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Managing Wild Resources: Institutional Choice and the Recovery of Resource Rent in Southwest China ☆

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Summary. — Managing harvests from natural resource systems is often seen as necessary to recover resource rent, that is, for wise and sustainable use. This paper develops a method to estimate resource rent recovery for a class of nontimber forest products and, using a unique dataset on the harvest of wild mushrooms in southwestern China, we empirically estimate this in open access, common access, and privately managed forests. We show that villages that lack rules (open access) do not always perform poorly. We explore how geographic context, resource endowments, transaction costs, and institutional goals may drive incentives for developing self-governing institutions.

Key words — institutional choice, nontimber forest products, resource rent, matsutake mushroom, China, Asia

1. INTRODUCTION

Much of natural resource economics is devoted to analyzing three classic management regimes: open access, common property, and private ownership. Early theoretical work laid the basis for these categories (Cheung, 1970; Faustmann, 1849; Gordon, 1954) highlighting the implications of these institutional settings for generating the full potential value of the natural resource, that is, for recovering resource rent. Comparison of institutions and various measures of their relative performance is common, but empirical quantification of how well communities recover resource rent in each setting is seemingly absent for resources other than fisheries (e.g., Sinan & Whitmarsh, 2010). Yet this is the fundamental issue we must address to understand how well wild resources are managed.

This paper makes two contributions to the literature on natural resource management and institutional choice. First, we develop a method to empirically evaluate resource rent recovery for a class of nontimber forest products (NTFPs). This class includes species of mushrooms, fruits, nuts, berries, bamboo, and medicinal plants, which we refer to collectively as "wild harvestable flora" (WHF), and is likely the largest and most important group of wild harvested species in developing regions of the world. NTFPs provide livelihood support for around one fourth of the world's population (Food and Agriculture Organization, 2008), making their harvest dramatically underexplored in the natural resource economics and bioeconomic literature. Second, we construct a unique dataset through original fieldwork and apply the method for evaluating rent recovery to the harvest of wild matsutake mushrooms in rural southwestern China. In these cases, bridging bioeconomic theory and community-level empirics requires careful consideration of the larger socio-economic context.

We are able to make these empirical and methodological contributions for several reasons. First, we investigate a situation in which all three classic management regimes exist in a similar setting for a single resource, the matsutake mushroom harvested from villages in Yunnan, China. Second, the bioeconomics of our class of NTFPs allow us to empirically estimate a feasible index for resource rent, as we will discuss in depth below. This index relies on two features of WHF. First, biological growth or productivity is not impacted by harvests and, second, markets pay more for mature products. Our index calculates the proportion of the maximum attainable revenue a harvesting system recovers.

This study also provides practical insight for development practitioners. Resource management institutions are often promoted as a win–win solution for local livelihoods and the

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environment, a notion that is supported by theoretical literature that stresses the need for clear "rules of use" for sustainable local management (Berkes, 1989; Klooster, 2000). Projects that help communities develop such rules fundamentally assume communities without resource management institutions squander the potential value of their resources, value that could otherwise be captured to improve rural livelihoods. That is, when rules are absent, resource use is assumed unsustainable or otherwise wasteful. This research questions these assumptions and may help clarify why many projects that intend to foster community-based management are unsuccessful (Blaikie, 2006; Larson & Soto, 2008; Leach, Mearns, & Scoones, 1999; Morrow & Hull, 1996; Songorwa, 1999). Decades of research emphasize that context matters for successful collective action (Bromley, 1992; Olson, 1965; Ostrom, 1990; Poteete, Janssen, & Ostrom, 2010), and here we provide evidence that a *lack* of rules (*res nullius*) can also be a conscious collective institutional choice based on local costs and benefits of developing, implementing, and enforcing regulations.

The next sections of the paper sketch out the bioeconomic theory of WHF and explain how we calculate our index of resource rent. We then describe the setting, data, and methods used in our empirical application. After presenting results from our empirical cases we explore hypotheses for villages' choice of management institutions. The final section concludes with a summary of our findings, a discussion of the endogeneity of institutional choice and resource endowments, and a reflection on the classic resource harvest model.

2. BIOECONOMICS OF WILD HARVESTABLE FLORA

The bioeconomic open access harvest framework (Clark, 1990; Gordon, 1954) has been applied to NTFPs as a general category (e.g., Gunatileke & Chakravorty, 2003; López-Feldman, Mora, & Taylor, 2007; Robinson, Albers, & Williams, 2008). But the term "nontimber forest product" is rooted in context, not biology, and refers to a variety of resources (Belcher, 2003). Here we focus on a class of NTFPs we call wild harvestable flora (WHF), which includes species of fruits, berries, nuts, and mushrooms, among others. These NTFPs have several features that cause resource rent to be positively correlated with the average price of harvested units, as observed in local markets. This result is not typical of other resources, and implies that the ratio of the observed average price of an individual to an expected "best" price is a measure of the relative efficiency of the management regime. To get to this result requires several steps, the details of which we discuss in this section. Intuitively, these NTFPs grow quickly enough that it should make sense for harvesters to only harvest mature specimens. If there is no good reason to harvest early, then each individual specimen has the potential to achieve its full potential price, and we use this potential price as a benchmark for how well a harvest system performs.

In more detail, the first relevant feature of these NTFPs is that they ripen or mature within a harvest season, and price increases in response, so harvesters can increase revenue by choosing to postpone harvesting individual specimens. The decision to harvest a specimen is a decision problem weighing the benefits and costs of postponing harvest. The benefit of postponement is obvious—a higher price; the cost includes the cost of returning to harvest and the possibility that another harvester will find the specimen and harvest it first. Since age is positively correlated with price and is thus fundamental to the harvesting decision-making process, for this class of resources we must explicitly consider age cohort dynamics. The Appendix presents a simple mathematical treatment of the harvester's decision problem.

Second, and unlike many renewable resources such as fisheries, harvests of this class of NTFPs have little impact on the stock's rate of reproduction, so that the stock available in the future is effectively independent of the current harvest rate. Certainly if harvested rates are high enough, the population's reproductive capacity can be compromised since disturbance of any part of the life cycle of a species has an impact on future production (Peters, 1994). However, harvests of fruits, seeds, nuts, bamboo, and mushrooms can be sustained at very high rates without appreciably affecting the communities' population structure. Ticktin (2004) reviews population dynamic studies of the impact of fruit and seed harvests, which estimate sustainable harvest rates of 80-93% depending on the species. Emanuel, Shackleton, and Baxter (2005) estimate 92% of marula fruit can be harvested without impacting the population profile of marula trees. A multi-decade study of mushroom harvests shows fruiting is closely correlated with climactic factors, but not harvest rates (Straatsma, Ayer, & Egli, 2001), and a publication from an updated version of this dataset is even titled "Mushroom picking does not impair future harvests" (Egli, Peter, Buser, Stahel, & Ayer, 2006). Another decade-long study shows similar results as long as harvesters do not unnecessarily disturb the soil during harvests (Luoma *et al.*, 2006). Thus while harvests by definition interfere with resources' life cycle, in most empirical settings we find little evidence that normal harvests from this class of NTFPs has an appreciable impact on the harvestable stock in following seasons. Therefore, our theoretical argument here assumes harvest rates below what might threaten the sustainability of the resource. But these rates are quite high, with the available evidence showing harvesters can remove at least 80% of the fruiting bodies or propagules without adversely affecting future production.

Empirically, this allows us to use the value of the best resources observed in a community as a theoretical benchmark for the maximum average revenue attainable per specimen, which we cannot assume in the traditional case. For example, consider a deer population where older males are most valuable to hunters. Harvesting the maximum quantity of only large bucks is not an optimal strategy due to inter-seasonal deer population dynamics (e.g., Jensen, 1996). Similarly, one would not aim to only fish for older salmon since they have greater reproductive capacity relative to younger fish (Forbes & Peterman, 1994). In these cases one must understand the resource's population dynamics to derive an optimal harvest strategy over different population cohorts. For our class of NTFPs, by contrast, harvesting the greatest number of the most valuable cohort is a rent-maximizing strategy that, in most empirical cases, is also sustainable. Further, for the resources considered here, a user cost only arises from harvesting individual resources several days or weeks too early (an *intra*-seasonal effect), so we can effectively ignore time discounting and focus on current rents to understand a system's efficiency.

A third feature of WHF, an assumption shared with the standard model, is that marginal costs (effort) monotonically increase with increasing aggregate quantity harvested. As community harvest effort increases, search costs increase from crowding and competition in the harvest labor force. That is, finding greater quantities of resources means individual harvesters must spend more time finding the next unit of resource, driving up the average search cost per unit resource. The goal of management, as in the traditional resource model, is to limit aggregate effort in the harvest system.

Together these three features imply a particular relationship with an empirical implication: The higher the average price per unit received, the greater the current resource rent, and the closer the value of harvests to its maximum value. The empirical implication of this result is that it presents an opportunity to make ordinal comparisons between harvesting communities at relatively low cost. All that is required is the average unit price received by harvesters within each community, which is a relatively easy piece of information to obtain.

This relationship between average price, current resource rent, and the value of the resource is not generally true for all renewable resources. Consider current-period harvests for the usual "textbook" case, shown in panel (a) in Figure 1. Prices are exogenous, so average revenue (AR), marginal revenue (MR), and the per-unit price (P) are constant and equal for all quantities (Q). Average and marginal harvest costs (AHC and MHC) are initially constant with quantity until harvest labor "saturates" the system such that harvests become rival. As competition increases, finding a unit of biomass takes more effort. Therefore, the AHC and MHC of, say, catching fish rise. Total marginal cost (MC) is the sum of MHC and the marginal user cost (MUC), which is the opportunity cost of harvesting biomass today at the expense of letting that biomass contribute to growth into the future, and in the traditional model is a function of the growth of total biomass. Here we distinguish between two sources of biomass accumulation in the resource population: biomass accumulation due to growth of individual organisms (i) and biomass accumulation due to reproductive population growth (r) so that MC = MHC + MUC(i,r). MUC is greater than 0 for any Q greater than 0 since even for the first unit harvest there is a cost associated with giving up the value of an individual organism's future growth (MUC(i) > 0). In this classic model, MUC(r) increases with quantity so the total MC curve slopes upward even when MHC are constant. The harvest quantity

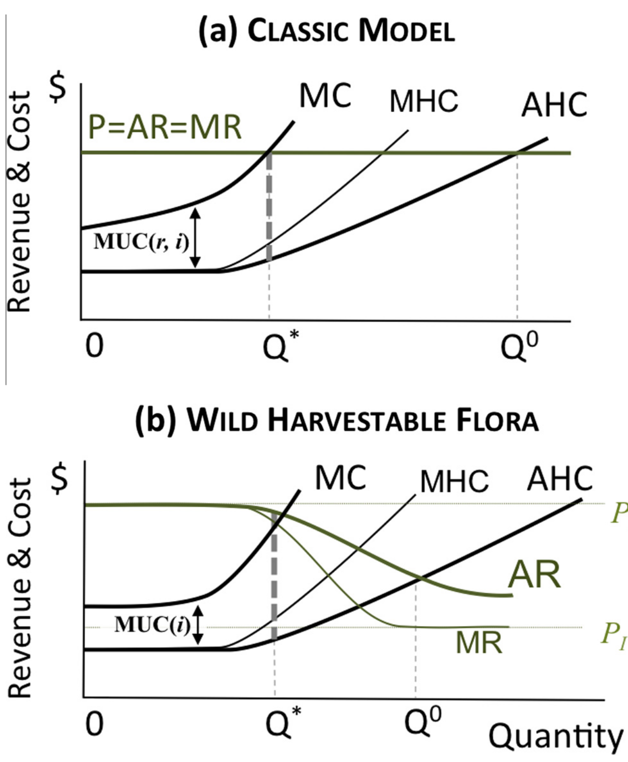

Figure 1. *Current-period harvests. Notes: AR = average revenue; MR = marginal revenue; Q = harvest quantity; AHC = average harvest costs; MHC = marginal harvest cost; MC = marginal cost; MUC = marginal user cost; i = individual component; r = reproductive component. Note Q^* is where MR = MC.*

that maximizes rent (Q^*) is where MR equals MC. The thick dashed gray line represents average rents (AR–AHC). Complete dissipation of extra-normal resource profits in the current period occurs at harvest level Q^0, where average harvest cost (AHC) equals average revenue (AR).

In contrast to the textbook treatment, consider instead the case for wild flora with the characteristics described above, shown in panel (b) of Figure 1. In this model, we separate the per-unit price to reflect two resource cohorts: mature and immature specimens (though the results apply generally to multiple cohorts). Mature resources are sold at a per-unit price P_M, and immature resource at price P_I. The optimal strategy at low harvest quantities (relative to its population size) is to take only mature fruit, in which case average and marginal revenue are equal at the mature price P_M. In this current-period framework, to harvest higher quantities one must begin to pick less valuable immature specimens, so marginal and average revenue decrease. To harvest at higher quantity levels, harvesters pick any specimen they find. Average harvest cost rises, as in the traditional model, perhaps in part because the opportunity cost of harvest labor increases,[1] but mostly we are thinking of the competition effect described above. The fact that current harvesting has no appreciable effect on future stock implies that marginal user cost is only a function of individual growth: MUC(i). That is, the marginal user cost is only the opportunity cost of harvesting an individual today and forgoing the future net benefits that could come from allowing that specimen to grow to maturity, and is now divorced from the reproductive potential of that specimen. Again, this is an important distinction from the classic model—since harvests do not affect the population's reproductive capacity (and therefore future productivity), we can focus on current harvest and use the best specimens observed in a market as a benchmark for the idealized best possible outcome.

In panel (b) the average resource rent, which is the difference between average harvest cost and average revenue (AR–AHC), is maximized at the harvest level Q^*, where MC = MR, and falls monotonically until it dissipates completely at Q^0, where AHC = AR. Standard economic thinking implies this is the relevant economic range of harvest. A single owner of the resource would harvest at Q^*, and regimes that relax property rights over the resource invite excess effort as harvesters compete to capture rent.

As shown in panel (b) of Figure 1, a key feature of this class of resources is that resource rent is monotonically related to average revenue (average price), which is perhaps the most readily available economic datum in the system. Because we know the maximum average revenue attainable in the system (the expected price of a high-quality specimen) we can judge how effectively a community captures resource rent by the proportion of maximum revenue (PMR) captured in a system. We discuss empirical calculation of PMR in the next section.

This is not the case in the classic model of renewable resource exploitation, in which, at a given stock level, average revenue is equal to price, which is constant. Attempting instead to develop an index based on costs is generally problematic because rent is maximized where marginal cost is equal to price, but calculating marginal cost requires calculating marginal harvest cost *and* marginal user cost, for which we must understand the inter-seasonal dynamics of the system. To make this point another way, consider the classic fisheries model. Two regimes with different stock levels have different MHC and MUC and so comparing rent capture between the two systems requires accurate knowledge of not only harvest costs, but also the stock level *and* population dynamics of the fishery. The ceteris paribus implied by panel (b) in Figure 1 is violated *structurally*, even if the cost and revenue fundamentals are the same across two regimes, simply because the underlying stocks are different. So compared to the case of WHF, the classical case requires far more information to assert the relative efficiency of the regime and even comparison within the same fishery over time becomes problematic.

In calculating the PMR from panel (b), we can use the *observable* average revenue as an index of efficiency since it is correlated with rents, which relies on the fact that future stock is not affected by current harvests. Further, structural changes in the system may affect the absolute rents available, but a proportional comparison still captures how well communities capitalize on their resource endowments given the prices they face.

3. CALCULATING THE PROPORTION OF MAXIMUM REVENUE (PMR)

We identify the effectiveness of a harvest community by the percent of potential revenue a system captures given the institutions it enforces. That is, if a community only harvests resources that sell for the highest prices, it is said to capture 100% of the potential revenue available. If some specimens are harvested that have not reached their optimal state, then the revenue captured is less than its full potential.

To make observations across harvest communities comparable, two main empirical issues must be addressed. First, resource productivity may vary geographically so that the total quantity of resources harvested may vary between communities. To normalize the magnitude of harvests we use the empirical probability distribution of the harvested product's age so that the sum probability of observing any given age is equal to one.

Second, prices may vary across communities. To control for such variation one can normalize age-specific prices by the maximum expected price within a harvest community and then multiply the vector of age probability densities by the normalized vector of associated age-specific prices. This gives the proportion of the maximum revenue captured. Setting the maximum expected price equal to one ensures that, when multiplied by the proportion of products sold at that price, the maximum revenue that can be "achieved" is 100%. In this way incentives for collecting various cohorts of resources within a harvest community are preserved, but the *proportion of maximum revenue* results in a measure of the harvest value that is comparable across harvest communities.

4. EMPIRICAL APPLICATION

The matsutake mushroom (*Tricholoma matsutake*) grows wild in pine and oak forests in Yunnan, China, and has become an important element of the local economy. Demand for matsutake comes almost solely from Japan, where it is highly prized for its iconic and medicinal properties. This results in farm gate prices that earn some villages 70% of their annual cash income (He, 2003).

In this part of Yunnan, many villages have *de jure* communal rights over forest use (Rozelle, Huang, & Benziger, 2003; Su, Zhao, Gan, Xu, & Ren, 2008; Weyerhaeuser, Kahrl, & Yufang, 2006). These communal rights include the autonomy to develop village-level rules for NTFP management (He, 2003; Salick, Yang, & Amend, 2005; Yeh, 2000). Since villages have the explicit ability to self-monitor and enforce their own rules of use, in this study we explicitly focus on *de facto* institutions practiced within each village. Some villages in the area have gone through Forest Tenure Reform, a national policy initiative through which households sign 30–70 year contracts for use rights over forest plots (Xu & Jiang, 2009). Thus the villages sampled in this study fall into one of three types of matsutake management: open access (no matsutake-related rules in their communal forest), common access (only village members can harvest in their communal forest) and private access (household-based use rights to forest plots).

Our data consist of harvest information from 13 rural villages in northwest Yunnan and includes 6,770 mushroom observations and 256 household questionnaires. Descriptive statistics for these villages are given in Table 1. Some have nominal restrictions prohibiting the harvest of "small" mushrooms. In practice, however, most residents could not specify what is meant by "small," and we never observed enforcement of this rule. Many villages have additional rules excluding livestock from forests, and against using pesticides or pesticide bags to prevent contamination of matsutake, which is valued for its natural and wild properties, but none of these were observed to affect harvesting decisions in practice. In the sample of villages, most residents are Chinese ethnic minorities, with about half being ethnically Tibetan.

Matsutake mushrooms are the fruiting body of an underground network of mycelia (Allen, 1991; Hosford, Plitz, Molina, & Amaranthus, 1997; Wang, Hall, & Evans, 1997), which sprouts with the biological purpose of spore dispersal, but is not a vital part of the organism as a whole. So picking the mushroom is like picking fruit from a tree and, as noted above, decade-long studies of such mushrooms, including the American matsutake (*Tricholoma magnivelare*), show no relationship between mushroom harvest rates and future fruiting productivity (Egli *et al*., 2006; Luoma *et al*., 2006; Norvell, 1995; Straatsma *et al*., 2001). In relation to the bioeconomics of WHF, this implies that matsutake satisfy the first bioeconomic criteria for WHF established above, that current harvest practices have no discernable impact on the future rate of productivity of a mycelial colony. There are no biological studies of matsutake fruiting rates or productivity specific to our study sites, but Yang *et al*. (2008) present data on matsutake exports from the region over an eight-year period. During this time export quantity varies dramatically despite increasing or constant levels of collection effort, thus showing no apparent correlation between harvests and future productivity. This at least gives us no reason to question that harvests of matsutake in Yunnan can be considered "normal."

The second criterion dictates that rent dissipation occurs from harvesting the resource too early. For matsutake we take the size of the mushroom as a proxy for its age. Figure 2 shows the average price for a given mushroom length over all mushrooms in our dataset showing, on average, higher prices are paid for larger individual matsutake mushrooms. Additionally, the bioeconomic theory presented above predicts that open access systems harvest the smallest mushrooms, common access forests harvest slightly larger mushrooms, and private systems allow mushrooms to grow to their economic optimum (see the Appendix for a mathematical argument). We will return to the third criterion, that costs increase with decreasing revenues, at the end of the paper. Matsutake take five to eight days to go from an immature to mature state, making time-discounting irrelevant. [2]

5. DATA & METHODS

(a) *Village markets*

Data were collected during the summer of 2008 and 2009 for 13 villages in northwestern Yunnan Province, China.

Table 1. *Village descriptive information*

Village name	Institutional system	Rules	Pop density (ppl/km^2)	Elevation	Nonresidents	
					Nonresid allowed? Is there a fee?	# Nonresid/year
1. Gezan	Common access	Only village residents can pick, cannot pick small ones (not specific)	2–5	3,113	No	
2. Haitangwa	Private	Nonharvest seasons no one can enter matsutake forest; no firewood, pine needles or livestock in forest; don't steal matsutake; no fires; no tourists; contracts individually arranged	>50	3,250	No	
3. Shanglehe	Open access	None	>50	2,075	Yes	50–60
4. Xiagezan	Common access	Only village residents can pick, no small ones (not specific)	2–5	3,230	No	
5. Wengshui	Common access	Only village residents can pick, no small ones (not specific)	2–5	3,255	Yes, few hundred per person	A few
6. Jiangdong	Common access	Only village residents, no metal to harvest, no pesticide bag to cover matsutake, cannot harvest <5 cm, no cows or cutting trees in forest	6–9	1,968	Yes, few hundred per person per year	~10
7. Xinhua	Contracted	Forests contracted to families via lottery system, groups randomly assigned	>50	3,000	No	
8. Bamei	Open access	None	2–4	2,490	Yes	?
9. Adong	Common access, rest day	Only village residents, (voluntary) rest day on sunday, no cows in forest	5–10	3,235	Yes, few hundred per day	None
10. Miheimen	Private/contracted	Village forest contracted to households	>50	2,548	No	
11. Wujie	Private	Private household forest	>50	2,400	No	
12. Lizui	Open access	None (currently)	2–5	2,800	Yes	1 or 2
13. Jidi	Common access	Only village residents can pick, no small ones (not specific)	5–15	3,400	No	

Matsutake mushroom buyers separate mushrooms into g grades of quality with a per-weight price p_g. While grades are quality-based, smaller mushrooms are generally sorted into lower grades while bigger mushrooms go to higher grades, and most buyers separate mushrooms into two to four grades. Markets observed had at a minimum two buyers and the largest markets accommodate up to 20 buyers in formal seller stalls, but the majority of village markets had four to eight buyers.

(b) *Mushroom length distributions*

We primarily use photographs of buyers' mushroom purchases as a sample of village harvests. From a ruler placed on top of buyers' mushroom baskets, we measure the length x of fully visible mushrooms. A village sample of mushrooms is first binned into two-centimeter length bins $c = \{1 < x \leqslant 3, 3 < x \leqslant 5, \ldots, q-2 < x \leqslant q\}$, where q is the maximum length observed. Frequencies are then tabulated into a grade-specific probability distribution. Within village v, the probability that a mushroom in grade g is between length a and b is $P_{vg}[a \leqslant x \leqslant b] = \int_a^b f_{vg}(x)\mathrm{d}x$, where $f_{vg}(x)$ is the observed length distribution within village v for mushroom grade g. Call the vector of grade-specific frequencies in two-cm length bins within a village $\mathbf{f}_{vg} = \{f_{vg,1}, f_{vg,2}, \ldots, f_{vg,C}\}$, where C is the total number of length bins.

Buyers provided estimates of the total weight (kg) they purchased in each grade, which field staff verified with rough estimates of an average weight per basket and by counting the number of baskets for each grade. Summing the total weight purchased in each grade gives an estimate of the relative proportion of harvest in grade g which we denote as η_{vg}. To make our sample representative of a village's total harvest distribution, we apply these proportions η_{vg} as weights to the grade-specific distributions $\mathbf{f}_{vg}$.

(c) *Price data*

The average price received for a mushroom is strongly correlated with its length (see Figure 2), showing the financial incentive for waiting to harvest mushrooms when they are older. However, mushrooms are sold in price grades p_g, and the units for p_g are RMB/kg, so we need an estimated weight of each mushroom to determine its individual price. We purchased mushrooms from several villages from which we measured mushrooms' length, cap width, stem width, and weight ($n = 61$). From this set of mushrooms we develop predictive relationships between observable characteristics (length, cap width and stem width) and a mushroom's weight ($R^2 = 0.95$, see Table A.1.). From the photographs of buyers' baskets, we measured observable mushrooms' length, cap width and stem width ($n = 1{,}674$). Using the estimated regression coefficients from the purchased set of mushrooms, we predict the weight of each mushroom observed in photographs and multiply it by the mushroom's grade price to estimate the implied

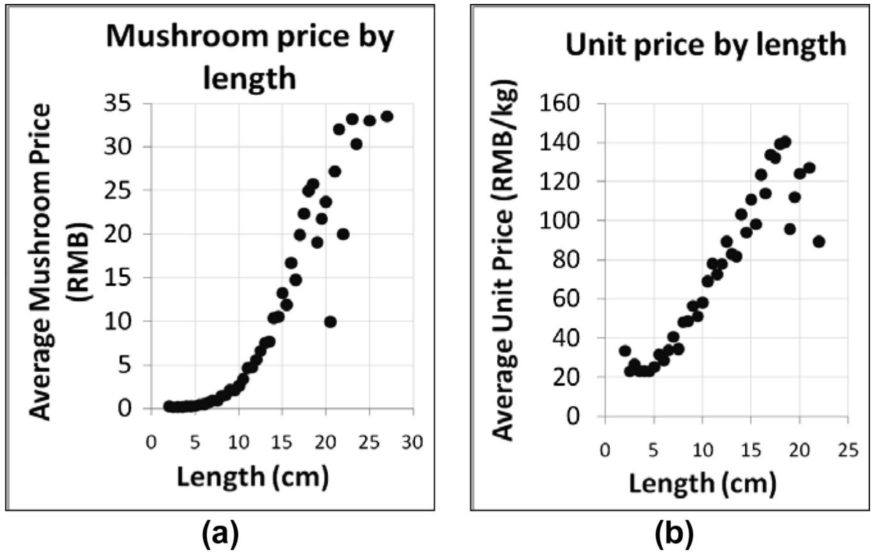

Figure 2. *Mushroom price-length relationship. Notes: Data averaged for each ½ cm mushroom length category. Data shown for categories with n > 3 (total n = 6,770).*

per-mushroom price. Observations are then separated by grade g and a vector of the average price by grade-specific length bin is calculated within each village, $\mathbf{p}_{vg} = \{p_{vg,1}, p_{vg,2}, \ldots, p_{vg,C}\}$.

Since harvested quantities and, therefore, the magnitude of revenues from productive villages are much greater than revenues from low productivity villages, revenues are not directly comparable. To develop a comparable metric across villages, we divide the vector of grade-specific length bin prices in each village by a common normalization factor to remove the effect of absolute prices on the data: $\widetilde{\mathbf{p}}_{vg} = \mathbf{p}_{vg}/p_{norm}$.

The normalization factor p_{norm} aims to remove the effect of the magnitude of price and allow us to compare villages' ability to capitalize on the total available revenue in any given harvest system. One obvious candidate for normalization is (i) maximum mushroom price observed in the village. Yet maximum prices are often outliers and may produce spuriously low estimates for $\widetilde{\mathbf{p}}_{vg}$. To ensure our choice of p_{norm} is not significantly biasing our results, we compare three additional candidates for normalization that aim to capture the expected price for a high-quality mushroom within a village: (ii) the average of the highest 5% of mushroom prices, (iii) the average price of all mushrooms in the top grade, plus two standard deviations, and (iv) the average of length-averaged prices for the top grade, plus two standard deviations.[3]

(d) *Revenue distributions*

We calculate total normalized revenue from mushroom harvests by multiplying the grade-specific price and frequency vectors by the appropriate grade weight, and then summing all grade-specific vectors within a length bin. The vector of a village's normalized revenue estimates from each length-bin is $\boldsymbol{\pi}_v = \{\pi_{vg,1}, \pi_{vg,2}, \ldots, \pi_{vg,C}\} = \sum_{g=1}^{G}[\eta_{vg} \cdot \widetilde{\mathbf{p}}_{vg} \cdot \mathbf{f}_{vg}]$, where G is the total number of grades within a village.[4] The notation here should be read as each element of $\boldsymbol{\pi}_v$ is an element-wise multiplication of the corresponding elements of $\widetilde{\mathbf{p}}_{vg}$ and $\mathbf{f}_{vg}$, with each element pair multiplied by the scalar weight η_{vg}. All vector sums of $\widetilde{\mathbf{p}}_{vg}$, $\mathbf{f}_{vg}$ and η_{vg} are less than or equal to one, so summing the values in $\boldsymbol{\pi}_v$ gives the percent of total realized harvest value in a village,[5] showing how well a village maximizes the value of their resources given the prices they face:

$$\Pi_v = \sum_{c=1}^{C}\boldsymbol{\pi}_v = \sum_{c=1}^{C}\sum_{g=1}^{G}[\eta_{vg} \cdot \widetilde{\mathbf{p}}_{vg} \cdot \mathbf{f}_{vg}]. \tag{1}$$

Π_v represents a village's actual revenue as a percentage of its total revenue potential. This is the PMR.

(e) *Uncertainty*

The main source of empirical uncertainty in our data is the variance associated with the price paid for a "typical" mushroom of length x. As matsutake grow, they can be damaged from insects or develop esthetic flaws, reducing the price buyers are willing to pay for it. Thus there is uncertainty around the value one can expect to receive for leaving a mushroom in the ground to grow larger. To understand the magnitude of this uncertainty, for each grade within each village we fit price observations in a length-bin to a lognormal distribution and use the parameters to estimate the sample mean and 95% confidence intervals for bins with more than three observations.[6] Figure 3 shows the price variance exhibited in village 7 (Xinhua) as an example. Using the high and low within-bin price estimate we compute high and low revenue estimates via Eq. (1) for each normalization candidate.

6. EMPIRICAL COMPARISON OF CLASSIC MANAGEMENT REGIMES

(a) *Village revenue comparisons*

Figure 4 shows villages' cumulative revenue distribution from the elements of the vector $\boldsymbol{\pi}_v$ based on the fourth normalization candidate described above, the average of length-averaged prices for the top mushroom grade plus two standard deviations. The highlighted endpoint of each cumulative distribution represents Π_v, the proportion of maximum reve-

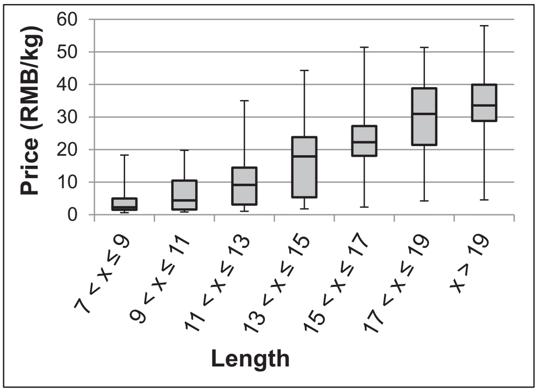

Figure 3. *Price variance by mushroom length, Xinhua (village 7). Notes: The variance from prices within length bins is used to develop upper and lower price estimates from 95% confidence intervals from a lognormal distribution. The whiskers on the boxplots show the maximum and minimum prices from within a length bin. The middle line shows the median price, with upper and lower boxes representing the second and third quartile, respectively.*

nue (PMR), which shows how well villages capitalize on the prices they face. Of interest is comparing communities by their choice in institutional management strategy. As theory predicts, private access villages (dark solid lines) generally best realize the value of matsutake harvests, attaining 30–45% of the maximum attainable revenue. But contrary to theoretical prediction, the open access villages (light dotted lines) empirically out-perform all common access villages (dark dotted lines) in our sample except one, village 9 (Adong), which employs weekly rest days.

As a simple "back of the envelope" calculation for how well villages could do, Table 2 shows the potential increase in revenue villages could expect to gain from having harvest outcomes similar to those observed in private access villages based on Figure 4. We use the average PMR from the top three private villages and the PMR from the worst performing private access village to compute upper and lower bounds, respectively, on what a village might expect to gain from better management. The values in Table 2 are the ratio of the comparison "reference" PMR divided by the revenue for the village, minus one. The five worst-performing villages, all common access, could at least double their revenues and some seem able to gain four- to five-fold increases in earnings that are not currently captured. For some, namely the open access villages, the potential gains from management are not as great.

To ensure that the normalization factor is not driving these results, we calculate the PMR based on the three other normalization factors described above and plot how villages' rank order changes (Figure 5). Not surprisingly, changes in rank order are greatest when the PMR measures are close, most notably for villages in the high and low clusters seen in Figure 4. We also see that the normalization factor used to calculate the results in Figure 4 (square marker) seems to be a moderate choice of the four normalization candidates.

(b) *Costs increase with decreasing revenues*

From our household questionnaire we calculate the percent of a village's total household labor devoted to harvesting (total village harvest hours/village's total working hours) to estimate a comparable metric of the opportunity cost of harvest labor, with the assumption that higher relative opportunity costs lead to less participation in harvesting. Harvest labor allocation in private villages (18%) is less than open access (36%; private < open, $p = 0.12$) and common access (50%; private < common, $p = 0.01$) suggesting private villages' net profits are likely greater than either open or common access villages. From Table 3, labor is also strongly negatively correlated with the PMR ($r = -0.88$) on the village level. Private access villages seem to enjoy lower labor costs, but so do open relative to common access villages. Therefore, it does not seem likely that common access villages' low PMR scores are matched by similarly low labor costs, making profits increase with PMR, and our original assumption that revenue is a good proxy for profits is supported.

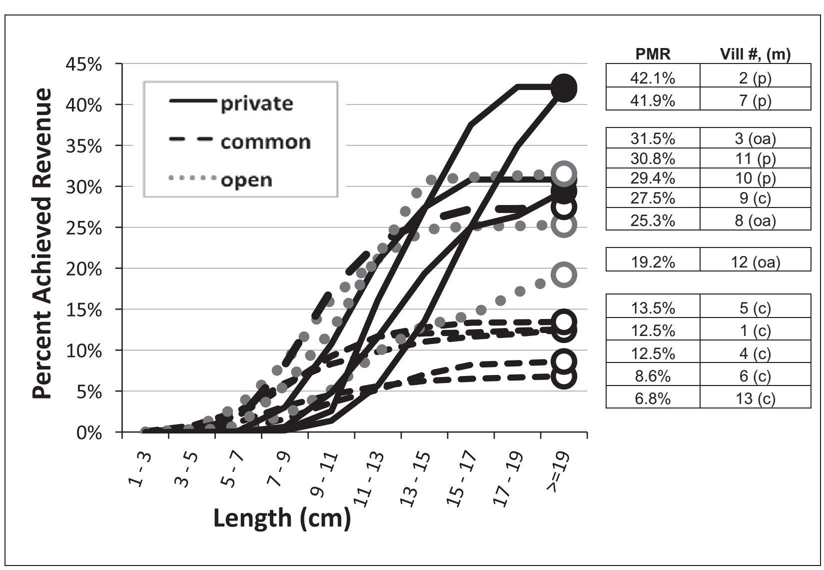

Figure 4. *Cumulative revenue distribution for 13 villages by management type. Notes: The right-most endpoint of the cumulative revenue distribution is Π_v (Eq. (1)), the proportion of maximum revenue (PMR), and is given for each village in the table to the right. The distributions show that private villages (solid lines) generally do the best at capturing the value of the prices they face. Surprisingly, open access villages (dotted lines) perform better than common access villages (dashed lines) except for one common village (Adong, village 9) that employs additional rules in combination with excluding outsiders from harvesting.*

Table 2. *The potential value of implementing institutions*

Village	Management type	PMR (%)	Expected increase in revenue [least—most gain (%)]
2. Haitang	Private	42.1	Upper bound reference
7. Xinhua	Private	41.9	
3. Lehe	Open	31.5	−7–21
10. Miheimen	Private	30.8	Upper bound reference
11. Wujie	Private	29.4	Lower bound reference
9. Adong	Common w/rules	27.5	7–39
8. Bamei	Open	25.3	16–51
12. Lizui	Open	19.2	53–99
5. Wengshui	Common	13.5	119–185
1. Gezan	Common	12.5	135–206
4. Xiagezan	Common	12.5	136–206
6. Jiangdong	Common	8.6	242–345
13. Jidi	Common	6.8	332–462

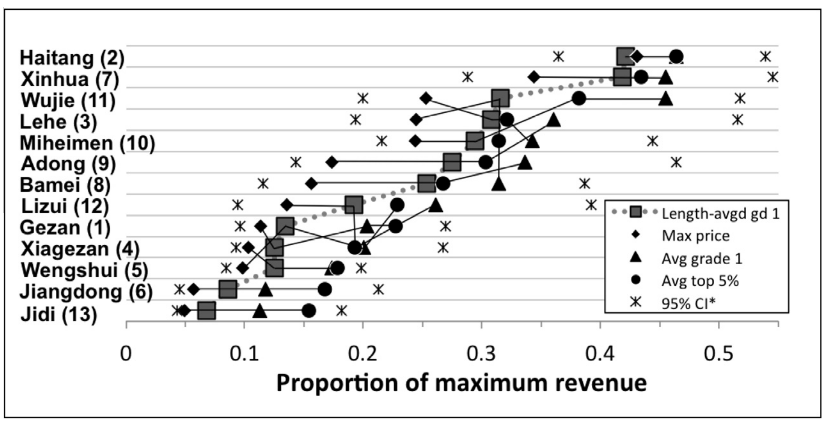

Figure 5. *Proportion of Max Revenue (PMR) for four normalization candidates by rank order. *Min and max log-normal 95% confidence intervals from the min and max normalization factor, respectively. Notes: Rank order changes for different normalization candidates, but the lower and upper ends of the rank order spectrum are consistent. The chart's village labels on the right are correspond to the left-most normalization factor (maximum price, which result in the minimum PMR values) so one can follow the connector-lines to the right to see how villages' rank order changes with candidate. Rank orders are most likely to change across normalization candidates for villages with similar PMR measures. Figure 4 uses the length-averaged price from grade 1 (the square here in Figure 5) which is bound by all the other normalization factors.*

7. WHY DO VILLAGES DIFFER?

Our empirical example shows that villages with no rules (open access) generally capture more revenue than those that limit forest entry to villagers (common access), opposite what we expect from theory. Research on self-governed resource management (Agrawal, 2001; Gibson, McKean, & Ostrom, 2000; Ostrom, 1990; Poteete *et al*., 2010) describes how institutional outcomes are embedded in local social, economic, and ecological conditions. Given the descriptive data in Table 3 and our experience in the field, we now turn to four factors that we think hold the most explanatory power for understanding villages' institutional choice in the setting studied here: limited entry, biological productivity, transaction costs of rule enforcement, and institutional goals. Given the relatively small number of villages in our dataset, these factors are best viewed as hypotheses to explore in future research.

(a) *Limited entry*

One explanation for our results is that the open access cases are simply *de facto* limited entry systems and therefore effectively common access cases. Indeed, Table 1 shows that there is relatively limited outside entry into most open access villages. In a setting of limited entry, we can think of the cost of labor as discontinuous or sharply rising at the margin. Average harvest costs (AHC_{oa}) terminate short of average revenue, with rents accruing to the community at $Q^{0,oa}$. In the context of the model described in panel (b) of Figure 1, we represent this in Figure 6 below.

(b) *Biological productivity*

When biological productivity is high, relative scarcity is low, so institutions may not be necessary. No biological survey of matsutake exists for the region, so productivity is unobservable. Our best proxies for productivity, the average number of mushrooms harvested per week per household and the average number of mushrooms harvested per harvester per hour, are endogenous since they are derived from harvest estimates, which itself is impacted by competition. Still, Table 3 shows that most common access villages enjoy greater matsutake harvests both in terms of absolute number of mushrooms per household and the average hourly rate of

Table 3. *Village-level summary statistics*

Management (village #)	PMR (%)	% Village labor to harvesting (%)*	Index of mushrooms/hh/week	Index of mushrooms/h	Index of # harvesters/hh
Private (2)	42	9	0.01	0.05	0.22
Private (7)	42	25	0.02	0.03	0.24
Private (10)	31	18	0.02	0.05	0.33
Private (11)	29	–	0.03	0.45	0.32
Open (3)	32	18	0.05	0.14	0.29
Open (8)	25	31	0.50	1.00	0.29
Open (12)	19	–	0.03	0.27	0.26
Common (9)	28	34	0.07	0.11	0.47
Common (5)	14	43	1.00	0.77	0.76
Common (1)	13	66	0.76	0.57	0.87
Common (4)	13	58	0.40	0.32	0.73
Common (6)	9	60	0.27	0.20	0.71
Common (13)	7	–	0.21	0.40	1.00

* Data are not available for villages sampled in the 2008 field season.

harvest. Harvesters in villages with seemingly high productivity can still earn high revenues, suggesting that as long as earnings are greater than foregone opportunities, there may not be enough of an incentive to develop profit-maximizing institutions.

Figure 6 also shows how the shape of the cost curve (AHC_1 versus AHC_2) may influence the relationship between PMR and the amount of rent available in a system. A vertical shift in average harvest costs is not a primary concern since PMR is a proportional measure, but factors that affect how quickly harvest costs rise with a harvested quantity may have an impact on the lower bound of feasible PMR measures in a system. One such factor could be the density of resources or the productivity of a resource system. The cost of finding the next unit of resource may be less if, in our case, a forest produces a greater quantity of mushrooms (AHC_2 implies greater productivity than AHC_1). So while our index tells us how close a village gets to their maximum revenue, cost information would help us pin down the lower bound of a village's PMR, and therefore how far a village keeps itself from the rent-dissipating equilibrium. Regardless, in our case here common access villages are generally more productive than open access villages *and* they perform worse, making their absolute gains from implementing institutions that much larger.

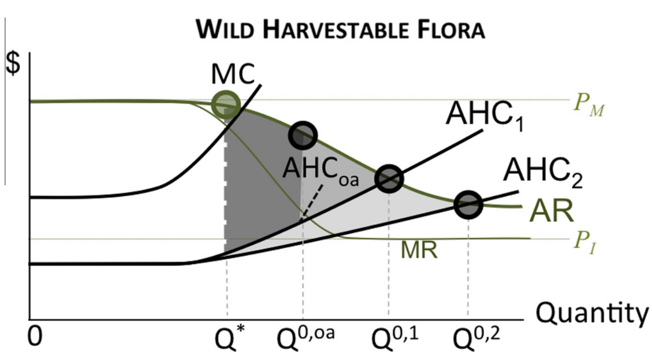

Figure 6. *Costs and Rent for Wild Harvestable Flora. Notes: The average harvest cost curve from Figure 1 (AHC_1) is now contrasted with an average harvest cost curve for the case where labor is constrained (AHC_{oa}), for instance due to the opportunity cost of an additional unit of labor in a geogrpahically remote area, and an average harvest cost curve for the case where harvest costs are low (AHC_2), for instance due to greater resource productivity. These factors may affect the lower bound on average revenue (dark circles) relative to the maximum revenue (light circle), and may help explain why some open access villages seem to perform relatively well compared to the highly productive forests of common access villages. As in Figure 1, Q^* is defined as the point where $MR = MC$.*

(c) *Transaction costs*

A third factor affecting institutional choice seems to be high transaction costs for monitoring and enforcement. We have no quantitative measure of transaction costs, but village leaders provided detailed narratives of the institutional history of the village. These give some indication of the relationship between villages' past ability to monitor and enforce rules and other contextual characteristics such as resources, forests, and socio-demographics.

First, in some villages a number of complex rules were implemented and later abandoned. For example, Jidi (common village 13) attempted rotating group harvests and rest days, as detailed in other reports (He, 2003; Yang *et al.*, 2006, 2009). At the time of our data collection no such rules were in place, reportedly due to the difficulties in monitoring and enforcing adequate compliance of the rules. Gezan (common village 1) and Xiagezan (common village 4) had a similarly poor experience after implementing rest days.

Ambitious leadership seems to play a role in overcoming initial transaction costs related to developing and implementing creative rules. For example, a village leader in Lizui (open access village 11) spearheaded a village bidding process for matsutake use rights in 2003. In this process, households would submit bids for the percent of their own harvest revenue they would be willing to give back to a village collective. The highest household bids (around five bids were accepted) would receive harvest rights for the year in exchange for their bid amount paid to the rest of the villagers. With low matsutake prices (in 2005), the village abandoned the bidding process and it was never reinstated. There was not popular support for bringing these rules back since harvesters from outside villages are suspected of picking the high quality mushrooms and some residents were never happy with the revenue-sharing scheme. In another case, Xinhua (private village 7), a village leader initiated the private contract system in the early 1990s where groups of four or so households are randomly assigned together to harvest from a specific forest plot as a group. This system, in contrast, is still intact.

Finally, privatization in Miheimen (private village 10), Wujie (private village 11) and Haitangwa (private village 2) is the result of an early wave of China's Forest Tenure Reform program in the 1980s, before the discovery of the value of matsutake. Dividing communal forest into household plots takes time and technical resources, and can be contentious. Shanglehe (open access village 3) and a village group in Lizui (open access village 12) were starting the process of Forest Tenure Reform at the time of data collection.

Adong (common village 9) has also undergone Forest Tenure Reform, but since its forest area is so large it has chosen to maintain household rights only for trees, and not NTFPs like matsutake. In Gezan, Xiagezan, Wengshui, and Jidi (common villages 1, 4, 5 and 13, respectively) the size of the forest was often cited as a reason for a lack of rules. Exclusionary rules (at the household or group level) are generally impossible to monitor and enforce since their forests are so large.

(d) *Institutional goals*

Finally, equitable access to resources seems to drive some villages' institutional choice. A harvester from Gezan (common village 1) describes why some communities may shun the development of rules:

> We used to have two or three rest days per week, but it was a little dangerous. People would spend too much time in the forest on harvest days—especially the elderly and sometimes younger children. So we gave up those rules some years ago.

With rest days, harvesters feel pressure to utilize harvest days as much as possible. In this case the village decided the occupational risk resulting from this rule was not socially acceptable. Other common and open access villages also voiced reluctance to implement institutions that might put some residents at a risk or competitive disadvantage. Communal access is seen as the most egalitarian way to distribute revenues and, given the heterogeneous distribution of matsutake in a forest, villagers assume more individualized rights will result in higher levels of inequality.

(e) *Summary*

In addition to the factors described above, other factors that could plausibly affect institutional choice include competitive pressure (when competition for resources is high, there is incentive to develop restrictions to manage that competition), social capital (group cohesion and trust within a community make development and enforcement of village rules easier) and within-village opportunity costs (high opportunity costs lead to low harvest participation, making institutions unnecessary). However, at least in our descriptive data and anecdotal observations, these did not seem to be major driving factors in our study villages.

Our goal in this section is to develop economic intuition for villages' institutional choice. Statistical tests for any of these explanatory hypotheses are not reliable since our sample size is relatively small. But, in summary, these factors seem to imply several potential conclusions. First, high resource productivity in common access settings seem to make the presence of complex rules (i.e., rules stronger than simply excluding outsiders) less necessary. Leadership can help overcome initial barriers to developing and implementing rules, but the costs of monitoring and enforcing rules as determined by the resource base, land area, and social context seem to eventually determine a village's institutional outcomes. When a village's forest size is large (or population density low), monitoring and enforcing anything but the simplest of rules, like exclusion of outsiders, has been generally unsuccessful. Enforcing village boundaries seems to be the least costly option regarding enforcement and monitoring, so the poorest performing villages undertake this rule at a minimum. Where privatization of forests have been nationally mandated (but also aided), only villages with relatively small amounts of matsutake forest area apply their private use rights to matsutake, showing that costs for monitoring private plots are high, despite the potential for higher revenues. Given villages' institutional histories and the desire for rules to be fair and equitable, open and common access are choices made by communities, not the outcome of myopic communities with illogically high discount rates.

8. CONCLUSIONS

This paper makes two contributions to the literature on natural resource governance in developing countries. First, we present an empirical comparison of resource rent capture for villages that have chosen various institutions to manage their resources. We use a unique dataset that shows how outcomes from classic management regimes may not always empirically behave as predicted by theory. Second, we develop an index for ordinally ranking how well villages recover the value an important class of nontimber forest products. This method takes into account differences in resource productivity and differences in price grades across systems.

The methods developed here apply to a class of NTFPs with unique characteristics, but these resources are vital for the livelihoods of many rural residents dwelling in and around forests. Generalizing the findings of this study should be treated with caution given the small number of villages in this study, but we present a unique quantitative index of village management that would allow for simple replication. Our medium-N sample size is also a strength. Qualitative work on common property assessments focus on context and detail, but are often difficult to generalize. Some larger-N studies of resource systems are emerging (Gibson, Williams, & Ostrom, 2005; Persha, Agrawal, & Chhatre, 2011; Van Laerhoven, 2010) but these can sacrifice context for statistical power. This paper provides a large enough sample size to suggest the results are not spurious, but a manageable number of cases so we can explore case-specific explanations for the observed behavior.

In most textbook discussions of renewable resource systems, costs borne by those outside of a resources system are typically not represented. For instance, when explaining the gains in moving a fishery from open access to effort levels under sole ownership or with individual transferable quotas, the transaction costs of developing and monitoring such institutional change is not typically an integral part of the accounting. However, a full-cost accounting of these issues, including the impact of local labor availability (as we saw above in the open access situation), needs to be explicitly taken into account when developing policy prescriptions. Full-cost accounting to implement self-governing institutions would include:

1. the change in harvest revenue with enforced institutions,
2. the change in harvest costs with enforced institutions, and
3. the transaction costs of developing and enforcing those institutions (the cost of organizing and developing rules and the costs of monitoring and enforcement).

Harvests under such "costly cooperation" have been explored in a theoretical context (McCarthy, Sadoulet, & de Janvry, 2001), but these costs are not often recognized in many aid and development programs. Moreover, there is little empirical work that shows how ecological, geographic, and social factors might impact institutional transaction costs.

We assess the institutional effect on harvest revenue (part 1) through a comparison of villages' PMR in Section 6. We find that private access villages capture the most value from their forest resources, but open access villages generally outperform common access villages. Importantly, private forest plots in our study villages were developed before discovery of the matsutake mushroom, so this institutional change was not precipitated by matsutake productivity, although villages do have autonomy to decide whether those private rights apply to NTFPs. In the system studied here, quantitative estimation of the institutional effect on harvest costs (part 2) requires measuring aggregate labor changes. Cross-village comparison of the percent of village labor devoted to forest harvests shows that labor costs generally decrease as village institutions are able to capture more resource rent (measured as PMR). Finally, measuring the transactions costs associated with resource management institutions (part 3) would account for time, resource, and social costs that arise when developing, monitoring and enforcing an institution.

In the villages surveyed here, open access systems are a conscious choice by villages that have little harvest pressure on resource harvests. They have less labor participation and capture more revenue than most common access villages, and receive minimal outside entry into their forest. Enacting rules, even if only to restrict outsiders, would not have much practical impact. Our interpretation is that open access areas are open access *only* because there would be relatively little gains from institutions. If there were demand for better-performing institutions within the village, there would at a minimum be a call for enforcement of village boundaries—the least-cost tool available to village residents.

Common access systems, in contrast, seem to suffer from an *overabundance* of forest and forest products. Table 2 shows that many common access systems could capture much greater revenue from those resources, and institutional histories show rich experimentation with rules that try to capture that revenue. But large forest areas impede monitoring and enforcement of rules, and high resource productivity provides an adequate level of income for residents, even though additional restrictions could dramatically increase profits. Common access villages seem victim of an unfortunate economic circumstance: a wealth of resources results in transactions costs that are too high to capture much profit from the system. Importantly, however, villages' endowment of land and resources are to blame, not a lack of human understanding of the resource system or a myopic focus on short-term needs.

Empirically, this research underscores the importance of understanding the context within which a natural resource harvest strategy is embedded. Residents seem to have the ability to manage natural resources efficiently given the constraints they face. The evidence here suggests development assistance should move from building management programs to better understanding and relieving village-level constraints that limit livelihoods derived from local resources.

NOTES

1. In many developing regions, production and consumption decision are inseparable (Singh, Squire, & Strauss, 1986) implying that the opportunity cost of foregone agricultural labor increases as forest labor increases.

2. Even an extremely high annual discount rate of 30% has a 5-day equivalent discount rate of 99.6%.

3. Initially, one may think that since normalization has a linear effect on any given price vector, one's choice of normalization factors may change the absolute values in $\tilde{\mathbf{p}}_{vg}$ but not the ordering, which is our main interest. However, note some candidates for p_{norm} rely on aggregate measures to calculate $\tilde{\mathbf{p}}_{vg}$, and sample sizes and price variance differ by village, so different normalization factors can result in different orderings of village revenue.

4. When resources grow slow enough such that discounting should not be ignored, $\boldsymbol{\pi}_v = \sum_{g=1}^{G}[\eta_{vg} \cdot \tilde{\mathbf{p}}_{vg} \cdot \mathbf{f}_{vg}]\rho^{g-1}$, where ρ is the discount factor for the amount of time represented between cohorts.

5. For example, if all mushrooms sold for the maximum price, we would have $100\% * 1 = 100\%$. Alternatively, consider a village where half a village's harvests are sorted into a low grade and half in a high grade. If there is no price difference between grades, the village would equally maximize their potential revenue: $50\% * (p = 1) + 50\% * (p = 1) = 100\%$. When price differences exist and harvests are less than "perfect" we get a measure <1.

6. Bins with fewer than three observations result in unrealistic parameter values. In the rare cases where this is true, we take their mean as the point estimate, and use the max and min values as the high and low 95% confidence interval values for that bin.

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APPENDIX A

A.1 *The relationship between observable factors and mushroom weight*

A.2. *A two-cohort harvest decision model*

When an immature specimen is encountered in the forest, the harvester can pick it now and receive the revenue from harvests $p_I x_I$ where p_I is the per-unit price of an immature individual x_I. Harvest costs in these systems are just labor costs, and once a resource is encountered, travel costs are sunk. If the harvester leaves the specimen to further mature, she would receive the price for mature resources minus the cost of returning $p_M x_M - wl_x$, where w is the per-unit cost of labor and l_x is the marginal amount labor needed to return to individual x given the harvester's expected future search path. If x_I is in units

Table A.1. *Weight-length relationship*

Depvar: ln(mushroom weight)		
	Coeff.	Std. Error
Length	0.204	(0.040)***
Length^2	−0.005	(0.001)***
Cap width	0.138	(0.036)***
Cap width^2	−0.004	(0.001)***
Stem width	0.979	(0.234)***
Stem width^2	−0.086	(0.039)**
Constant	−0.385	(0.288)
adjusted R^2	0.95	
n	61	

Results are from an ordinary least squares regression.
** $p < 0.05$.
*** $p < 0.01$;

of mass and p_I is a price per unit mass, then the maturation of a resource can be described through the state equation $x_M = x_I(1 + r)\phi$, where r is the percentage mass gained during the maturing process. The variable ϕ is the probability that the specimen will still be there upon return (i.e., one minus the probability that it is picked by someone else, eaten by animals, etc.). If an institutional setting increases the probability that resources grow to maturity, ϕ can be considered a management parameter where effective management increases ϕ and situations with insecure harvest rights bring ϕ closer to zero. Although this kind of parameterization of management dramatically oversimplifies institutional complexity, it captures the broad issue in a meaningful way. A similar assumption and justification is made in Robinson et al. (2008), although they use the discount factor as a management parameter. This is also similar to parameters imposed by Reed (1984) and Mendelsohn (1994) regarding land tenure insecurity.

When encountering an immature specimen in the forest, the harvester's problemis to

$$\max(p_I x_I,\ p_M x_m - wl_x) \quad \text{such that } x_M = x_I(1 + r)\phi \tag{A.1}$$

The necessary condition for harvesting immature stock is $D_I = p_I x_I - [p_M x_I(1 + r)\phi - wl_x] \geqslant 0$ or, in terms of revenue,

$$R_I \geqslant R_M\phi - wl_x \tag{A.2}$$

We can see that $\partial D_I/\partial\phi < 0$, so a harvester that is less sure a resource will still be there upon return harvests more immature stock. Importantly, this implies that as institutions become weaker more immature stock will be harvested, all else equal. Additionally, $\partial D_I/\partial l_x > 0$ so that the farther one has traveled when the immature resource is encountered, the more likely it will be picked. Even if $\phi < 1$ under perfect management, it may be optimal to harvest some immature resources due to travel (search) costs, but it is *always* optimal to harvest any mature specimen encountered. If resources die after maturing, then when a harvester encounters mature resources the decision problem is trivially to max ($p_M x_M$, 0). Of course, the best strategy is to harvest any mature stock one finds. This model is suited for resources that mature quickly over time so that time-discounting has a negligible effect. For resources that mature over longer periods, we could easily incorporate time discounting by setting the maximization problem in Eq. (A.1) equal to $\max(p_I x_I, \rho(p_M x_M - wl_x))$ where ρ is the discount factor.

Taken together, this model shows that weaker management institutions should induce the harvest of proportionally greater immature stock. Better management yields proportionally greater harvests of mature stock. So, in a relative sense, open access systems should harvest the smallest stock, common access proportionally greater resources, and private systems the greatest number of mature specimens.

In its setup this problem explicitly assumes there is no relationship between a specimen and the future biological productivity of the population, for which we make the case in Section 2 for "normal" harvest practices. Here there is only user cost attributable to foregone individual growth: $MUC_i = R_{\mathbb{M}} - wl_x - R_I$.

We assume ϕ is a function of total community harvest labor L such that $\partial\phi/\partial L < 0$; increased total community labor decreases the probability that a specimen will remain to be found in the next period. So as L increases, ϕ decreases and makes picking immature stock more likely.