Developing and testing comparative statics for appropriation and provision decisions in common pool resource settings for improved policymaking

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Abstract. Appropriation and provision are key human-environmental interactions affecting the sustainability of common pool resources. Hereby appropriation refers to the extraction from the common pool, while provision refers to investments made to enhance the common resource stock. Unfortunately, both situations contain social dilemmas, as individual's self-interest is to maximize appropriation and to minimize provision activities and thereby freeriding on joint users' efforts. In many real-world settings, existing governance arrangements link appropriation to provision requirements to balance costs and benefits of resource use. The aim of this paper is to provide a more realistic representation of individuals' decision-making process in common pool resource dilemmas by analyzing the two situations in conjunction. We use the example of Swiss common property pastures to develop a formal model to derive testable predictions for the determinants of appropriation and provision behavior. We then test these predictions, including individual attributes, local and federal governance parameters with regression analysis on empirical data. Our results suggest that farmers include the costs of provision in their appropriation decision, and that the structural developments in the agricultural sector affects individuals' attributes in a way that leads to reduced use of common property pastures. Based on these insights, we suggest adapting the incentive structure by redesigning local governance and federal governance institutions to account for the principles of marginality.

1 Introduction

The value of the world's natural capital is estimated at $125 trillion for 2011, a figure exceeding global gross domestic product by far. Most of these values result from non-marketable public goods or common pool resources (CPRs) producing ecosystem services (Costanza *et al.*, 2014). The state of CPRs such as water, forest, or pasture not solely depends on the appropriation of resource units, but also on provision activities that benefit the productivity of the resource and the respective infrastructure (Anderies *et al.*, 2004; Cox *et al.*, 2010). Both, appropriation and provision activities comprise social dilemmas, as users' self-interest—to maximize harvesting activities and to minimize investment activities—stands opposed to the interest of the group (Gardner, Ostrom, & Walker, 1990; Ostrom, 1990).

Empirical and meta-theoretical studies emphasize that successful local governance needs institutional arrangements that establish congruence between appropriation and provision efforts to balance the benefits from using the resources with the costs of maintaining it (Agrawal, 2001; Cox *et al.*, 2010; Wilson *et al.*, 2013). Trawick (2001) shows for irrigation systems in the Andes of Peru that farmers' with larger holdings are required to make larger contributions for the upkeep of tanks and channels. Equally Cox (2010) observes for Taos valley of New Mexico that irrigators contribute labor and resources towards the maintenance of the irrigation in proportion to their land and water rights. Klooster (2000) documented a similar example for forest user communities in Mexico, where the successful communities follow governance principles that secure the reinvestments of some of benefits from wood harvest into public infrastructure. Baur and Binder (2013) show for common property pastures (CPP) use in Switzerland that local governance arrangements require farmers to work 8 hours for the upkeep of the pastures per livestock unit sent for grazing.

Experimental research has much contributed to understanding of both appropriation (Falk *et al.*, 2002; Osés-Eraso and Viladrich-Grau, 2007) and provision problems (Fehr and Gächter, 2000; Janssen *et al.*, 2010), and the factors that foster cooperation. However, to our knowledge the two situations have never been studied in conjunction, although in real CPR-settings the two decisions are often interlinked. In settings where institutions link appropriation to provision requirements, any user

will carefully weight expected benefits from appropriation against the cost of provision. Users may therefore even restrain from eligible appropriation activities to avoid the costs imposed by provision duties, which may even imped resource use to drop below optimal activity

Although empirical and experimental research generally assumes that unsustainable use of CPRs is associated with problems of over appropriation (Berkes *et al.*, 1989; Acheson, 2003), a growing amount of literature now points to problems of CPR underuse and its adverse environmental effects. Empirical examples concern mostly semi-natural grassland in highly develop economies such as Japan (Shimada, 2015), Norway (Olsson *et al.*, 2000), and the central European Alps (Keenleyside *et al.*, 2010; Baur *et al.*, 2014). The adverse effect of underuse in these cases are twofold. On the one hand, under-grazing reduces biomass production just as overgrazing does (McNaughton, 1979; Hilbert *et al.*, 1981). On the other hand, pasture underuse results in undesired landscape changes with large-scale afforestation resulting from pasture abandonment as currently observed in the European Alps (Gellrich *et al.*, 2007; Tasser *et al.*, 2007; Vigl *et al.*, 2016). These land use changes result not just in loss of productive agricultural land (Keenleyside *et al.*, 2010), but also reduce biodiversity (Zimmermann *et al.*, 2010), and landscape diversity (Tasser *et al.*, 2007).

The aim of this paper is to contribute to more realistic behavioral models for appropriation and provision situations by studying the two situations in conjunction. These insights allow for a better understanding of the decision-making process of real CPR users in general, and for the case of common property pasture underuse in particular. To do so, we proceed as follows: We first provide background information on common property pasture usage in Grindelwald, Switzerland which herein serves as the empirical example for the analysis. We then formulate a formal model to mimic the farmers' decision setting in the region. This includes linking appropriation and provision decisions and using comparative statics to identify behavioral determinants. We then test the predictions with regression analysis on empirical data for the case study region. Based on these insights we finally formulate policy alternatives for both local and federal governance, and conclude with implications for the study of the commons.

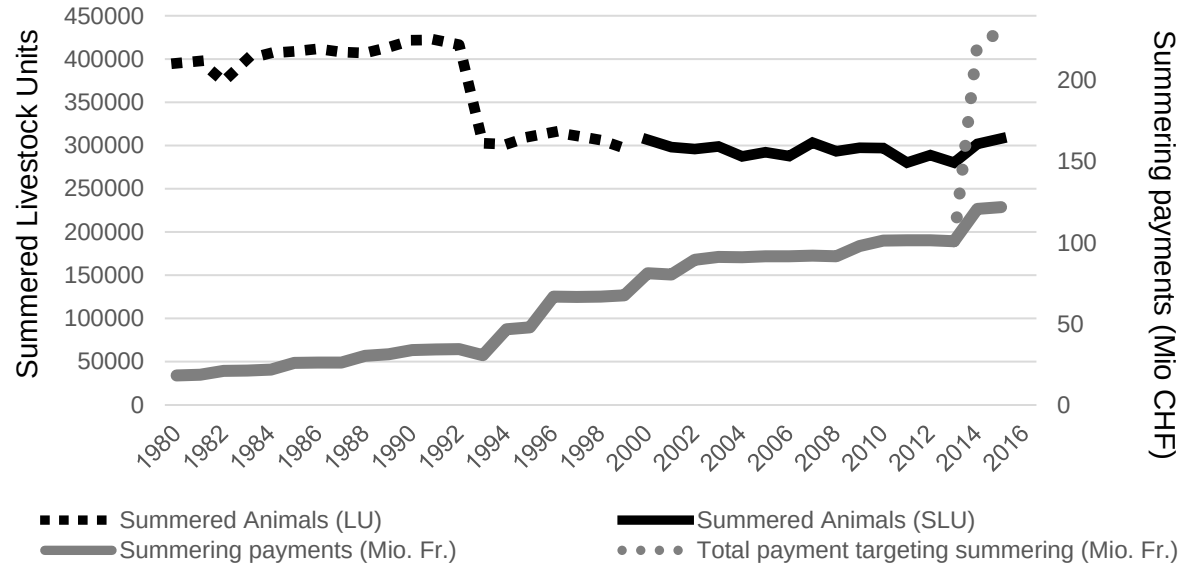
2 Background on common property pastures management in Switzerland.

2.1 Federal governance incentives

Summer pastures in Switzerland account for more than 10% of the national area (Lauber *et al.*, 2008). Around 80% of these summer pastures are managed as common property. During the past decades, summer pastures, in particular in less favorable areas, became less intensely used (Baur *et al.*, 2007). Therefore, the federal government introduced *"summering payments"* to foster the use of summer pastures in the early eighties with 50 CHF per summered livestock unit (SLU). Since then, summering payments have been stepwise increased to the current 400 CHF/SLU paid to the summering enterprise or to the corporate body governing the CPP. Summering payments aim at supporting infrastructural maintenance, and are incrementally reduced if the net appropriation falls below 80% of state defined MSY or exceeds 110%. As displayed in Fig. 1a, the federal government spent a total of 121 Mio. CHF on summering payments in the year 2014. Nevertheless, despite growing expenditures, the livestock summered decreased between 2000 and 2013 by 10% (Fig 1a.).

In response to decreasing number of livestock summered, the new agricultural policy frame launched in 2014, introduced an additional measure to foster the use of summer pasture. The *"appropriation contribution"* is a subsidy of 370 CHF/SLU paid to the owner of the livestock (FOAG, 2016), to directly incentivize the appropriation decision of the farmer. Together the two subsidies accounted for 233 Mio. CHF in the year 2014 (Fig 1a). As a result, summering has already increased by nine percent under the new scheme (Fig 1a).

1a.)



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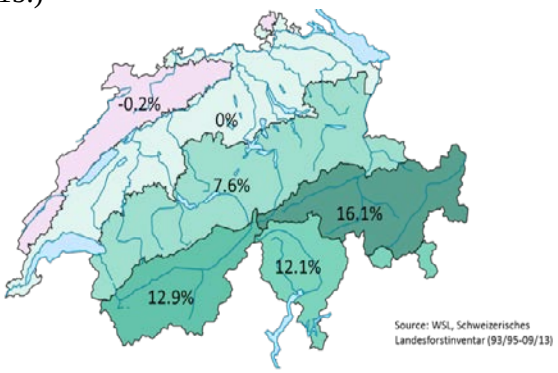

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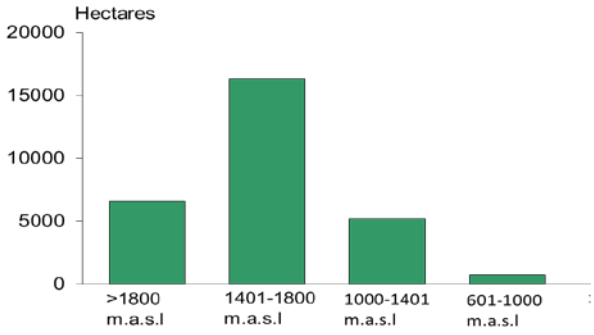

Figure 1a.: Decreasing appropriation levels despite increasing expenditures on subsidies targeting the use of summer pastures in Switzerland (sources: data from 1980-2002 provided by Felix Herzog (Baur *et al.*, 2007), data from 2003 onwards based on official statistics provided by Federal Office for Agriculture (FOAG, 2016). Fig 1b.: Afforestation ratios from 93/95-09/13, in different Swiss regions with significant increase in the mountainous regions (NFI, 2015). Fig 1c.: Topographical distribution of afforestation, suggesting that most of the afforestation is due to land use change occurring below timber line (below1800 m.a.s.l.), while only a minor share of forest regrowth may be associated with upwards shifting timber lines as indicated by the category > 1800 m.a.s.l (NFI, 2015).

Despite increasing subsidies, mountainous regions experienced areal forest regrowth between 8% and 16% (see Fig. 1b) in the past 20 years. As displayed in Fig. 1c, most of this forest regrowth takes place in an altitude between 1400-1800 meters above sea level, which is where summer pastures are typically located (Fig. 1c). These land cover changes indicate that Switzerland faces major challenges to avoid the underuse of CPP (Baur *et al.*, 2007), to maintain the desired landscape patterns, and the diverse set of ecosystem services associated with sustainable used summer pastures (Brunner and Grêt-Regamey, 2016).

2.2 Local governance institutions

Corporate resource management in Switzerland served as an example for successful self-designed institutions that prevent resources from being overused (Netting, 1976; Netting, 1981; Ostrom, 1990). A key function of local self-governance is to assign use rights that define who is to access the resource as well as limiting appropriation activities of the eligible user. In return for their rights to benefit from the resource, individuals are expected to contribute to the maintenance of the respective infrastructure through provision activities which are typically conditional on the appropriation level (Baur and Binder, 2013) or the actual amount of use rights one holds (Landolt and Haller, 2015). As displayed by Fig. 2, such an institutional setting linearly links provision requirements to appropriation levels. And assuming optimality of the institutions, the system is most sustainable, where maximum sustainable yield (MSY) is meet, times the required provision activities (Fig. 2).

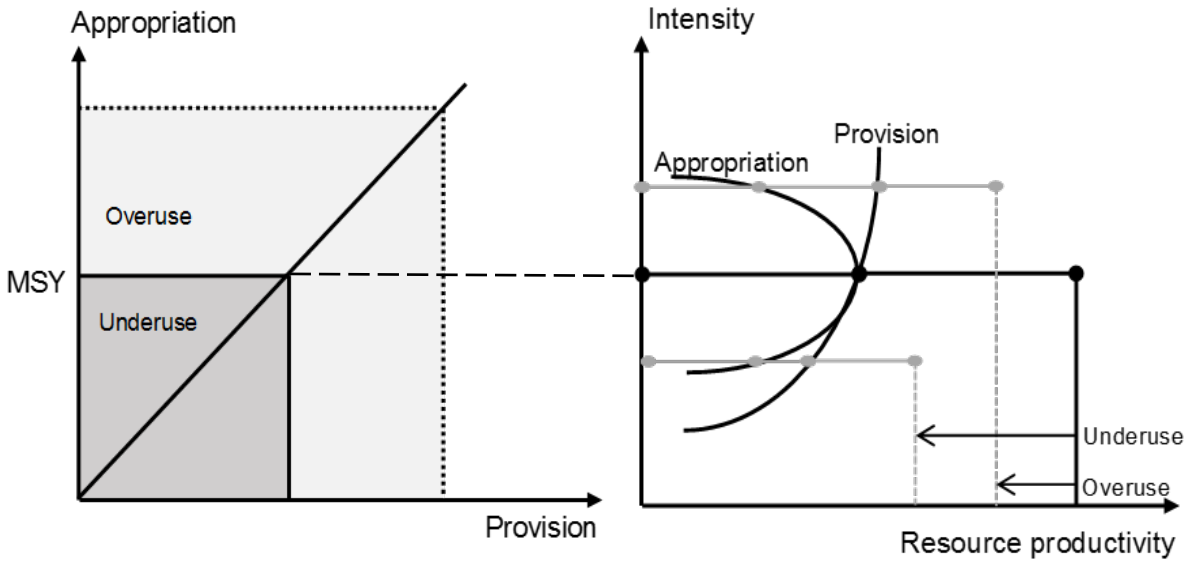

Figure 2. Stylized example of a CPR institution linearly linking appropriation to provision activities, and its effects on resource productivity above and below maximum sustainable yield.

As indicated by Fig. 2, the linear link between appropriation and provision is rather suited to deal with overuse than with underuse. If appropriation moves upwards away from MSY, the adverse effects of over appropriation are moderated by increased provision activities. On the other hand, when appropriation drops beyond MSY, provision also reduces and the negative effect of underuse on

resource productivity is reinforced. Accordingly, the negative effects on resource productivity due to under grazing accompanied by negative effects on resource quality from reduced provision (see Fig. 2).

In the study region, the actual provision requirements for an appropriated unit (the slope in Fig.2a) is defined on the level of the corporation. In Grindelwald there are seven corporations which function as operational units. Six of the seven corporations require 8 hours of communal work per summered livestock unit, while one corporation requires ten hours. Similarly, Corporations define the height of fine for provision defection, which ranges between 24-30 CHF/hours. Furthermore, corporations also vary in the size and productivity of the resource system as reflected by the range in maximum sustainable from 74 to 256 SLU.

3 Methods

3.1 Model development

We abstracted from the case of Grindelwald and built a game theoretical model for the appropriation and provision decision of local farmers using CPP. The model includes parameters describing farmer's attributes, federal subsidies and the local institutions. Accordingly, the model reflects the incentive structure so that the appropriation and provision decisions of the individual lead to payoffs that mirror the real world. In particular, we included the two federal governmental subsidies into our payoff equations (as described in 2.1), and we linked appropriation and provision decisions through the existing appropriation-provision link and the respective fines for provision defections (as described in 2.2).

We computed the Nash equilibria of the resulting interaction which constitutes a "game" in the sense of game theory as individuals' decisions and payoffs are interactively dependent. These we characterize by analyzing the individual appropriation and provision decisions regarding their comparative statics, that is, we evaluate whether higher/lower appropriation and provision result from

marginal changes in the relevant parameters, including individual characteristics such as farm income, local institutional parameters, and federal subsidies. Modeling the relevant interaction "close-to-reality", and thus linking the appropriation and provision decisions is the key novelty of our formal analysis. In particular, we model the appropriation and provision decisions as a two-stage game. First, farmers individually decide on appropriation. Determined by the local institutions, the individual and total appropriation decisions result in a subsidy and fee scheme including individual provision duties that depend on the private appropriation decisions. Second, farmers decide how much to provide and how much to abate by paying fees. Our game-theoretic analysis will solve for the subgame-perfect Nash equilibria of this game.

3.2 Model testing

3.2.1 Data

To test our predictions resulting from the game theoretical model, we rely on data for the study region of Grindelwald, Switzerland from the year 2011. The sample included 95 (76%) of the 125 local farmers. The questionnaire included information on the individual farmer with regards to demographic and economic composition of the farm household, their land-use decision of private and common property, and their income situations. Part of these data have already been used for a previous analysis (Baur *et al.*, 2014). As farmers in Grindelwald organize in seven corporations that enjoy a certain autonomy in rule design, individuals are nested in groups (corporations), with local governance parameters varying across groups.

3.2.2 Statistical procedure

We tested our predictions with regression models. For both appropriation and provision, we estimated two models each – a simple regression model including solely parameters describing the individual, and a mixed effects model to account for variation in local governance parameters. Appropriation was measured as the ratio of animals a farmer sent to graze CPP, we therefore performed OLS for the individual level model, and logit estimates for the group level model. For the

provision models, we proceed similar except that the provision was measured on an ordinal scale ranging from one to five. Therefore, we performed ordered logistic regressions for the individual level models, and mixed effects ordered logistic regressions for the group level model.

4 The behavioral model

4.1 Utility function of appropriation and provision decisions

Suppose society consists of a population N of farmers N=[1,2,...,n]. Farmers i ∈ N are characterized by different livestock endowments $W_i > 0$ and by heterogeneous opportunity costs O_i that determine their non-farm incomes. Each farmer's income is separable into a component that is due to the use of the CPR and a component that is purely private. The latter component is independent of the decisions by others. The former component is an interactive decision, and his commons-related income a function of his appropriation-provision decision and those by others. Therefore, we write $a_i \in 0,1,\dots,W_i$ for farmer i's appropriation decision and $a = \sum_{i \in N} a_i$ for the total appropriation. Similarly, we write $p_i \in [0,1]$ for the level of provision requirements fulfilled by farmer i, and $p = \sum_{i \in N} p_i$ for the total provision. We also write $a_{-i} = a - a_i$, and $p_{-i} = p - p_i$. Accordingly, the farmers' overall utility depends on a two-component structure as defined by the payoffs from his appropriation decisions minus the costs of the resulting provision requirements.

The payoff side consist of the following three sub-components: First, there is the **non-appropriation farming payoff.** This income part increases with the number of cows not appropriated to the commons and with the proportion of non-provision farming activity as expressed by $(1 - p_i) * (W_i - a_i)$. Importantly, this part does not depend on others' choices. The second payoff subcomponents is the **payoff from appropriation subsidies.** As mentioned before, there are to subsidies: one that the farmer receives directly for his appropriation (sub_1) and one that is related to appropriation total and relative to optimum (sub_2) –we write $a_i * a * +(a_i * MSY_c - (MSY_c - a)^2) * sub_2$. Note that this expression contains a squared component, $(MSY_c - a)^2$, which enter negatively. This term models how far total appropriation is from the optimum, and the indirect benefit of improving the resource is

reduced by how far away from the optimum appropriation is. Also, note that this subcomponent depends both on own and other appropriation decisions, as subsidies are paid both directly (as a function of individual appropriation) and indirectly (as a function of total appropriation). Finally, the third payoff subcomponent is the **appropriation farming payoff.** This part of his income increases with his appropriation, with provision, and with the quality of the resource (relative to optimum, depending on total provision) – hence, we write $(a_i * MSY_c - (MSY_c - a)^2 + a_i * p)$

In addition to payoffs, we also model the costs incurred by the farmers' appropriation and provision decisions. Accordingly, costs have two sub-components. First, the cost that result from defection of one's provision requirements, which needs to be settled with a **non-provision fine:** providing less than your actual provision requirement (which is a function of own appropriation and the appropriation of joint users) incurs a fine, providing more than your provision requirements (in principle) provides a benefit – we write $\left((a_i * inst_c - p_i) * F_c\right)$. Secondly, we included **opportunity cost**, that is, foregone income that increases with time spent on provision activities. We can think of this cost representing the income that he would receive from his non-farming activities, to which he allots less time as a function of his provision activities. We write $O_i * p_i^2$ to capture this cost, including a squared term on the provision activity to account for the increasing nature of the foregone income (working one hour less on non-provision may not have a very large marginal effect, but spending almost all the time on provision will have a very large effect at the margin).

Before we can formulate the total utility function, it remains to specify the cost that non-provision will incur as determined by the local institution. Under the provision regime that is currently in place, each unit of appropriation incurs a fix hourly provision requirement, which needs to be fulfilled or abated by a monetary fee. The following formula summarizes this institution:

$$inst_c\colon\ p_i = a_i * \mathrm{c} \qquad (1)$$

Given this policy, in combination with our list of payoff components (payoffs P1-P3) and cost components (costs C1 and C2), this yields the following utility function:

$$u_i = [(1 - p_i) * (W_i - a_i) + a_i * a * sub_1 + (a_i * MSY_c - (MSY_c - a)^2) * sub_2 + (a_i * MSY_c - (MSY_c - a)^2 + a_i * p)] - \left[O_i * p_i^2 + \left((a_i * inst_c - p_i) * F_c\right)\right] \quad (2)$$

4.2 Optimal decisions

Backward induction. The timing of the game is such that the farmer first decides on appropriation, then on provision. Hence, we can solve for the optimal decision using backward induction: given appropriation, we first solve for the optimal provision decision; and then evaluate the optimal appropriation. This will give us the subgame perfect Nash equilibrium of the appropriation-provision game.

Step 1. Optimal provision, given appropriation. Taking first-order conditions yields optimal provision, given appropriation, identified by:

$$p_i^* = \frac{F_c - W_i + 2 * a_i}{2 * O_i} \quad (3)$$

Accordingly: the following comparative statics predictions result from the analysis of p_i:

- F_c: A higher fine increases the incentives to fulfill provision activities. Hence, we expect a positive effect between the height of the fine and provision fulfillment.
- W_i: Larger livestock endowment leads to more workload in valley, hence to less provision. We thus expect a negative effect between of livestock endowment on provision fulfillment.
- a_i: Higher own appropriation increases income and thus the willingness to perform provision activities: We expect a positive effect of appropriation and provision
- O_i: Higher outside option makes paying fine for provision defections relatively cheaper, hence we expect a negative effect of opportunity costs on provision.

Step 2. Optimal appropriation, predicting optimal appropriation. Predicting one's own optimal provision, optimal appropriation then becomes

$$a_i^* = \frac{-1-\frac{\mathrm{W_i}}{\mathrm{O_i}}-a_{-i}*sub_1+3*MSY_c*(sub_2+1)-F_c*inst_c+\frac{F_c}{\mathrm{O_i}}-2*a_{-i}*(sub_2+1)+p_{-i}}{2*\left(1+sub_2-sub_1-\frac{1}{O_i}\right)} \quad (4)$$

Inspection of this formula yields the following comparative statics predictions:

- $inst_c$: Increased provision requirements leads to higher provision duties per appropriated unit, hence to avoid these duties, appropriation is strategically decreased: negative effect between provision requirements an appropriation levels.
- F_c: A higher fee leads to higher cost of defecting on provision duties, hence those with high outside option (if $O_i$high) will avoid these additional costs by lower appropriation levels, while those with low outside option (if $O_i$low) will fulfill their whole provision duties and appropriate at the same or higher levels: Hence we expect a negative effect for high O_i, and positive effect for other O_i
- a_{-i}: Higher appropriation by others makes the land (for the case of under-appropriation) better, hence less incentive to mitigate negative effect on the resource by oneself, expecting a negative effect on provision.
- MSY_c: The better the resource, the higher the incentive to use it, and the higher the cost of falling short of the optimum: positive effect on provision.
- sub_1: increasing this subsidy – similar to the effect of a higher resource quality – makes appropriation more attractive: positive effect (denominator effect dominating numerator effect).
- sub_2: increasing this subsidy makes appropriation and resource quality improvements more attractive. Hence, the incentive to appropriate (in case of under-appropriation) increases: positive effect unless the quality of the resource is very low (i.e. for the case of a low msy, in which case the adverse incentive of reducing appropriation in order to reduce one's provision duty is stronger).
- p_{-i}: higher provision by other increases the yield from the resource, and makes appropriation more attractive: positive effect

- W_i: owning more cows makes the non-provision time spent down more valuable, so that provision becomes costlier. Effectively, farming down in the valley becomes the most attractive option: negative effect
- O_i: Higher outside option reduces appropriation for farmers owning few cows, while it increases appropriation for farmers owning many cows. A farmer who has many cows and a high outside option chooses to appropriate, expecting to not do his provision work, in order not to have to deal with his farming duties at all: positive effect for farmers owning many cows, negative effect for farmers owning few cows.

5 Model testing

5.1 Descriptive statistics

Farmers send most of their livestock to the CPP. With seven farmers restraining from the use of CPP, still 87% of the livestock is appropriated to graze the CPP. With regard to provision duties, very few farmers defect on their obligations. Provision activities measures on a five-level ordinal scale, with farmers indicating if they (1) didn't fulfill any provision duties or much less than he had to; (2) a little less than he had to, (3) the amount he had to, (4) a little more than he had to, or (5) much more than he had to. From the 95 farmers, seven farmers were exempted from provision obligations, and another seven farmers stated that they were not fulfilling all their obligations. The majority of farmers therefore fulfilled their provision duties, and 57% even stated that they conducted more provision activities than required. Considering assets, farmers owned on average 11.6 LU and earned more than double per hours working off-farm compared to on-farm (Table 1).

With regard to local governance parameters, the seven corporations govern differently sized resource systems as reflected by variances of the MSY ranging from 74 LU to 256. While governance parameters such as provision rules are among most corporations set at 8 hours per livestock unit with one corporation requiring 10 hours. Equally the height of fines is relatively homogenous with 5 corporations requiring 25 CHF per hour with one being above 30 CHF and one below 24 CHF.

Table 1.Descriptive statistics

Term abb.	Description	Mean (SD) or Frequency (%)	Appropriation (a_i)		Provision (p_i)	
			Predicted effect	Tested	Predicted effect	Tested
Individual parameters (i) (N=95)						
W_i	Farmers' livestock endowment (LU)	11.6 (7.8)	(–)	Yes	(–)	Yes
a_i	Farmers' appropriation ratio. Endowment divided by net appropriation (LU/SLU)	87.3 (25.5)	/	/	(–)	Yes
p_i	Provision fulfillment level (ordinal variable)	Much more 13 (14.9%) A little more 37 (42.4%) Exact fulfillment 30 (34.5%) A little less 4 (4.6%) Much less/none 3 (3.4%) non-appropriators exempted from provision 7	/	/	/	/
O_i	Farmers' opportunity costs. Ratio of hourly wage of-farm vs on-farm. j	2.2 (2.1)	(–) if W_i large and fee low; (+) if W_i low and fee high	Yes	(–)	Yes
Local governance parameters (c) (7 groups)						
MSY_c	Maximum sustainable yield (SLU)	74, 149, 167, 217, 234, 251, 256	(+)	no[a]	/	/
$inst_c$	Provision rules/requirements (hrs./SLU)	8 (6*), 10	(–)	Yes		
F_c (fine/fee)	Fine for provision defection	24, 25 (5*), 30 20 (2*), 22 (2*), 25 (2*), 29	(–) if O_i high, (+) if O_i low	Yes	(+)	Yes
a_{-i}	Peers appropriation (within group)		(–)	Yes	/	yes
p_{-i}	Peers provision (within group)		(+)	Yes		
Federal governance parameters						
$sub1$	Subsidy for the appropriation paid to the owner of the animal CHF/SLU	370	(+) if a_{-i} high, (–) if a_{-i} low	No[b]	/	/
$sub2$	Subsidy for appropriation paid to the summer farm/cooperative	400	(+) if $MSY_c > a_i > a_{-i}$	No[b]	/	/

[a] Not tested as strongly correlated with a_{-i}. [b] Not tested due to lack of variance in parameter.

5.2 Appropriation

The OLS estimates confirm our predictions from the formal model with regard to the parameters describing the individual. Accordingly, farmers with larger endowments have lower appropriation rates which suggests that it is challenging for larger farmers to fulfil all provision duties if they appropriated all their livestock. Therefore, larger farmers tend to reduce appropriation levels as they can't or don't want to make time to fulfill their provision requirements. Furthermore, farmers using their private land more intensely also depend more heavily on the additional fodder sources available from the CPP and thus show stronger appropriation levels (Fischer *et al.*, 2012; Baur *et al.*, 2014). Farmers achieving a larger share of the income from agricultural then to use the CPP more intensely. As predicted by the model, opportunity costs have a negative effect on appropriation levels for smaller farmers (W_i<11.5 LU) and a positive effect for larger farmers (W_i>11.5 LU). Other variables controlling for livestock composition and social attributes do not significantly affect farmers' appropriation decisions.

Table 1. OLS model predicting appropriation behavior

	OLS	RE
	Coef. (SE)	Coef. (SE)
W_i	-1.07**	-0.97**
	(0.52)	(0.49)
lu_intens	21.89**	20.03**
	(10.32)	(10.11)
farminc	0.25**	0.21*
	(0.12)	(0.12)
O_i	-1.00	-1.45
	(1.52)	(1.5)
O_i (small N=38)	8.18*	
	(4.746)	
O_i (large N=41)	-3.19*	
	(1.673)	
livest_small	-0.23	-0.27
	(0.21)	(0.2)
livest_young	0.26	0.1
	(0.66)	(0.63)
leadership	-0.71	-1.3
	(5.71)	(5.61)
succ_d	6.05	5.61
	(5.78)	(5.34)
yrs_left	0.20	0.26
	(0.26)	(0.26)
$inst_c$		3.07
		(3.35)

F_c		0.16
		(1.44)
a_{-i}		-0.02
		(0.05)
p_{-i}		30.26
		(52.03)
Constant	69.21***	19.95
	(12.65)	(47.04)
Observations	86	86
R-squared	0.148	
Number of groups		7
p		0.351
chi2		14.32

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

With regard to group parameters the random effects model (RE) did not show significant effects but direction of the effects is in line with the predictions. Accordingly, individuals' appropriation levels decrease with group appropriation levels and increases with group provision. Provision requirements ($inst_c$) was the only variable that did not show the expected effect. Accordingly, farmers would increase appropriation as provision requirements increase, but the effect is likely to be coincidental because of low variance.

5.3 Provision

Concerning provision, none of the predictions from the comparative statics were confirmed with significant effects in the regression analysis, but all the parameters describing the individual showed the expected directions. Accordingly, herd size and opportunity costs had a negative effect on provision fulfillment, suggesting that the workload form additional livestock reduced time to fulfill provision requirements. Also, higher opportunity costs had a slight negative effect on provision as paying a fine becomes more attractive with increased opportunity costs. In turn, appropriation levels increase provision fulfillment suggesting that farmers who appropriate intensely also feel more obligated towards contributing for the upkeep of CPP.

Table 2. Log likelihood estimation predicting provision behavior

	Ologit	Mixed-effects
	Coef (SE)	Coef (SE)
W_i	-0.01	-0.02
	(0.04)	(0.05)
a_i	0.43	0.02
	(1.14)	(0.01)
lu_intens	1.18	1.37
	(0.12)	(0.88)
farminc	-0.01	-0.01
	(0.01)	(0.01)
O_i	-0.14	-0.12
	(0.12)	(0.12)
succ_d	0.52	0.49
	(0.52)	(0.52)
y_left	-0.02	-0.02
	(0.02)	(0.02)
$inst_c$		-0.18
		(0.29)
F_c		-0.04
		(0.1)
a_{-i}		0.37
		(0.42)
N	84	84
Number of groups		7
p>Chi	0.18	0.59
Log likelihood	-96.36	-95.69

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Concerning local governance variables, we expected that a higher fine would increase provision, which was not confirmed. Instead increased fines had a slightly negative effect on provision fulfillment, which again is likely to result from small variance in the fines.

6 Policy Options

6.1 Local Governance

Recalling the logic of current local governance institutions linking appropriation and provision proportionally. Hereby, the overall provision requirements increase linearly with appropriation.

Defections on those provision requirements (or exceeding it) is sanctioned (sponsored) with fixed hourly wages. This local institution promised success in situations where the resource is prone to over-appropriation, as the adverse effects of overuse, that is where $\sum_{i \in N} a_i > MSY_c$, is mitigated for two reasons. First, the negative effects of overgrazing gets (partially) offset by increased provision levels. Second, the additional provision requirements incurred by appropriating an additional unit limits activity at the margin. In a setting where underuse of the CPR becomes a problem, the linear link between appropriation and provision in combination with principles of diminishing marginality utility results in suboptimal incentive structure. As the analysis and data indicate, such an institution creates strategic incentives not to appropriate to avoid additional provision costs. Hence, in a situation where $\sum_{i \in N} a_i < MSY_c$ such a provision institution reduces incentives for both appropriation and provision, and reinforces the adverse effects of underuse.

As a consequence, we suggest to reformulate the appropriation-provision link, to increase the incentive to appropriate at the margin. This could be done by setting the provision requirements marginally in relation to the total appropriation. Then, each additional cow costs marginally less, just like in bulk pricing – higher quantities cost marginally less than smaller quantities. In particular, if $\sum_{i \in N} a_i < MSY_c$, then sending up an additional cow should incur a proportionally lower provision requirement than if $\sum_{i \in N} a_i > MSY_c$. This can be implemented via the following incremental quantity-based provision requirements system: (Denote by a_i^k the k-th appropriated unit by farmer i, and by $inst_c(a_i^k)$ the provision requirements for this appropriated unit is therefore,

$inst_c(a_i^k) = inst_c(\left(\frac{MSY_c}{n} - k\right)^2)$, so that the total provision requirements become

$$inst_c = \sum_{\{k=1,2,\ldots,a_i\}} inst_c\,(a_i^k)$$

Notice that appropriating the k-th cow such that one's own contribution to achieving the MSY is exactly met, incurs no additional provision requirement. As a result, the negative link (avoiding provision by reducing appropriation) is broken up, and each individual has an incentive to appropriate at the margin. Such a reformulated local institution can be expected to resolve the effect that farmers

with larger endowments show lower appropriation levels, and therefore helps mitigating both the under-appropriation and the under-provision problem.

6.2 Federal Governance

On the federal governance level, a policy reform could be implemented by re-designing the subsidies. Our model predicted a positive effect for both of these subsidies, unless the quality of the pasture declined and reduces MSY, in which case sub_2 had a negative effect. However, both $sub_1$and sub_2 could be redesigned to mitigate the problem of under-appropriation more efficiently when being paid marginally by livestock units instead of a constant rate. Currently, this idea is partially realized in the design of Sub2, as payments are reduced if above overall appropriation is above 110% or below 80% of MSY. However, it would be more efficient to have both subsidies designed in accordance with the principles of marginality. Similar to the incremental quantity-based system proposed for re-designing the provision requirements above, federal subsidies should consider incremental direct and communal quantity-based subsidies:

Sub1: (direct subsidy): $sub_1(a_i^k) = sub(\left(\frac{MSY_c}{n} - k\right)^2)$, so that the total direct subsidy received is;

$$sub_1 = \sum_{\{k=1,2,\dots,a\}} sub(a_i^k)$$

Sub2: (communal subsidy): $sub_2(a^k) = sub_2((MSY_c - k)^2)$, so that the total becomes;

$$sub_2 = \sum_{\{k=1,2,\dots,a\}} sub\left(a^k\right)$$

As with Policy 2, these staggered subsidies that peak around MSY, would mitigate the under-appropriation problem, and, in combination the redesigned local institution, also the under-provision issue.

7 Discussion and Conclusion

Since Netting's (1976) seminal study, the Swiss alpine grazing commons have been heralded as one of the prime counterexamples of "tragedy of the commons" predicted by Hardin (1968). The fact that they have been managed successfully and that over-appropriation has been avoided for centuries, has inspired a lot of work aimed at identifying the principles for successful community based governance of natural resources. What eluded the attention of many researchers who mention the Swiss alpine commons is that they have begun to suffer from the new problem of underuse. Only through massive targeted subsidies, and other measures such as "importing" cows from the lowlands the grazing of alpine common property pastures is maintained.

In this study, we explored how individual attributes, local and federal governance measures affect farmers' use of CPP with regards to their appropriation and provision behavior. The crucial innovation of our analysis is to link appropriation and provision decisions in a unified game-theoretic model. This is an essential modeling aspect, because local governance systems typically enforce rules that link provision requirements to the individuals' appropriation activities. In such a constellation, each user will carefully evaluate whether the benefits from appropriation will pay off the costs of associated provision activities. Hence, we study these two situations in conjunction, and in game-theoretic language solve for these decisions in terms of strategic subgame perfection. Previous game-theoretical models did not link these two decisions. When no institution is in place, this is the right approach, but once an institution is in place, these two decisions become strategically interlinked. In any CPR setting, such an institution may lead a user to restrain from appropriation in order to save on provision costs which is a particular problem when the resource systems are adversely affected from underuse.

Furthermore, our empirical analysis is a first attempt of pursuing a serious in-the-field validation of the theoretical results. Overall our regression analysis validated the model predictions regarding appropriation. Results concerning provision validated certain aspects qualitatively, but these effects were not statistically significant. The scope of the regression analysis, however, suffers from two problems. First, we worked with a rather small sample of farmers. Second, the group-specific

local governance parameters did not encompass sufficient variance to produce solid robust effects in the nested models. Nevertheless, we still suggest that with a larger sample the local governance parameters such as provision requirements, the height of the fine or the role maximum sustainable yield could be confirmed.

The effect of individual attributes on appropriation and provision behavior. On the level of the individual, we found that the individual reduces appropriation with increasing endowment and opportunity costs in the case of small farmers while the opposite effect exists for larger farmers. The strongest effect was found for land use intensity, as farmers using their private land intensely are more dependent on additional fodder sources such as CPP. Concerning provision, we expected that the individual parameter herd size has and opportunity costs have negative effect on provision fulfillment. Although the regression models confirmed the direction of the relationship, effects were non-significant.

Considering trends in the agricultural sector with increasing endowment (+16% from 2000-2014), increasing opportunity costs (+5% from 2000-2014), and slightly decreasing land use intensities (-3.7% from 2000-2014) (Agroscope, 2000-2014; FSO, 2016) all significant parameters on the individual level are currently developing as to reduce farmers appropriation levels. Therefore, the sustainability of CPP will be even more dependent on the incentives shaped by local and federal governance to stimulate appropriation and provision.

Adapting local governance institutions to avoid underuse. With regard to federal governance, the theoretical model suggested that farmers increase appropriation if provision requirements are lower, and when fines for non-provision are reduced especially for farmers with lower opportunity costs. With regard to provision behavior, the formal model suggested that higher fines positively affect provision fulfillment. Although the regression model showed the expected direction for the individual parameters, effects were non-significant. For the fines, the regression even suggests that an increase in the fines will lead to higher defection rates on provision, but this effect may be due to insufficient variance in the height of fines. Therefore, validation of the assumptions on local governance policies

on provision behavior would require larger datasets with more intergroup variance in local governance parameters.

Local governance parameters showed no significant effects in the regression analysis, but this may be due to insufficient variance. Nevertheless we demonstrated that local governance systems could improve their incentive structure to foster appropriation by making use of the principles of marginality. Instead of requiring just a fixed amount of labor hours per appropriated unit, the institutions should be designed as to lower the marginal provision requirements as a function of total appropriation. Given that total appropriation is too low, one should make higher individual appropriation "cheaper" by lowering provision requirements for every additional appropriated unit.

Improving the efficiency of federal governance incentives. Our theoretical model suggested that both subsidies incentivize appropriation. Although we could not test the actual effect on the appropriation decision of the farmers it is indisputable that subsidies increase payoff and thereby incentivize appropriation. The question is rather if the two subsidies in place are the most efficient in stimulating the use of CPP. Our analysis suggested that federal governance could improve its efficiency by changing the relative height of the subsidy (Sub1 < Sub2), and by making use of marginality principles again. The design of Sub2 is an initial attempt to implement this, given the reduction in payments when total appropriation is too far from MSY. Such efforts to include marginality into the policy design should be extended to Sub1 to increase the efficiency of the governance expenditures.

Limitations future avenues for behavioral studies in the Commons. Our findings are limited to common pool settings where appropriation and provision are institutionally linked in a particular way as given by the present-day institutional setting in Switzerland. Although that link is considered key to successful local governance (Cox *et al.*, 2010; Wilson *et al.*, 2013), many social-ecological system may function without an institutional arrangement linking appropriation and provision. For such settings, the implications of our results are less relevant. However, in our analysis we have argued that adhering to principles of marginality in designing the appropriation-provision link may provide an option for local governance to fine tune institutions to better steer appropriation towards optimal use.

Another limitation of our study was the fact that our model of human decision-making assumes standard (rational and selfish) economic decision-making. Provided that our model captures the relevant structural parameters of the decision-making, the residuals in the regression models suggest that other decision factors are at play, including strong presence of other social motives beyond economic rationales (Levine *et al.*, 2015). For example the experimental literature shows that variables including norms (Camerer and Fehr, 2004; Bicchieri, 2006), inequality aversion (Blanco *et al.*, 2011), reciprocity (Fischbacher et al., 2001), amongst other factors (Nax et al., 2015; Nax et al., 2016), can influence behavior beyond economic rationality. Other more complex models for farmers' decision making highlight the role of variables such as norms (Feola and Binder, 2010), and attitudes (Burton and Wilson, 2006). Future behavioral research, including experimental and applied empirical approaches will require continuous efforts to integrate the variety of non-pecuniary motives, and other factors interfering with rationality to produce more robust empirically based models of behavior in common-pool resource dilemmas.

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