed per unit cost of poaching effort. As a result, there is a probability of being caught, denoted by $\theta_0(\cdot)$, if community members engage in illegal harvesting of wildlife resources. If caught, the community is levied a fixed fine $\theta_0(\cdot)c_0$, paid to the park agency.

As usual, the unit price of agricultural output P_a and illegal wildlife off-take ω are assumed to be fixed, where $\omega = P^* - \varepsilon$ and ε is the discount associated with illegal sales. It is reasonable to assume that the price of the illegal off-take could be far less that the market price

(*i.e.* $\omega \ll P^*$) because of institutional constraints associated with selling on the black market. Poachers sell their trophies at a lower price because they want to attract buyers and dispose of the trophies as quickly as possible to reduce the risk of being caught. The legal benefits from wildlife conservation $\tau(P^* - s)h_0$ are exogenous to the local community. We assume that τ is fixed over time and is decided on by the RDC at the beginning of the CAMPFIRE programme. In a way, this also removes the decision power of the RDC in deciding how much revenue to allocate to CAMPFIRE communities, where all elements are given and not at its discretion. The CAMPFIRE community is taxed twice, first by the safari operator, who charges a total commission of τsh_0 for the specialised services offered, and then a second tax amount of $(1-\tau)P^*h_0$ by the RDC for general programme administration.

We assume that local people maximise short-run gains. Johannesen and Skonhoft (2014) argue that this myopic behaviour is reasonable because, in most cases, the legal benefits from conservation going into the hands of CAMPFIRE communities are too small relative to the cost of living with wildlife. Therefore, it is rational for the CAMPFIRE community to harvest as much as possible today, because of perceived risk and uncertainty in the future; for example, they may be effectively prevented from harvesting tomorrow due to improved law enforcement. Thus, the CAMPFIRE community maximizes current net benefits, shown in equation (12), subject to the labour constraint.

$$\begin{aligned} &\underset{\{T_0^p\}}{\text{Max}} \pi_2(T_0^p) = P_a A_0(\overline{T_0} - T_0^p) + \tau(P^* - s)h_0 + \omega \psi_0(L, T_0^p) - \eta_0 T_0^p - \theta_0(L, T_0^p)c_0.....(12) \\ &\overline{T_0} = T_0^a + T_0^p......(12) \end{aligned}$$

The first-order conditions are given by

The local communities employ T_0^P until the benefits from employing an additional unit of poaching effort equates to the loss in agriculture, the cost of poaching effort and marginal loss due to paying fines. On the assumption of the functional forms indicated in the appendix, the market equilibrium level of poaching effort by the local communities can be computed from the first-order conditions.

If benefits from wildlife conservation increase, then the welfare of the local community as a whole also increases. This could be achieved when the poaching effort exerted by the CAMPFIRE community is reduced and the population of wildlife on communal land increases, such that the quota allocation given to the local community also increases. Using proceeds from wildlife conservation, local communities around the GNP invest in public goods that benefit the society as whole, such as schools, clinics, electricity and grinding mills, rather than distributing the income to households. Investing in public goods could have a significant impact on community welfare.

3.4 The Social Planner's Problem

The social planner chooses anti-poaching enforcement, poaching effort and hunting quotas in order to maximise the present value of net benefits from the activities of all the agents (e.g., agricultural production, trophy hunting, tourism activities, state budget, the public good value of the wildlife stock and proceeds from poaching fines) subject to stock dynamics, budget, participation and harvesting constraints. The existence value or cultural value of the public goods might be different from what the park agency assumes. The social planner knows about the existence value φ that the local community places on the wildlife stock in their area and, hence, incorporates it in his valuation. The social planner is confronted with the following maximization problem:

$$\begin{aligned} &\underset{\{L,T_1^e,T_0^p,h_1,h_0\}}{\text{Max}} \pi_3(.) = \int_{t=0}^{\infty} [G^{SP}(X_0,X_1) + \varphi X_0 + R(X_0) + \overline{M} + P_a A_1(\overline{T_1} - T_1^e) + P^* h_1 + R(X_1).....(13) \\ &\quad + \theta_1(T_1^e,T_1^p)c_1 + P_a A_0(\overline{T_0} - T_0^p) + \tau(P^* - s)h_0 + \omega \psi_0(L,T_0^p) - \eta_0 T_0^p - v_0 L - v_1 T_1^e] e^{\hat{\alpha}} dt \\ &\dot{X}_0 = F(X_0,L) - h_0 - \psi_0(L,T_0^p) \\ &\dot{X}_1 = F(X_1) - h_1 - \psi_1(T_1^e,T_1^p) \\ &v_0 L \leq \overline{M} \text{ [Budget constraint - assumed to hold with equality]} \\ &P^* h_1 \geq \overline{U_1} \text{ [Participation constraint for private game farms - assumed to hold with equality]} \\ &(P^* - s)h_0 \geq \overline{U_0} \text{ [Participation constraint for local community - assumed to hold with equality]} \\ &h_1 \leq \overline{h_1} \text{ [Harvesting cannot exceed quota]} \\ &h_0 \leq \overline{h_0} \text{ [Harvesting cannot exceed quota]} \end{aligned}$$

The current value Hamiltonian is, therefore, given by Equation 13(a), where λ and μ are the shadow values (co-state variables) for the wildlife stock in the park, outside the park and in the conservancy.

$$\begin{split} H(.) &= G^{SP}(X_0, X_1) + R(X_0) + \overline{M} + P_a A_1(\overline{T_1} - T_1^e) + P^* h_1 + R(X_1) + \theta_1(T_1^e, T_1^P) c_1 + P_a A_0(\overline{T_0} - T_0^P) + \tau(P^* - s) h_0 \\ &+ \omega \psi_0(L, T_0^P) - \eta_0 T_0^P - v_0 L - v_1 T_1^e + \lambda [F(X_0, L) - h_0 - \psi_0(L, T_0^P)] + \mu [F(X_1, T_1^e) - h_1 - \psi_1(T_1^e, T_1^P)] \\ &+ \varphi X_0 + \Lambda_0[\overline{M} - v_0 L] + \Lambda_1[\overline{U_1} - P^* h_1] + \Lambda_2[\overline{U_0} - (P^* - s) h_0] + \Omega_1[\overline{h_1} - h_1] + \Omega_2[\overline{h_0} - h_0]. \end{split}$$

The first-order conditions with respect to anti-poaching effort are given by:

$$\lambda \frac{\partial F(X_0, L)}{\partial L} = (\lambda - \omega) \frac{\partial \psi_0(\cdot)}{\partial L} + v_o(1 + \Lambda_0).....13(b)$$
$$\frac{\partial \theta_1(\cdot)}{\partial T_1^e} c_1 + \mu \frac{\partial F(\cdot)}{\partial T_1^e} = P_a \frac{\partial A_1(\cdot)}{\partial T_1^e} + v_1 + \mu \frac{\partial \psi_1(\cdot)}{\partial T_1^e}.....13(c)$$

According to Equation 13(b), the social planner employs anti-poaching effort until the benefit of growing the stock in and outside the park equals the value of reduced poaching, plus the cost of employing the anti-poaching effort. Equation 13(c) says that the social planner will allocate labour between agriculture and anti-poaching enforcement in the conservancy until the benefit of catching a poacher and the value of growing the wildlife stock as a result of a marginal increase in anti-poaching effort equate to the value of losing agricultural harvest as a result of employing anti-poaching enforcement, the marginal cost of anti-poaching enforcement and the value of forgone poaching.

The first-order condition with respect to poaching effort is given by:

The social planner would allocate labour between agriculture and poaching until the benefits of reduced poaching due to an additional unit of poaching effort (corrected for market distortions) equates to the loss in agriculture and the cost of poaching effort. Equation 13(e) and 13(f) state that the social planner will allocate hunting licenses until the shadow price and market price are equated, again correcting for market distortions.

 $\mu = P^* (1 - \Lambda_1) - \Omega_1 \dots 13(e)$ $\lambda = (P^* - s)(\tau - \Lambda_2) - \Omega_2 \dots 13(f)$

Equations 13(g) and 13(h) show the evolution of the co-state variables over time. The social planner would, therefore, maintain the wildlife stock at a level that equates the return from wildlife conservation with the return from alternative investments. The return from the stock of wildlife is in terms of the change in the marginal valuation of the stock and stock effects on revenue from wildlife tourism (in the case of wildlife stock in the conservancy) and natural growth of the wildlife stock.

The social planner's explicit solution can be computed from the first-order conditions using the functional forms assumed and presented in the appendix. From the maximization problems discussed above, one can solve for the optimal anti-poaching effort by the park agency and conservancy community, i.e. L^* and $T_1^{e^*}$, respectively; poaching effort exerted by the CAMPFIRE communities, i.e. $T_0^{p^*}$; the steady state wildlife stock, i.e. X_0^* and X_1^* ; and the optimal quota allocation, i.e. h_1^* and h_0^* , from all the equations presented in Sections 3.1 through 3.4. Table 2 shows the comparison between the market equilibrium and the social planner's solution.

Market Solution	Sign	Social Planner
$L^* = \left[\frac{\lambda\gamma b_0}{v_o(1+\Lambda_0)+\lambda b_0 - g_0 c_0}\right]^{\frac{1}{1-\gamma}}$	< >	$L^* = \left[\frac{\gamma \lambda b_0}{v_o(1 + \Lambda_0) + \lambda b_0 - \omega b_0}\right]^{\frac{1}{1 - \gamma}}$
$X_0^* = K_0 \frac{\lambda(r-\delta) + 2q}{2r\lambda}$	<	$\Rightarrow X_0^* = K_0 \frac{\lambda(r-\delta) + 2q + \varphi}{2r\lambda}$
$X_1^* = K_1 \frac{\mu(r-\delta) + q}{2r\mu}$	<	$\Rightarrow X_1^* = K_1 \frac{\mu(r-\delta) + 2q}{2r\mu}$
$h_1^* = F[X_1^*] - \psi_1(T_1^{e^*}, T_1^{P^*})$	<	$h_1^* = F[X_1^*] - \psi_1(T_1^{e^*}, T_1^{P^*})$
$h_0^* = F[X_0^*] - \psi_0(L^*, T_0^{P^*})$	<	$h_0^* = F[X_0^*] - \psi_0(L^*, T_0^{P^*})$
$T_1^{e^*} = \left[\frac{\alpha\mu b_1}{P_a A_1 + v_1 + \mu b_1 - g_1 c_1}\right]^{\frac{1}{1-\alpha}}$	=	$T_1^{e^*} = \left[\frac{\alpha\mu b_1}{P_a A_1 + v_1 + \mu b_1 - g_1 c_1}\right]^{\frac{1}{1-\alpha}}$
$T_0^{p^*} = \left[\frac{\phi a\omega}{P_a A_0 + \eta_0 + g_0 c_0}\right]^{\frac{1}{1-\phi}}$	>	$T_0^{p^*} = \left[\frac{\phi a(\omega-\lambda)}{P_a A_0 + \eta_0}\right]^{\frac{1}{1-\phi}}$

 Table 2: Comparison of the Market Solution and the Social Planner's Solution

Source: own calculations 2015

4. Results and Discussion

In this section, we start by commenting on the differences in Table 2 and then narrow them down to the key roles of poaching and institutions in influencing biodiversity outcomes. We also consider some comparative statics, including the related policy implications, and numerical illustrations of the theoretical model.

4.1 Comparative Statics

Our results are consistent with theoretical expectations. The results above show that the stock of wildlife roaming in and outside the protected area, i.e., the shared stock X_0^* and the stock managed by the conservancy X_1^* , could be less than what the social planner would prescribe. This also implies that the optimal harvest on communal land and in the conservancy is less than that of the social planner; see Table 2 above. The solution of anti-poaching enforcement by the park agency L^* is ambiguous. The market solution is greater than the social planner's prescription if $g_0c_0 > \omega b_0$ and vice versa. The fact that the market solution differs from the social

planner's outcome suggests that anti-poaching effort exerted by the park agency is suboptimal. Duffy (1999) reported some inefficiency associated with anti-poaching enforcement in Zimbabwe. Anti-poaching effort exerted by the park agency decreases with the cost of employing that effort, i.e., $\partial L^* / \partial v_o < 0$, while increasing anti-poaching enforcement increases the probability of being caught, i.e., $\partial L^* / \partial g_o > 0$. Given the latter result, it might be beneficial for the park agency to increase *L* in order to grow the shared wildlife stock X_0^* .

If the conservancy community values wildlife as much as the social planner does, then the level of anti-poaching enforcement $T_1^{e^*}$ exerted by the conservancy achieves social optimality, i.e., both the market and the social planner's solution are the same. This is the case when a market efficient outcome is equal to a socially optimal level. With this level of antipoaching enforcement, poaching activities are kept at their lowest level and, hence, the stock inside the conservancy will grow. We argue that the off-take inside the conservancy is efficient because harvesting is determined by the quota set by the park agency, and poaching is contained through the employment of an efficient level of effort, which increases the probability of being caught, i.e., $\partial T_1^{e^*} / \partial g_1 > 0$. Therefore, starting from a lower level of stock, if the anti-poaching effort exerted by the conservancy toward optimality, provided that harvesting does not exceed the maximum sustainable yield.

The CAMPFIRE communities exert more poaching effort than the level the social planner would recommend. The role of poaching is to reduce the stock of wildlife when it is roaming on communal land. The off-take on communal lands is suboptimal, since harvesting is not only determined by the quota set by the park agency, but also by communities through poaching. Again, starting from a lower level, the wildlife stock in the community could diverge from the social planner's recommendation due to resource overexploitation. The differences between the market and the social planner's solutions are driven by externalities. Given the fact that we are considering non-marketed goods, the market solution suffers from externalities, while the social planner takes externalities into account. To capture the deviation between the market and social equilibria, a parameter ω is included in the model to take into account the potential for the divergence to worsen under market equilibrium. Thus, as the price of the illegal harvest increases, the community increases its poaching effort (i.e., $\partial T_0^{p^*} / \partial \omega > 0$) in order to increase net benefits. This behaviour could lead to overexploitation of wildlife resources on communal land as the community seeks to maximize net benefits.

Our results show a negative relationship between poaching effort and the price of agricultural output $\partial T_0^{p^*} / \partial P_a < 0$, the discount associated with illegal sales $\partial T_0^{p^*} / \partial \varepsilon < 0$ and the probability of being caught $\partial T_0^{p^*} / \partial g_0 < 0$. From the analysis, it is evident that the CAMPFIRE communities suffer a double tax; initially, the safari operator charges a commission *s* for the services rendered, and then the community loses a fraction, $1 - \tau$, which goes to the RDC. Effectively, the price faced by the local community becomes $\tau(P^* - s)$, while the conservancy community gets P^* . Consequently, anything that deviates from the social planner's solution is not optimal and, thus, must be corrected.

4.1.2 Policy implications derived from comparative statics

The real result from this analysis is the uncovering of the policy instrument to improve outcomes in the CAMPFIRE communities. That policy instrument should not be imposed exogenously. We focus on policy because it is crucial on the conservation side through its effect on stock dynamics, and also crucial on the welfare side through its effect on economic benefits. The following policy interventions could potentially benefit the CAMPFIRE communities if they were to be implemented.

i. Reducing taxation on CAMPFIRE communities: From a policy standpoint, local communities would benefit if they could operate with the same self-sufficiency as the conservancy community because both taxes could be avoided. This could be achieved by hiring a manager or building internal capacity to match that in the conservancy community. The differences in the level of education between these two communities are revealing: the average number of years in school in the CAMPFIRE community is 7 compared to 15 in the conservancy.

ii. Reduce the price of illegal off-take: Likewise, a policy instrument that increases the risk premium ε could decrease the effective price of the illegal off-take and, hence, poaching effort, i.e., $\partial T_0^{p^*} / \partial \varepsilon < 0$. Reducing the effective price of the illegal off-take discourages the community from poaching by eroding the incentives, because $\partial T_0^{p^*} / \partial \omega > 0$. It is possible to integrate the risk premium into CPR institutions by carefully designing policy instruments that are adapted to local conditions.

iii. Appropriate institutional reforms: As reported earlier, the survey results for the CAMPFRE community point to weak institutions that are not supportive of proactive conservation. This is dramatically opposite to the behaviour observed in the conservancy community. As a result, it motivates us to explore whether an institutional reform in the CAMPFIRE community could move its welfare and conservation outcomes closer to those of the

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seemingly successful conservancy community. Because the CAMPFIRE community exerts more poaching effort in the market solution than the level that is socially optimal, we investigate the transition to social optimality by introducing an institutional variable which portrays a constraint on poaching behaviour. We argue that institutions affect biodiversity indirectly through constraining human behaviour (Ntuli and Muchapondwa 2015). Thus, we introduce an institutional variable ρ , which enters the model through the poaching function $\psi_0(\cdot)$. For this purpose, we will consider a variable ρ that measures lack of cooperation, such that, when ρ is zero, the community has sound institutions and cooperation is also high. When ρ is one, then institutions are very weak and there is no cooperation in the community. Accordingly, $\rho = 0$ produces zero poaching, while $\rho = 1$ produces maximum poaching. Assuming the following explicit form, $\psi(.) = a[\rho T_0^P]^{\phi} - b_0 L, b_0 > 0$ and $\rho \in [0,1]$, the modified solution for poaching effort is thus given by:

$$T_2^{p^*} = \left[\frac{\rho^{\phi}\phi a\omega}{P_a A_0 + \eta_0 + g_0 c_0}\right]^{\frac{1}{1-\phi}}$$

Most importantly, improvement in institutions might have significant impact on growth of the wildlife stock through its role in constraining behaviour, i.e., $\partial T_0^{p^*} / \partial \rho > 0$. Thus, constraining poaching effort might drive the stock shared by the park agency and CAMPFIRE communities toward the social planner's solution and avert a tragedy of the commons. The institutional variable ρ is a function of several other variables, such as governance, monitoring and enforcement, community level trust and endogenous punishment (see Ntuli and Muchapondwa 2015). As a matter of policy, we want ρ to be a number which is low and very close to zero.

One way to iron out all issues with the current CAMPFIRE setup is to give local communities autonomy and to empower the wildlife management committees, so that they are able to effectively discharge their duties. This entails building local level institutions that will, in turn, set the community agenda on new social norms which are pro-conservation. For instance, an improvement in governance structures at the community level, monitoring and enforcement, and community level trust might contribute toward the attainment of a healthy biodiversity outcome as well as contain poaching activities. This could also be achieved through capacity building (institutional capacity) or training and funding to equip CAMPFIRE communities with much-needed resources. Moreover, if the community is allowed to endogenize punishment, then poaching might subside to socially optimal levels.

4.2 Numerical Illustration of Stock Dynamics

The theoretical model will now be illustrated using functional form assumptions and data which fit well with the exploitation of the African elephant population by communities around the Gonarezhou ecosystem. African elephants are threatened by local communities because they cause more damage to agricultural crops than do other wild animals (Fischer et al. 2011). Each year, quite a significant proportion of elephants leaves the national park and visits the nearby communal areas during the agricultural season. Using MATLAB, we compute the optimal solutions from all the optimization problems presented above, and then proceed to show the stock dynamics as we vary anti-poaching effort and poaching effort and constrain the poaching effort while holding other variables constant. Model simulation was done using the following stock dynamic equation in discrete form.

$$X_i(t+1) = X_i(t) + F(X_i, \cdot) - h_i(X_i(t)) - \psi_i(\cdot, T_i^P)$$
 given $X_i(0)$ at time t = 0.....14

Following Johannessen and Skonhoft (2000), we normalize the catch-ability coefficient η to one so that the Schaefer harvesting function becomes $h_i(t) = \sigma X_i(t)$. The harvesting effort now belongs to the interval $0 < \sigma < 1$ so that the off-take cannot exceed the available resources. The natural growth function is specified as shown in the appendix, and again we normalise the size of the stock by setting the carrying capacity equal to one, i.e., K = 1. The size of the wildlife stock (measured in biomass level) is thus expressed as a fraction of the carrying capacity and must be in the interval $0 \le X_i(t) \le 1$. Furthermore, the intrinsic growth rate *r* is set equal to 0.3 (Caughley and Sinclar 1994; and Johannessen and Skonhoft 2000). In line with other studies, we also force both poaching and anti-poaching effort to lie between 0 and 1, i.e.,

$$0 \le L \le 1, 0 \le T_1^e \le 1 \text{ and } 0 \le T_0^p \le 1$$

The model simulation results confirm the theoretical predictions in Section 4.1. In equilibrium, the anti-poaching effort by the park agency is less than the level of effort recommended by the social planner, while anti-poaching effort exerted by the conservancy community is just the same as that prescribed by the social planner. The poaching effort employed by the CAMPFIRE community is twice as much as that required for social optimality. The equilibrium stocks under the market solution are less than the social planner's solution.

Markert Equilibrium	Social Equilibria
$L^* = 0.6957$	$L^* = 0.6231$
$X_0^* = 0.5321$	$X_0^* = 0.5877$
$X_1^* = 0.5622$	$X_1^* = 0.5901$
$T_1^{e^*} = 0.5992$	$T_1^{e^*} = 0.6012$
$T_0^{P*} = 0.5183$	$T_0^{p^*} = 0.2640$

Table 3: Numerical Illustration – Optimal Solutions

Source: model simulation results 2015

Figure 1 shows the changes in the next period stock (i.e., the shared stock) as we vary anti-poaching enforcement exerted by the park agency between 0 and 1 while holding other variables constant. The figure shows that the size of the wildlife stock on communal land increases as the park agency increases anti-poaching effort up to a certain point, and later on stabilizes at a slightly lower level than the social planner's recommendations. The gap between the market solution and the social planner's prescription does not completely iron out due to resource limitations. The numerical illustrations show that anti-poaching enforcement might grow the stock on communal land up to a certain level of effort $L^* = 0.62$ that is socially optimal, beyond which the stock ceases to grow due to other factors beyond the park agency's control.

Figure 1: Market Solution for the Park Agency versus the Social Planner



Figure 2 shows the changes in stock inside the conservancy in the next period as we vary the anti-poaching effort exerted by the conservancy community between 0 and 1 while holding other variables constant. The diagram shows that, if anti-poaching effort by the conservancy community is optimal, then the stock size prescribed by the social planner and the market solution will eventually coincide. This is the case when the market solution is equal to social

optimality. The convergence of the two solutions is very fast in the case of the conservancy community.



Figure 2: Market Solution for the Conservancy Community versus the Social Planner

Figure 3 shows the changes in the next period stock (i.e., shared stock) as we vary the poaching effort exerted by the CAMPFIRE community between 0 and 1 while holding other variables constant. The figure shows that the stock size on communal land diverges from the social planner's solution if poaching continues unabated. Initially, the wildlife stock outside the park increases with very low levels of poaching up to a certain point (about 0.26), then starts to decrease tremendously. If local communities continue to increase the level of poaching effort beyond this point, then this could drive the resource system toward economic or physical extinction. Beyond a certain level of stock, again, the wildlife stock will not be able to regenerate itself without human intervention.





Figure 4 shows the changes in the next period stock of wildlife (i.e., shared stock) as we introduce a variable for institutions and vary constrained poaching effort exerted by the

CAMPFIRE community between 0 and 1 while holding other variables constant. Starting from a lower level, the stock size in the local community's conservation area grows in a nonlinear fashion until the solution coincides with the prescriptions of the social planner, if the poaching effort is constrained. Ideally, we would want parameter ρ to be some number which is close to zero for faster convergence. The figure below shows that, starting with $\rho = 1$ (i.e., with the situation in Figure 4 above), an improvement in institutions, such that the parameter rho is forced toward zero (*i.e.* $\rho \rightarrow 0$), means that the shared stock will mimic the dynamics of the wildlife stock inside the conservancy. The sensitivity analysis demonstrates how stronger institutions help to bridge the divide between the market and social planner's solution more quickly than do weaker institutions. The graph below is drawn for the different values of rho, i.e., $\rho = 1.00, 0.65, 0.02, 0.09$ and $\phi = 0.3$.





5. Conclusion

Integrated Conservation and Development Projects are central for future rural development in Southern Africa. However, the impact of benefit-sharing schemes, such as the CAMPFIRE programme in Zimbabwe, is limited by possible dilemmas in the actual design of the scheme or trade-offs inherent in linking development and conservation objectives. The objectives of this paper are to compare wildlife management and utilization under the CAMPFIRE communities and conservancy community, and to consider the possibility of wildlife tenure and institutional reforms that might replicate conservancies' successful outcomes on communal areas implementing CAMPFIRE. Therefore, unlike previous studies, this paper seeks to establish the conditions under which a CAMPFIRE community can be incentivized to

behave like the conservancy community, which is more successful in revenue generation and stewardship practice.

To achieve the objectives above, we used a bioeconomic model. We developed and compared the problems for benefit-sharing arrangements under CAMPFIRE and the conservancy communities operating adjacent to Gonarezhou National Park. Firstly, the paper showed that the conservancy community is superior to the pure benefit-sharing scheme in terms of employment of effort and the long-run wildlife stock. Secondly, the paper analysed wildlife management and utilization under the assumption that the communities in question are given autonomy to the degree that they are able to invest in stronger CPR institutions.

Our results show that the level of anti-poaching enforcement by the park agency could be lower than the social planner's prescription. It might not be optimal for the park agency to provide anti-poaching enforcement inside the national game park and in communal areas. This result seems to support policy or institutional reforms that convey greater control of natural resources through devolution and decentralization of NRM functions, and decision-making to the community's grass roots level, since the community incurs lower cost of monitoring and enforcement. Specifically, to strengthen the incentives in CAMPFIRE communities, we propose that the RDC should transfer wildlife management functions and benefits to sub-district producer communities.

The social planner recommends higher levels of wildlife stock in the conservancy and on communal land, i.e., shared stock. If the conservancy community values wildlife to the same degree as does the social planner, then their level of anti-poaching enforcement achieves social optimality. This could drive the wildlife stock in the conservancy toward the social planner's solution, starting from a lower stock level. CAMPFIRE communities exert more poaching effort than what the social planner would recommend. As a result, the size of the shared stock might diverge over time from the social planner's prescription, starting from a lower level.

Because both the CAMPFIRE and conservancy communities are carrying out similar activities, they should potentially be able to achieve similar results. The differences in observed outcomes between them could be a result of the differences in community institutions. Our results confirm that an improvement in community institutions might have significant impact on growth of the wildlife stock through its role of constraining behaviour. This result calls for policy instruments that will facilitate or promote the development of sound CPR institutions that are tailored to suit local conditions and endogenous to the community.

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References

- Balint, P.J., and J. Mashinya. 2006. The Decline of a Model Community-based Conservation Project - Governance, Capacity, and Devolution in Mahenye, Zimbabwe. *Geoforum* 37: 805-815.
- Barrett, C.B., and P. Arcese. 1998. Wildlife Harvest in Integrated Conservation and Development Projects: Linking Harvest to Household Demand, Agricultural Production, and Environmental Shocks in the Serengeti. *Land Economics* 74: 449-465.
- Bell, R.H.V. 1984. "Problems in Achieving Conservation Goals." In *Conservation and Wildlife Management in Africa*, edited by R.H.V. Bell and E. McShane-Caluzi, 31-41.
 Proceedings of a Workshop, 17–25 October 1984, Kasung National Park, Malawi.
 Washington, DC: Office of Training and Program Support, Forestry and Natural Resource Sector, U.S. Peace Corps.
- Bond, I., and P.G.H. Frost. 2005. CAMPFIRE and the Payment for Environmental Services. Paper prepared for the workshop "Payments for Environmental Services (PES) – Methods and Design in Developed and Developing Countries."
- Campbell, B., and S. Shackleton. 2001. The Organizational Structures for Community-Based Natural Resource Management in Southern Africa. *African Studies Quarterly* 5(3) 87-114.
- Carlson, G.A., and M. Wetzstein. 1994. "Pesticides and Pest Management." In Agricultural and Environmental Resource Economics, edited by G.A. Carlson, D. Zilberman, and J.A. Miranowski. Oxford: Oxford University Press.
- Caughley, G., and A. Sinclair. 1994. *Wildlife Ecology and Management*. Oxford: Oxford University Press.
- Child, B. 1996. The Practice and Principles of Community-based Wildlife Management in Zimbabwe: The CAMPFIRE Programme. *Biodiversity and Conservation* 5(3): 369-398.
- Duffy, R. 1999. The Role and Limitations of State Coercion: Anti-poaching Policies in Zimbabwe. *Journal of Contemporary African Studies* 17(1): 97-121.
- Fischer, C., E. Muchapondwa, and T. Sterner. 2011. A Bioeconomic Model of Community Incentives for Wildlife Management under CAMPFIRE. *Environmental and Resource Economics* 48: 303-319.

- Fitzgerald, K. 2012. Understanding the Ecological, Economic and Social Context of Conservancies in Zimbabwe. *Africa Biodiversity Collaborative Group, USAID*.
- Gadgil, M., and P.R.S. Rao. 1994. On Designing a System of Positive Incentives to Conserve Biodiversity for the Ecosystem People of India. Workshop on Exploring the Possibilities of Joint Management of Protected Areas IIPA, New Delhi, 1-3 September.
- Gandiwa, E., I.M.A. Heitkönig, P.H.C. Eilers, and H.H.T. Prins. 2014. Rainfall Variability and its Impact on Large Mammal Populations in a Complex of Semiarid African Savanna Protected Areas. Extract from PhD Doctoral thesis, Wageningen University, The Netherlands, ISBN: 978-94-6173-746-5.
- Gandiwa, E., I.M.A. Heitkönig, A.M. Lokhorst, H.H.T. Prins, and C. Leeuwis. 2013a. CAMPFIRE and Human-wildlife Conflicts in Local Communities Bordering Northern Gonarezhou National Park, Zimbabwe. *Ecology and Society*, in press.
- Gandiwa, E., I.M.A. Heitkönig, A.M. Lokhorst, H.H.T. Prins, and C. Leeuwis. 2013b. Illegal Hunting and Law Enforcement during a Period of Economic Decline in Zimbabwe: A Case Study of Northern Gonarezhou National Park and Adjacent Areas. *Journal for Nature Conservation* 21: 133-142.
- Gandiwa, E. 2011. Preliminary Assessment of Illegal Hunting by Communities Adjacent to the Northern Gonarezhou National Park, Zimbabwe. *Mongabay.com Open Access Journal -Tropical Conservation Science* 4(4): 445-467.
- Hueth, B.M., J. Zivin, and D. Zilberman. 1998. Managing a Multiple-use Resource: The Case of Feral Pig Management in California Rangeland. Working Paper, Department of Agricultural and Resource Economics, University of California.
- Johannesen, A.B., and A. Skonhoft. 2014. Conservation versus Exploitation of Wild Animal Species Property Rights and Conflicts. Work in progress.
- Johannesen, A.B., and A. Skonhoft. 2005. Tourism, Poaching and Wildlife Conservation: What Can Integrated Conservation and Development Projects Accomplish? *Resource and Energy Economics* 27: 208-226.
- Johannessen, A.B., and A. Skonhoft. 2000. Property Rights and Natural Resource Utilisation: A Bioeconomic Model with Numerical Illustrations from the Serengeti-Mara Ecosystem. Department of Economics, Norwegian University of Science and Technology.

- Kreuter, U., M. Peel, and E. Warner. 2010. Wildlife Conservation and Community-based Natural Resource Management in South Africa's Private Nature Reserves. *Society and Natural Resources* 23: 507-524.
- Krug, W. 2001. Private Supply of Protected Land in Southern Africa: A Review of Markets, Approaches, Barriers and Issues. Workshop Paper World Bank/OECD International Workshop on Market Creation for Biodiversity Products and Services Paris.
- Logan, B.I., and W.G. Moseley. 2002. The Political Ecology of Poverty Alleviation in Zimbabwe's Communal Areas Management Programme for Indigenous Resources (CAMPFIRE). *Geoforum* 33(1): 1-14.
- Marks, S.A. 1984. *The Imperial Lion: Human Dimensions of Wildlife Management in Africa*. Boulder: Westview Press.
- Muchapondwa, E., and T. Sterner. 2012. Agricultural Risk Management through Communitybased Wildlife Conservation in Zimbabwe. *Journal of Agribusiness in Developing and Emerging Economies* 2(1): 41-56.
- Muchapondwa, E. 2003. The Economics of Community-based Wildlife Conservation in Zimbabwe. PhD dissertation, Göteborg University, Sweden.
- Muir-Leresche, K., and R.H. Nelson. 2000. Private Property Rights to Wildlife: The Southern Africa Experience. University of Zimbabwe, University of Maryland and ICER.
- Mukanjari, S., E. Muchapondwa, P. Zikhali, and B. Bednar-Friedl. 2013. Evaluating the Prospects of Benefit Sharing Schemes in Protecting Mountain Gorillas in Central Africa. *Natural Resource Modelling* 26(4): 455-479.
- Munthali, S.M. 2007. Transfrontier Conservation Areas: Integrating Biodiversity and Poverty Alleviation in Southern Africa. *Natural Resources Forum* 31: 51-60.
- Murombedzi, J.C. 1999. Devolution and Stewardship in Zimbabwe's CAMPFIRE Programme. Journal of International Development 11: 287-293.
- Ntuli, H., and E. Muchapondwa. 2015. The Role of Institutions in Community Wildlife Conservation in Zimbabwe. Environment for Development (EfD) Discussion Paper 15-23. Gothenburg, Sweden: Environment for Development, and Washington, DC: Resources for the Future.
- Poshiwa, X., R.A. Groeneveld, I.M.A. Heitkönig, H.H.T. Prins, and E.C. van Lerland. 2013. Reducing Rural Households' Annual Income Fluctuations Due to Rainfall Variation

through Diversification of Wildlife Use: Portfolio Theory in a Case Study of South Eastern Zimbabwe. *Mongabay.com Open Access Journal - Tropical Conservation Science* 6(2): 201-220.

- Songorwa, A.N., T. Buhrs, and K.F.D. Hughey. 2000. Community-Based Wildlife Management in Africa: A Critical Assessment of the Literature. *Natural Resources Journal* 40: 603.
- Songorwa, A.N. 1999. Community-Based Wildlife Management (CWM) in Tanzania: Are the Communities Interested? *World Development* 27(12): 2061-2079.
- Thomson, G.R., M.L. Penrith, M.W. Atkinson, S.J. Atkinson, D. Cassidy, and S.A. Osofsky.
 2013. Balancing Livestock Production and Wildlife Conservation in and around Southern Africa's Trans-frontier Conservation Areas. *Transboundary and Emerging Diseases* 60: 492-506.
- Wels, H. 2000. Fighting over Fences. Organisational Co-operation and Reciprocal Exchange between the Save Valley Conservancy and its Neighbouring Communities, Zimbabwe. Unpublished PhD Thesis, Vrije University, Amsterdam.
- Wells, M., S. Guggenheim, A. Khan, W. Wardojo, and P. Jepson. 1999. Investing in Biodiversity: A Review of Indonesia's Integrated Conservation and Development Projects. Washington, D.C.: The World Bank.
- Zivin, J., B. Hueth, and D. Zilberman. 2000. Managing a Multiple-use Resource: The Case of Feral Pig Management in Californian Rangeland. *Journal of Environmental Economics* and Management 39: 189-204.

Appendix

Summary of Definitions of Symbols Used in This Paper

~ ()	
G(.)	Public goods value
X_{0}	Stock of wildlife roaming on communal land (shared stock)
X_{1}	Stock of wildlife in the conservancy
h ₀	Hunting quota for the CAMPFIRE community
h ₁	Hunting quota for the conservancy
$\psi_{i}(.)$	Poaching function
R(.)	Revenue from tourism activity
$\frac{L}{T_i}$	Anti-poaching enforcement by the park agency Total production effort
T_i^a	Amount of effort toward agricultural production
T_1^e	Anti-poaching enforcement by the conservancy
T_i^p	Poaching effort
θ_{i}	Probability of being caught
ρ	Effectiveness parameter/lack of cooperation/institutional variable
π_{i}	Net benefits
λ	Shadow value of the stock of wildlife roaming on communal land (shared stock)
μ	Shadow value of the stock of wildlife in the conservancy
τ	Proportion of income going into the hands of CAMPFIRE communities
$\eta_{_0}$	Fixed per unit cost of poaching effort
V _i	Per unit cost of anti-poaching effort
c _i	Fine imposed on poachers
A _i	Agricultural technology
β	Nuisance parameter
\mathbf{P}^*	Average fixed marginal valuation (price) of legal off-take
Pa	Price of agricultural produce
S	Premium charged by the safari operator for their services
ε	Risk premium charged on illegal off-take
$\overline{\mathbf{M}}$	Budget/income from the state

Functional Forms

$$\begin{aligned} G(.) &= qX_0 + qX_1 = q(X_0 + X_1) \\ R(.) &= qX_i \\ A_0(.) &= AT_0^a = A_0[\overline{T_0} - T_0^p] \\ A_1(.) &= AT_1^a = A_1[\overline{T_1} - T_1^e] \\ \psi_0(.) &= a[T_0^p]^{\phi} - b_0L, b_0 > 0 \text{ and } 0 < \phi < 1 \\ \psi_1(.) &= a[T_1^p]^{\phi} - b_1T_1^e, b_1 > 0 \text{ and } 0 < \phi < 1 \\ \theta_0(L, T_0^p) &= g_0(L + T_0^p) \\ \theta_1(T_1^e, T_1^p) &= g_1(T_1^e + T_1^p) \\ F(X_0, L) &= rX_0 \left[1 - \frac{X_0}{K_0} \right] + b_0L^{\gamma} \text{ [growth inside the national game park]} \\ F(X_1, T_1^e) &= rX_1 \left[1 - \frac{X_1}{K_1} \right] + b_1(T_1^e)^{\alpha} \text{ [growth inside the conservancy]} \end{aligned}$$

The Park Agency

The first-order conditions (maximum principle) are given by

$$\begin{split} \frac{\partial H(.)}{\partial L} &= 0 \Rightarrow \frac{\partial \theta_0(L, T_0^{\,p})}{\partial L} c_0 - v_o + \lambda \frac{\partial F(X_0, L)}{\partial L} - \lambda \frac{\partial \psi_0(.)}{\partial L} - \Lambda_0 v_0 = 0 \\ &\Rightarrow \frac{\partial \theta_0(L, T_0^{\,p})}{\partial L} c_0 + \lambda \frac{\partial F(X_0, L)}{\partial L} = v_o(1 + \Lambda_0) + \lambda \frac{\partial \psi_0(.)}{\partial L} \dots (b) \\ \frac{\partial H}{\partial h_1} &= -\mu - \Lambda_1 P^* = 0 \Rightarrow \mu = -\Lambda_1 P^* \dots (c) \\ \frac{\partial H}{\partial h_0} &= -\lambda - \Lambda_2 (P^* - s) = 0 \Rightarrow \lambda = -\Lambda_2 (P^* - s) \dots (d) \\ \dot{\lambda} &= \delta \lambda - \frac{\partial H(.)}{\partial X_0} = \delta \lambda - \frac{\partial G(.)}{\partial X_0} - \frac{\partial R(.)}{\partial X_0} - \lambda \frac{\partial F(.)}{\partial X_0} \dots (e) \\ \dot{\mu} &= \delta \mu - \frac{\partial H(.)}{\partial X_1} = \delta \mu - \frac{\partial G(.)}{\partial X_1} - \mu \frac{\partial F(.)}{\partial X_1} \dots (f) \end{split}$$

Solving for
$$X_0^*$$

$$\Rightarrow \dot{\lambda} = \delta \lambda - \frac{\partial G(.)}{\partial X_0} - \frac{\partial R(.)}{\partial X_0} - \lambda \frac{\partial F(.)}{\partial X_0}$$

$$\Rightarrow \dot{\lambda} = \delta \lambda - q - q - r \lambda \left[1 - \frac{2X_0}{K_0} \right]$$
In equilibrium

$$r\lambda \left[1 - \frac{2X_0}{K_0} \right] = \delta\lambda - 2q$$
$$X_0^* = K_0 \frac{\lambda(r-\delta) + 2q}{2r\lambda}$$

Solving for
$$L^*$$

$$\Rightarrow \frac{\partial \theta_0(L, T_2^p)}{\partial L} c_0 + \lambda \frac{\partial F(X_0, L)}{\partial L} = v_o(1 + \Lambda_0) + \lambda \frac{\partial \psi_0(.)}{\partial L}$$

$$\Rightarrow g_0 c_0 + \lambda b_0 \mathcal{H}^{\gamma - 1} = v_o(1 + \Lambda_0) + \lambda b_0$$

$$\Rightarrow \lambda \gamma b_0 L^{\gamma - 1} = v_o(1 + \Lambda_0) + \lambda b_0 - g_0 c_0$$

$$\Rightarrow L^{\gamma - 1} = \frac{v_o(1 + \Lambda_0) + \lambda b_0 - g_0 c_0}{\lambda \gamma b_0}$$

$$\Rightarrow L^* = \left[\frac{v_o(1 + \Lambda_0) + \lambda b_0 - g_0 c_0}{\lambda \gamma b_0}\right]^{\frac{1}{\gamma - 1}}$$

$$\Rightarrow L^* = \left[\frac{\lambda \gamma b_0}{v_o(1 + \Lambda_0) + \lambda b_0 - g_0 c_0}\right]^{\frac{1}{1 - \gamma}}$$

Solving for
$$X_1^st$$

$$\Rightarrow \dot{\mu} = \delta \mu - \frac{\partial G(.)}{\partial X_1} - \mu \frac{\partial F(.)}{\partial X_1}$$
$$\Rightarrow \dot{\mu} = \delta \mu - q + \mu r \left[1 - \frac{2X_1}{K_1} \right]$$

In equilibrium $\begin{bmatrix} 2X \end{bmatrix}$

$$\mu r \left[1 - \frac{2X_1}{K_1} \right] = \delta \mu + q$$
$$X_1^* = K_1 \frac{\mu (r - \delta) + q}{2r\mu}$$

$$F(X_{1},T_{1}^{e}) - h_{1} - \psi_{1}(T_{1}^{e},T_{1}^{P}) = 0$$

$$\Rightarrow h_{1} = F(X_{1}^{*},T_{1}^{e}) - \psi_{1}(T_{1}^{e},T_{1}^{P})$$

$$\Rightarrow h_{1}^{*} = rX_{1}^{*} \left[1 - \frac{X_{1}^{*}}{K_{1}} \right] + b_{1}(T_{1}^{e^{*}})^{\alpha} - \psi_{1}(T_{1}^{e},T_{1}^{P})$$

$$\Rightarrow h_{1}^{*} = rX_{1}^{*} \left[1 - \frac{X_{1}^{*}}{K_{1}} \right] + b_{1}(T_{1}^{e^{*}})^{\alpha} - (a[T_{1}^{P^{*}}]^{\phi} - b_{1}T_{1}^{e^{*}})$$

$$F(X_0, L) - h_0 - \psi_0(L, T_0^P) = 0$$

$$\Rightarrow h_0 = F(X_0^*, L^*) - \psi_0(L^*, T_0^P)$$

$$\Rightarrow h_0^* = rX_0^* \left[1 - \frac{X_0^*}{K_0} \right] + b_0(L^*)^\gamma - (a[T_0^{P*}]^{\phi} - b_0L^*)$$

$$\Rightarrow h_0^* = rX_0^* \left[1 - \frac{X_0^*}{K_0} \right] + b_0(L^*)^\gamma + b_0L^* - a[T_0^{P*}]^{\phi}$$

Private Game Farming Community

The first-order conditions are given by:

$$\begin{split} \frac{\partial H}{\partial T_1^e} &= 0 \Longrightarrow -P_a \frac{\partial A_1(.)}{\partial T_1^e} + \frac{\partial \theta_1(.)}{\partial T_1^e} c_1 - v_1 + \mu \frac{\partial F(X_1, T_1^e)}{\partial T_1^e} - \mu \frac{\partial \psi_1(.)}{\partial T_1^e} = 0 \\ & \Rightarrow \frac{\partial \theta_1(.)}{\partial T_1^e} c_1 + \mu \frac{\partial F(X_1, T_1^e)}{\partial T_1^e} = P_a \frac{\partial A_1(.)}{\partial T_1^e} + v_1 + \mu \frac{\partial \psi_1(.)}{\partial T_1^e} \\ \dot{\mu} &= \delta \mu - \frac{\partial H(.)}{\partial X_1} = \delta \mu - \frac{\partial R_1(.)}{\partial X_1} - \mu \frac{\partial F(X_1, T_1^e)}{\partial X_1} \end{split}$$

Solving for $T_1^{e^*}$

$$\begin{split} &\frac{\partial \theta_{1}(.)}{\partial T_{1}^{e}}c_{1}+\mu \frac{\partial F(X_{1},T_{1}^{e})}{\partial T_{1}^{e}}=P_{a}\frac{\partial A_{1}(.)}{\partial T_{1}^{e}}+v_{1}+\mu \frac{\partial \psi_{1}(.)}{\partial T_{1}^{e}}\\ &\Rightarrow g_{1}c_{1}-P_{a}A_{1}-v_{1}+\alpha \mu b_{1}(T_{1}^{e})^{\alpha-1}-\mu b_{1}=0\\ &\Rightarrow \alpha \mu b_{1}(T_{1}^{e})^{\alpha-1}=P_{a}A_{1}+v_{1}-g_{1}c_{1}+\mu b_{1}\\ &\Rightarrow (T_{1}^{e})^{\alpha-1}=\frac{P_{a}A_{1}+v_{1}+\mu b_{1}-g_{1}c_{1}}{\alpha \mu b_{1}}\\ &\Rightarrow T_{1}^{e}=\left[\frac{P_{a}A_{1}+v_{1}+\mu b_{1}-g_{1}c_{1}}{\alpha \mu b_{1}}\right]^{\frac{1}{\alpha-1}}\\ &\Rightarrow T_{1}^{e^{*}}=\left[\frac{\alpha \mu b_{1}}{P_{a}A_{1}+v_{1}+\mu b_{1}-g_{1}c_{1}}\right]^{\frac{1}{1-\alpha}} \end{split}$$

The Local Community

The first-order conditions are given by:

$$\frac{\partial \pi_0}{\partial T_0^P} = 0 \Longrightarrow -P_a \frac{\partial A_0(.)}{\partial T_0^P} + \omega \frac{\partial \psi_0(.)}{\partial T_0^P} - v_0 - \frac{\partial \theta_0(.)}{\partial T_0^P} c_0 = 0$$
$$\Longrightarrow \omega \frac{\partial \psi_0(.)}{\partial T_0^P} = P_a \frac{\partial A_0(.)}{\partial T_0^P} + v_0 + \frac{\partial \theta_0(.)}{\partial T_0^P} c_0$$

Solving for $T_0^{p^*}$

$$\Rightarrow \omega \frac{\partial \psi_0(.)}{\partial T_0^p} = P_a \frac{\partial A_0(.)}{\partial T_0^P} + \eta_0 + \frac{\partial \theta_0(.)}{\partial T_0^p} c_0$$

$$\Rightarrow \phi a \omega [T_0^p]^{\phi - 1} = P_a A_0 + \eta_0 + g_0 c_0$$

$$\Rightarrow [T_0^p]^{\phi - 1} = \frac{P_a A_0 + \eta_0 + g_0 c_0}{\phi a \omega}$$

$$\Rightarrow T_0^{p^*} = \left[\frac{P_a A_0 + \eta_0 + g_0 c_0}{\phi a \omega}\right]^{\frac{1}{\phi - 1}}$$
$$\Rightarrow T_0^{p^*} = \left[\frac{\phi a \omega}{P_a A_0 + \eta_0 + g_0 c_0}\right]^{\frac{1}{1 - \phi}}$$

Introducing the Institutional Variable

$$\Rightarrow \omega \frac{\partial \psi_0(.)}{\partial T_0^p} = P_a \frac{\partial A_0(.)}{\partial T_0^p} + \eta_0 + \frac{\partial \theta_0(.)}{\partial T_0^p} c_0$$

$$\Rightarrow \phi \rho^{\phi} a \omega [T_0^p]^{\phi-1} = P_a A_0 + \eta_0 + g_0 c_0$$

$$\Rightarrow [T_0^p]^{\phi-1} = \frac{P_a A_0 + \eta_0 + g_0 c_0}{\rho^{\phi} \phi a \omega}$$

$$\Rightarrow T_0^{p^*} = \left[\frac{P_a A_0 + \eta_0 + g_0 c_0}{\rho^{\phi} \phi a \omega}\right]^{\frac{1}{\phi-1}}$$

$$\Rightarrow T_0^{p^*} = \left[\frac{P_a A_0 + \eta_0 + g_0 c_0}{\rho^{\phi} \phi a \omega}\right]^{\frac{1}{\phi-1}}$$

$$\Rightarrow T_0^{p^*} = \left[\frac{\rho^{\phi} \phi a \omega}{P_a A_0 + \eta_0 + g_0 c_0}\right]^{\frac{1}{1-\phi}}$$

$$\Rightarrow T_0^{p^*} = \left[\frac{\rho^{\phi} \phi a \omega}{P_a A_0 + \eta_0 + g_0 c_0}\right]^{\frac{1}{1-\phi}}$$

The Social Planner

$$\begin{split} & \text{First-order conditions} \\ & \frac{\partial H(.)}{\partial L} = 0 \Rightarrow \omega \frac{\partial \psi_0(.)}{\partial L} + \lambda \frac{\partial F(X_0, L)}{\partial L} - \lambda \frac{\partial \psi_0(.)}{\partial L} - v_o - \Lambda_0 v_0 = 0 \\ & \Rightarrow \lambda \frac{\partial F(X_0, L)}{\partial L} = (\lambda - \omega) \frac{\partial \psi_0(.)}{\partial L} + v_o(1 + \Lambda_0) \dots \dots (13b) \\ & \frac{\partial H}{\partial h_1} = P^* - \mu - \Lambda_1 P^* - \Omega_1 = 0 \Rightarrow P^*(1 - \Lambda_1) - \mu - \Omega_1 = 0 \Rightarrow \mu = P^*(1 - \Lambda_1) - \Omega_1 \dots (13c) \\ & \frac{\partial H}{\partial h_2} = \tau(P^* - s) - \lambda - \Lambda_0(P^* - s) - \Omega_0 = 0 \Rightarrow (P^* - s)(\tau - \Lambda_0) - \lambda - \Omega_2 = 0 \Rightarrow \lambda = (P^* - s)(\tau - \Lambda_2) - \Omega_2 \dots (13d) \\ & \frac{\partial H}{\partial h_2} = \frac{\partial \theta_1(.)}{\partial T_1^e} c_1 - P_a \frac{\partial A_1(0)}{\partial T_1^e} - v_1 + \mu \frac{\partial F(.)}{\partial T_1^e} - \mu \frac{\partial \psi_1(.)}{\partial T_1^e} = 0 \dots (13e) \\ & \frac{\partial H}{\partial T_0^p} = -P_a \frac{\partial A_0(0)}{\partial T_0^p} + \omega \frac{\partial \psi_0(.)}{\partial T_0^p} - v_0 - \lambda \frac{\partial \psi_0(.)}{\partial T_0^p} = 0 \dots (13(f)) \\ & \dot{\lambda} = \delta \lambda - \frac{\partial H(.)}{\partial X_0} = \delta \lambda - \frac{\partial G(.)}{\partial X_0} - \frac{\partial R(.)}{\partial X_0} - \lambda \frac{\partial F(.)}{\partial X_0} - \varphi \dots (13(f)) \\ & \dot{\mu} = -\frac{\partial H(.)}{\partial X_1} = \delta \mu - \frac{\partial G(.)}{\partial X_1} - \frac{\partial R(.)}{\partial X_1} - \mu \frac{\partial F(.)}{\partial X_1} \dots (13(f)) \end{split}$$

Solving for L^*

Solving for X_0^*

$$\Rightarrow \lambda \frac{\partial F(X_0, L)}{\partial L} = (\lambda - \omega) \frac{\partial \psi_2(.)}{\partial L} + v_o(1 + \Lambda_0) \Rightarrow \gamma \lambda b_0 L^{\gamma - 1} = (\lambda - \omega) b_0 + v_o(1 + \Lambda_0) \Rightarrow \gamma \lambda b_0 L^{\gamma - 1} = (\lambda - \omega) b_0 + v_o(1 + \Lambda_0) \Rightarrow L^{\gamma - 1} = \frac{(\lambda - \omega) b_0 + v_o(1 + \Lambda_0)}{\gamma \lambda b_0} \Rightarrow L^{\gamma - 1} = \frac{(\lambda - \omega) b_0 + v_o(1 + \Lambda_0)}{\gamma \lambda b_0} \end{bmatrix}^{\frac{1}{\gamma - 1}}$$

$$\Rightarrow L^{\gamma} = \left[\frac{(\lambda - \omega) b_0 + v_o(1 + \Lambda_0)}{\gamma \lambda b_0} \right]^{\frac{1}{\gamma - 1}}$$

$$\Rightarrow L^{\gamma} = \left[\frac{(\lambda - \omega) b_0 + v_o(1 + \Lambda_0)}{\gamma \lambda b_0} \right]^{\frac{1}{1 - \gamma}}$$

$$\Rightarrow L^{\gamma} = \left[\frac{\gamma \lambda b_0}{v_o(1 + \Lambda_0 + (\lambda - \omega) b_0)} \right]^{\frac{1}{1 - \gamma}}$$

$$\Rightarrow X_0^{\gamma} = K_0 \frac{\lambda(r - \delta) + 2q + \varphi}{2r\lambda}$$

Solving for $T_0^{p^*}$ Solving for X_1^* $\Rightarrow \dot{\mu} = \delta \mu - \frac{\partial G(.)}{\partial X_1} - \frac{\partial R(.)}{\partial X_2} - \mu \frac{\partial F(.)}{\partial X_2}$ $\frac{\partial H}{\partial T_{e}^{p}} = -P_{a}\frac{\partial A_{0}()}{\partial T_{e}^{p}} + \omega \frac{\partial \psi_{0}(.)}{\partial T_{e}^{p}} - \eta_{0} - \lambda \frac{\partial \psi_{0}(.)}{\partial T_{e}^{p}}$ $\Rightarrow \dot{\mu} = \delta \mu - q - q - r \mu \left[1 - \frac{2X_1}{K_1} \right]$ $\Rightarrow -P_a \frac{\partial A_0()}{\partial T_o^P} + \omega \frac{\partial \psi_0(.)}{\partial T_o^P} - \eta_0 - \lambda \frac{\partial \psi_0(.)}{\partial T_o^P} = 0$ In equilibrium $\Rightarrow -P_a A_0 + \phi \omega a [T_0^p]^{\phi-1} - \eta_0 - \phi \lambda a [T_0^p]^{\phi-1} = 0$ $\Rightarrow r\mu \left| 1 - \frac{2X_1}{K_1} \right| = \delta\mu - 2q$ $\Rightarrow \phi \omega a [T_0^p]^{\phi-1} - \phi \lambda a [T_0^p]^{\phi-1} = P_a A_0 + \eta_0$ $\Rightarrow \phi a[T_0^p]^{\phi-1}(\omega-\lambda) = P_a A_0 + \eta_0$ $\Rightarrow 1 - \frac{2X_1}{K_1} = \frac{\delta\mu - 2q}{r\mu}$ $\Rightarrow [T_0^p]^{\phi^{-1}} = \frac{P_a A_0 + \eta_0}{\phi a(\omega - \lambda)}$ $\Rightarrow \frac{2X_1}{K_1} = 1 - \frac{\delta\mu - 2q}{r\mu}$ $\Rightarrow T_0^p = \left[\frac{P_a A_0 + \eta_0}{dq(\omega - \lambda)}\right]^{\frac{1}{\phi - 1}}$ $\Rightarrow X_1^* = K_1 \frac{\mu(r-\delta) + 2q}{2r\mu}$ $\Rightarrow T_0^{p^*} = \left[\frac{\phi a(\omega - \lambda)}{P_a A_0 + \eta_0}\right]^{\frac{1}{1-\phi}}$ $\Rightarrow X_1^* = K_1 \frac{\mu(r-\delta) + 2q}{2r\mu}$

Solving for
$$T_1^{e^*}$$

$$\frac{\partial H}{\partial T_1^e} = \frac{\partial \theta_1(.)}{\partial T_1^e} c_1 - P_a \frac{\partial A_1()}{\partial T_1^e} - v_1 + \mu \frac{\partial F(.)}{\partial T_1^e} - \mu \frac{\partial \psi_1(.)}{\partial T_1^e}$$

$$\Rightarrow \frac{\partial \theta_1(.)}{\partial T_1^e} c_1 - P_a \frac{\partial A_1()}{\partial T_1^e} - v_1 + \mu \frac{\partial F(.)}{\partial T_1^e} - \mu \frac{\partial \psi_1(.)}{\partial T_1^e} = 0$$

$$\Rightarrow g_1 c_1 - P_a A_1 - v_1 + \alpha \mu b_1 (T_1^e)^{\alpha - 1} - \mu b_1 = 0$$

$$\Rightarrow \alpha \mu b_1 (T_1^e)^{\alpha - 1} = P_a A_1 + v_1 - g_1 c_1 + \mu b_1$$

$$\Rightarrow (T_1^e)^{\alpha - 1} = \frac{P_a A_1 + v_1 + \mu b_1 - g_1 c_1}{\alpha \mu b_1}$$

$$\Rightarrow T_1^e = \left[\frac{P_a A_1 + v_1 + \mu b_1 - g_1 c_1}{\alpha \mu b_1}\right]^{\frac{1}{\alpha - 1}}$$

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Numerical Illustration of Stock Dynamics

 $X_{i}(t+1) - X_{i}(t) = F(X_{i}, L) - \psi_{i}(\cdot, T_{i}^{P})$ Shared stock $X_{0}(t+1) = X_{0}(t) + F(X_{0}, L) - \psi_{0}(L, T_{0}^{P}) \text{ given } X_{0}^{(0)} \text{ and } t = 0$

Shared stock (with constrained poaching)

 $X_0(t+1) - X_0(t) = F(X_0, L) - h_0 - \psi_0(L, \rho T_0^P)$ given $X_0^{(0)}$ and t = 0

In the conservancy

 $X_1(t+1) - X_1(t) = F(X_1, T_1^e) - h_1 - \psi_1(T_1^e, T_1^P)$ given $X_1^{(0)}$ and t = 0