Poverty and the Environment: Exploring the Relationship Between Household Incomes, Private Assets, and Natural Assets

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ABSTRACT. *This paper develops an analytical framework to examine how rural households in developing countries derive income from common-pool natural resource stocks. The focus is on how three types of private assets—land, livestock, and human capital—and one household characteristic—its size—interact with the natural assets to form the basis of household livelihood strategies. Predictions of the model are tested using purpose-collected data from rural households in Jhabua, India. Implications of our results for the potential of improved natural resource management to alleviate poverty are discussed.* (JEL Q12, Q21)

I. INTRODUCTION

Rural households in developing countries depend significantly on common-pool natural resources for their livelihoods (WRI 2005). The commons is often a source of food, energy (in the form of fuelwood or dung), fertilizer, fodder, construction materials, raw materials for crafts or other processed goods, medicine, and of course drinking and irrigation water. This raises the policy question of whether improved natural resource management can form the basis of poverty alleviation policies. The attempt to answer this question has given rise to a growing literature on poverty-environment interactions (for reviews, see Reardon and Vosti 1995; Duraiappah 1998; Horowitz 1998; and Barbier 2005).

One thread of this literature (recently reviewed by Beck and Nesmith 2001; Vedeld et al. 2004; and Kuik 2005) has examined how resource use by households—defined as the income they derive from collecting natural resources from the commons—varies with overall household income. The seminal study in this literature is Jodha (1986), with important recent contributions by Reddy and Chakravarty (1999), Cavendish (2000), Fisher (2004), and Adhikari (2005).[1]

In general, this literature has found no consistent trend. Jodha, for example, finds that use decreases with income, Reddy and Chakravarty find an initial slight increase followed by a decrease, and both Cavendish and Adhikari find an increase throughout. More consistent is the finding that resource dependence, defined as the share of resource income in overall income,[2] tends to decline with overall income, but even here, there are

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[1] Other, smaller-scale studies include Pasha (1992), Singh et al. (1996), Nadkarni (1997), Qureshi and Kumar (1998), and Beck and Ghosh (2000).

[2] As one of our reviewers points out, calling the income share of resources "resource dependence" is potentially misleading, since resources need not be crucial to the household's welfare even when their income share is large. While we agree with this point, we nonetheless use the term dependence in this paper, as this is in line with the existing literature.

exceptions. Adhikari (2005), for example, finds that poor households in rural Nepal are less dependent on common-pool resources than the (relatively) rich.[3] Similarly, Fisher (2004) finds that for households in rural Malawi, dependence on high-return forest activities such as charcoal and timber sales increases with income, while dependence on low-return forest activities decreases.

Missing from this literature thus far is an in-depth investigation into why the reported regularities between either use or dependence and income obtain. Reddy and Chakravarty conjecture, unsupported with evidence from their data, that the poor have less land and that this explains their higher dependence on forest resources. Cavendish conjectures that the decline in dependence with income may in part be due to cash constraints; poorer households are less able to purchase food and are therefore forced to collect it from the commons instead. Jodha provides a fairly detailed discussion of why poor households may be more dependent on the commons, suggesting three specific reasons: (1) common-pool resources act as a substitute for the private assets that poor households lack—instead of acquiring fuel and fodder from private lands, for example, land-poor households can collect these resources from common lands; (2) poor households have surplus labor that is well suited to resource extraction, an activity where labor is usually the only input; and (3) returns to extraction from the commons are often not very high, and are therefore unattractive to the rich. Jodha too, however, fails to support his discussion with evidence from his data.

Fisher (2004) and Adhikari (2005) are again exceptions, in that they do investigate empirically how various household characteristics affect forest income. Fisher's results lend support to Jodha's conjectures, in that dependence on forest income is found to (1) decrease with the household's ownership of goats, a private asset, (2) increase with the number of men in the household, and thereby possibly its surplus labor, and (3) decrease with the household head's education and thereby possibly the household's opportunity cost of time spent extracting from the commons. Adhikari similarly finds that forest income declines with the household's average level of education. However, and contrary to Jodha's conjectures, Adhikari also finds that forest income increases in household holdings of livestock and resource-collection tools. Livestock-rich households demand more fodder and therefore collect more grass and leaf litter from common forest lands. Similarly, households rich in resource-collection tools devote more time to collection and thereby derive more forest income.

In this paper, we build on Fisher's and Adhikari's work by developing and testing a theoretical model of optimal resource collection by households from a common-pool stock. A key result of the model is that the relationship between resource use or dependence and total household income—a focus of much of the existing empirical literature—cannot be predicted theoretically, as it depends on the empirical distribution of productive assets across as well as within income groups. The model does, however, generate predictions on how resource use should vary with household ownership of three types of private assets—land, livestock, and human capital—as well as with household size.

We test these predictions using purpose-collected data from 536 households in 60 villages in the district of Jhabua in the Indian state of Madhya Pradesh. Because the model indicates that a household's decision to participate in resource collection may vary differently with income or household size than its decision (conditional on participating) of how much to collect, we do so by estimating separate participation and conditional collection equations. We also consider not just resources that are collected "directly" by the household, that is, by hand, but also one resource that is collected

[3] Although here, and elsewhere in the paper, we refer to households with incomes at the higher end of the rural income distribution as "rich," it is important to note that these households are still poor in absolute terms.

"indirectly," by grazing livestock on common grazing lands.

Our estimation results turn out to be largely consistent with the predictions. Moreover, we find that the observed variation of resource use and dependence with total income in Jhabua—in particular, a surprising bimodality in resource use by households in the bottom and top income quartiles—can be explained, at least in part, by combining our estimation results with observations on the empirical distribution of private-asset ownership and household size.

The remainder of the paper is organized as follows. Section 2 describes the theoretical model and the predictions derived from it. Sections 3 and 4 describe the data collection process and the empirical model, after which sections 5 and 6 present our results on resource collection and grazing. Section 7 concludes.

II. THEORETICAL MODEL

Consider a region in which all households derive income from three activities: producing an agricultural output q^a, collecting a resource output q^r from the commons, and working off-farm for wages. The agricultural output, with price p^a, is produced using labor time t^a, agricultural capital K^a (e.g., land, farm capital, livestock), and a resource input c^r (the same resource that the household collects from the commons): $q^a = q^a(t^a, K^a, c^r)$. The resource output, with price p^r, is produced using collection time t^r, the stock of the resource in the commons R, and resource-collection capital K^r (e.g., carts, tractors, livestock): $q^r = q^r(t^r, R, K^r)$. The production functions $q^a(\cdot)$ and $q^r(\cdot)$ have standard properties. Each household's wage income is the product of the time t^w it spends working off-farm and the wage w, where w increases in the household's human capital K^h.

Each household faces the optimization problem of allocating its time endowment T across the three activities and choosing how much of the resource input to use so as to maximize its income, or profits, π:[4]

$$\max_{t^a,\, t^r,\, c^r} \pi = p^a q^a(t^a, K^a, c^r) - p^r c^r + p^r q^r(t^r, R, K^r) + w(K^h)(T - t^a - t^r).$$

The key first-order condition (assuming initially an interior solution) is

$$\frac{\partial \pi}{\partial t^r} = p^r \frac{\partial q^r(t^r, R, K^r)}{\partial t^r} - w(K^h) = 0, \qquad [1]$$

which implicitly defines the optimal time spent collecting, $t^{r*} = t^{r*}(R, K^r, K^h)$.

Define the household's resource income, or its use of resources, as $\pi \equiv p^r q^r$, and its dependence on that income as $D \equiv \pi^r/\pi$. The questions on which this paper focuses are (1) how resource use varies across households with overall income, (2) how dependence varies with overall income, and (3) the extent to which these variations can be explained by (a) variations in ownership of private assets, and the role that common-pool resource stocks serve as either a substitute for or complement to those assets in income generation, (b) variation in the productivity of time spent collecting resources, and (c) variation in the opportunity costs of such time. Formally, question (1) concerns the sign of $d\pi^r/d\pi$, and question (2) the sign of $dD/d\pi$. In the simplest case where households differ only with respect to ownership of a single productive asset X, question (3a) concerns the sign of $\partial^2\pi/\partial R\partial X$, question (3b) that of $\partial(p^r\partial q^r/\partial t^r)/\partial X$, and question (3c) that of $\partial w(K^h)/\partial X$.

It turns out that these five expressions are closely related, but in somewhat complex ways. Specifically, the signs of $d\pi^r/d\pi$, $dD/d\pi$, and $\partial^2\pi/\partial R\partial X$, i.e., the answers to questions (1), (2), and (3a), are all driven by the sign of dt^r/dX, that is, by variation

[4] This setup implicitly assumes that markets are complete, so that the household's overall utility-maximization problem is separable into the problem of maximizing its income and that of allocating its income across consumption goods. In subsection 2, we explore some implications of relaxing this assumption.

with X of the optimal time spent collecting. Specifically, if we let $\stackrel{s}{=}$ denote equality of sign, we have Proposition 1.

PROPOSITION 1.

(1) $d\pi^{r*}/d\pi \stackrel{s}{=} \partial\pi^r/\partial X \stackrel{s}{=} \partial^2\pi/\partial R\partial X \stackrel{s}{=} dt^{r*}/dX$,
(2) $dD/d\pi < 0$ if $d\pi^r/d\pi \leq 0$ and $dD/d\pi \geq 0$ only if $d\pi^r/d\pi > 0$.

PROOF. See Appendix.

Furthermore, totally differentiating first-order condition [1] shows that the sign of dt^{r*}/dX is in turn equal to that of $\partial(p^r\partial q^r/\partial t^r)/\partial X - \partial w(K^h)/\partial X$, and therefore driven by the answers to questions (3b) and (3c).

To illustrate these relationships, consider first a hypothetical case where households differ only in terms of their endowments of human capital K^h. In this case, we have

$$\frac{dt^{r*}}{dK^h} \stackrel{s}{=} \frac{d}{dK^h}\left\lfloor p^r \frac{\partial q^r(t^r, R, K^r)}{\partial t^r}\right\rfloor - \frac{dw(K^h)}{dK^h} = -w'(K^h) < 0.$$

In words, households with more human capital optimally spend less time collecting resources because they earn higher wages, and therefore face a higher opportunity cost of time spent in any activity other than wage labor. From Proposition 1, this in turn implies that $d\pi^r/dK^h < 0$, that is, resource income declines with human capital and thereby with overall income; $dD/d\pi < 0$, that is, dependence declines with overall income as well; and $\partial^2\pi/\partial R\partial K^h < 0$, that is, the common-pool resource stock acts as a substitute for human capital.

Consider next a case where households differ only in terms of their endowments of resource-collection capital K^r. In this case, we have

$$\frac{dt^{r*}}{dK^r} \stackrel{s}{=} \frac{d}{dK^r}\left\lfloor p^r \frac{\partial q^r(t^r, R, K^r)}{\partial t^r}\right\rfloor - \frac{dw(K^h)}{dK^r} = p^r \frac{\partial^2 q^r}{\partial t^r \partial K^r} > 0. \quad [2]$$

Households with more resource-collection capital, being by definition more productive at collecting, will optimally spend *more* time collecting resources. This in turn implies that $d\pi^r/dK^r > 0$, that is, resource income increases with collection capital and thereby with overall income; $dD/d\pi \stackrel{\geq}{\underset{<}{=}} 0$, that is, the relationship between dependence and income is ambiguous; and $\partial^2\pi/\partial R\partial K^r > 0$, that is, the common-pool resource stock acts as a complement for collection capital.

Consider finally a case where households differ only in terms of their endowments of agricultural capital K^a. In this case, we have

$$\frac{dt^{r*}}{dK^a} \stackrel{s}{=} \frac{d}{dK^a}\left\lfloor p^r \frac{\partial q^r(t^r, R, K^r)}{\partial t^r}\right\rfloor - \frac{dw(K^h)}{dK^a} = 0.$$

Even though households with more agricultural land are more productive in agriculture and therefore optimally spend more time working their land, this does not affect the optimal time spent collecting the resource. All households will collect up to the point where their marginal product of collection equals their wage, and in this case all households' marginal products and wages are equal.

This in turn implies that $d\pi^r/dK^a = 0$, that is, resource income is equal for all households as well; $dD/d\pi < 0$, that is, dependence declines with income; and $\partial^2\pi/\partial R\partial K^a = 0$, that is, the common-pool resource stock acts as a neither a substitute for nor a complement to agricultural capital. Note in particular that this is true despite the fact that the resource is used as an input to agricultural production, and that households with more agricultural capital use more of that input.

In reality, of course, households differ in all three types of asset holdings, with the mix of asset holdings varying not just across, but also within income groups. Given these facts, the model implies that the manner in which resource use (and thereby also dependence) varies with income cannot be predicted theoretically: whether it declines, stays constant, or increases with income depends on the particular distribution of assets across a sample, and can only be determined empirically. This may explain why, as noted in the introduction, the literature finds a range of relationships between resource use and income.

The model does, however, generate predictions about the impact of individual private assets on resource use. Specifically, the model implies that conditional on households' ownership of other assets, use will decline with human capital, increase with collection capital, and not vary with agricultural capital.

That said, the model is far too stylized to be directly applied to any real-world context. Some of its simplifying assumptions that in fact fail in the context of our own empirical study are that (1) all households engage in at least some collection, (2) household size does not matter, (3) there are no constraints on resource collection, (4) households do not hire labor for collection, (5) there are no fixed costs associated with resource sales, and (6) there are no privately produced substitutes for resources collected from the commons.

Presenting our full analysis of how relaxing each of these assumptions affects the model's predictions is beyond the scope of this paper. In the next subsection, we present only a summary, referring the reader to a mathematical appendix (available upon request) for details.

Extensions of the Model

Possible non-collection. If we expand the analysis to allow for non-collection by some households, we find that the probability of collection also varies unpredictably with income, depending on the distribution of asset holdings across a sample. More specifically, we find that under reasonable assumptions about the collection production function and the distribution of asset holdings, the probability of collection may exhibit the inversely U-shaped relationship with income that we identify empirically for our sample (see Section 5). That is, both the poorest and richest households are least likely to collect, the former because their collection capital is too low, and the latter because their human capital is too high. We find also, however, that under reasonable alternative assumptions, the probability of collection may be highest at the income extremes, and that other relationships are possible as well. Nevertheless, as is the case for the predicted level of collection (conditional on collecting at all), if other asset holdings are held constant, the predicted probability of collection declines with human capital, increases with collection capital, and does not vary with agricultural capital.

The role of household size. If, consistent with our empirical analysis, all non-price variables in the model are expressed in per-capita terms, and if (because larger households can have members specialize in collection) the marginal productivity of collection time increases in household size, then per-capita resource collection increases in household size as well, as does the probability of collection. However, as discussed below, per-capita collection may decline in household size when other assumptions of the model are relaxed.

Constraints on collection. For fodder collected by grazing livestock in the commons—an important form of resource collection in our study—the quantity collected is obviously constrained from above by the amount that livestock consume.

If the household meets this constraint through some mixture of grazing and stall-feeding, then both the probability of doing either, and the conditional time spent, vary unpredictably with biomass. This follows because it is not clear a priori how a change in biomass affects the relative marginal productivity of indirect and direct fodder collection.

As for variation in livestock holdings and household size, the fact that grazing typically takes only one person's time, almost regardless of the number of livestock being grazed, strongly favors grazing over collection by hand when (1) a household's livestock holdings are large, making grazing time particularly productive, or (2) a household has many members, making per-capita grazing time small. Specifically, the probability of direct collection decreases, while the probability of grazing increases with both livestock holdings and household size. Conditional on both collecting and grazing (very few households in our study only collect), the optimal time spent collecting also decreases in livestock and household size. The optimal time spent grazing, however, while increasing in livestock holdings, may still decrease in household size. It does so unambiguously if the household only grazes.

Hiring labor for collection. Although only one household in our study hired labor to collect a resource (fodder) by hand, a number of households hired labor to graze their livestock. Hiring labor is clearly optimal if the household's opportunity cost of time exceeds the wage rate for hired labor, and the probability of doing so therefore increases in the household's human capital.

Fixed costs associated with resource sales. Although many households in our sample buy fuelwood, construction wood, and dung for fuel, resource sales by households are much rarer. No household sells construction wood, only five households sell dung for fuel, and the lone household that sells fuelwood effectively specializes in that activity, deriving over 90% of its income from fuelwood sales. This suggests the presence of fixed costs associated with resource sales.[5] Households that choose not to incur these costs are in effect constrained to collect no more than they consume.

If this constraint binds, the household's collection behavior is no longer separable from its consumption preferences. In particular, for resources that are normal goods, collection will increase in the ownership of all productive assets except human capital. Human capital's effect is ambiguous because it raises not just income and thereby demand for normal goods, but also the opportunity cost of time spent collecting. Also, if household members share in the benefits of using resource products, it is reasonable to assume economies of scale in consumption. If these outweigh any economies of scale in production, then collection will decrease with household size.

Privately produced substitutes. Households in our study use three biomass-based substitutes for fuelwood and dung for fuel collected from the commons, namely fuelwood collected from private trees, crop residues, and dung collected from own livestock. Households also collect construction wood from private trees, and feed crop residues or fodder crops to their livestock. Very few households collect more of these substitutes than they consume, suggesting again the presence of fixed sales costs. Moreover, all these substitutes are produced as a byproduct of agricultural production (viewed broadly as including production of livestock outputs). Under these circumstances, resource collection may decrease with agricultural capital, as households with more livestock or land produce more of the resource substitutes.

III. DATA COLLECTION

The data used to test the above predictions were collected from 536 households in 60 villages in the Jhabua district in the Indian state of Madhya Pradesh, covering the period from June 2000 to May 2001. According to the Madhya Pradesh government's Human Development Report of 1998, Jhabua is the very poorest of the 45 districts in Madhya Pradesh, as measured by the state's human development index. Over 90% of rural households are employed in (predominantly rainfed) agriculture, and over 30% are classified as living below the poverty line. Households usually supplement their agricultural income with livestock rearing and collection of various products from the commons—most notably fuelwood, construction wood, fodder, dung

[5] These fixed costs could take the form of a risk of being fined or otherwise punished. By law, villages have rights, called *nistar*, that permit households to collect forest products from state forest lands, but only for noncommercial, household use (PRNRM 2002).

used for both fuel and fertilizer, *mahua* flowers and seeds (used to make liquor and cooking oil respectively), and *tendu* leaves (used to make cigarettes). Common-pool forests and grasslands are not abundant in the district, however: according to the Human Development Report, 54% of Jhabua's land area is used for agriculture, 19% is forest, and the rest is classified as "degraded."

Sampling Procedure

The survey sample of households was generated through a two-stage sampling design. In the first stage, a stratified random sample of 64 villages was selected to maximize variability in the forest stock. Unfortunately, political unrest in Jhabua at the time of the survey made it impossible to complete the survey in four of the selected villages, leaving 60 villages in all. In the second stage, household sample frames were constructed for each of the sample villages from village land ownership records and from the Madhya Pradesh state government's village-level list of households living below the poverty line (BPL). A random sample of 550 households was selected from three strata—BPL, land-poor (owning less than three hectares of land) and land-rich (owning more than three hectares of land)—with oversampling of BPL and land-rich households. Because of data problems, 14 households were ultimately dropped from the sample, leaving a final sample of 536 households.

Remote-Sensing Data

In addition to the data obtained through household and the village surveys, we relied on remote-sensing images, ground-truthed with tree and grass biomass measures from sample plots, to estimate forest and fodder biomass in a 5-km radius around the sample villages.[6]

[6] By law, villages within 5 km of any given tract of forest have legal rights to its forest products; villages outside this radius do not have the same rights.

IV. EMPIRICAL MODEL

Our empirical analysis proceeds in three steps. First, we establish empirically how resource use and dependence vary with total household income in our sample. Recall from Section 2 that this variation depends on the distribution of private assets and household size across the sample, and therefore cannot be predicted theoretically. Second, we empirically test our predictions from Section 2 on how variation in individual private-asset holdings and household size should affect resource use. Finally, we examine if, by combining our results from step two with observations on the empirical private-asset and household-size distribution, we can explain the relationships established in step one.

Empirical Strategy

Since not all households in the sample collect common-pool resources, the main data issue we need to confront is that resource use is censored at zero. For any given resource, households in our sample in effect make two decisions: whether or not to participate in collection of the resource and, conditional on participation, how much of the resource to collect.

Of the three regression models most commonly applied to censored data—the Tobit model, the Heckman selection model, and the two-part model—the Heckman model is the least restrictive, as it allows the "participation equation" modeling the first decision to differ arbitrarily from the "outcome equation" modeling the second, and moreover allows for arbitrary correlation of the two equations' error terms. The potential (selection) bias introduced by such correlation is controlled for by adding an inverse Mill's ratio term to the outcome equation. In contrast, the Tobit model requires the participation and outcome equations to be identical, with perfectly correlated error terms, while the two-part model allows the two equations to differ, but requires the error terms to be perfectly uncorrelated (and any selection therefore to be on observables only).

TABLE 1
VARIABLE DEFINITIONS, MEANS, AND STANDARD DEVIATIONS

Label	Definition	Units	Mean	S.D.
TOT.INC	Total permanent income	Rs/aeu	7,502	8,570
RES.INC	Income from collecting all common-pool resources	Rs/aeu	543	1,537
WFU.INC	Income from collecting fuelwood	Rs/aeu	212	837
DFU.INC	Income from collecting dung for fuel	Rs/aeu	61	207
FOD.INC	Income from collecting fodder	Rs/aeu	205	1,110
WCO.INC	Income from collecting construction wood	Rs/aeu	42	436
ORS.INC	Income from collecting other resources (mainly dung for fertilizer, *mahua* flowers and leaves, *tendu* leaves)	Rs/aeu	24	135
D.RES	Share of resource income in total household income	%	8	15
T.GRAZE	Total time spent grazing livestock in the commons	days/aeu	39	34
T.GR.OWN	Time spent by own labor	days/aeu	27	29
T. GR.HIR	Time spent by hired labor	days/aeu	11	28
LAND	Land owned by the household in June 2000	ha/aeu	0.3	0.5
LVSTK	Livestock (bullocks, cows, buffalo, goats, sheep, donkeys) owned in June 2000	#/aeu	0.8	0.9
HD.EDU	Education of the head of the household	years	2.8	4.3
BIO	Timber and fodder biomass availability within 5-km radius from village center	tons/aeu	704	1,258
HH.AEU	Household size	aeu	5.9	2.6
MKTDIS	Average distance to agricultural markets	km	10	9
WAGE	Weighted index of wage rates for in-village casual labor	Rs/day	21	5
JFM	Presence of Joint Forest Management project in village	dummy	0.28	0.45

It is clear from the results reported below that the Tobit assumption is too restrictive for our data: the estimated participation equation generally differs markedly from the outcome equation. Unfortunately, when we apply the Heckman model instead, we sometimes encounter a problem that frequently arises in econometric practice, namely a very high degree of collinearity between the Mill's ratio term and the explanatory variables in the outcome equation, making coefficient estimates for that equation imprecise and unstable.[7]

Leung and Yu (1996) and Puhani (2000) suggest that whenever collinearity as measured by Belsey, Kuh, and Welsch's (1980) condition number is "high" (Leung and Yu suggest a cutoff of 20), the two-part model is likely to outperform the Heckman model. Following this advice, we therefore generally report the two-part results whenever the condition number is high, but the Heckman results when (1) the coefficient on the Mill's ratio term is statistically significant, or (2) including the Mill's ratio term in the outcome equation turns out to reduce the standard errors of the participation equation (without materially effecting the estimated coefficients of either).[8]

Description of Variables

Table 1 lists the variables used in the analysis. Note that all variables representing physical quantities have been made comparable across households by dividing the household-level value by the number of adult-equivalent units (aeu) in the household.[9] Also, although the table presents means and standard deviations of the untransformed variables, in the regressions we use log transformations of all monetary

[7] Leung and Yu (1996) note that this problem affects not just the limited information maximum likelihood or "two-step" estimator of the Heckman model, which estimates the two equations sequentially, but also the full information maximum likelihood estimator, which estimates them simultaneously.

[8] Except in the regressions for fodder and construction wood (where the collinearity problem is particularly severe), the estimated coefficients from the two-part and Heckman models differ only marginally. This suggests that selection bias is in fact not a problem, and applying either model is appropriate.

[9] See Cavendish (1999) for a discussion of this adjustment procedure.

variables, land, livestock, biomass, and household size.

Incomes are calculated in two steps. First, income from each source in the survey year is calculated as the difference between total revenue obtained and total input costs incurred, where these totals include both market transactions and imputed values for non-market transactions. No cost is imputed for own labor, however. In particular, since for resource collection labor is the only input, current income from this source is calculated as just the imputed revenue from collection.

In the second step, "current" income in the survey year is used to estimate the household's "permanent" income from each source, defined as the flow of income that the household can expect to derive from that source over the long run.[10] For incomes derived from agriculture, livestock rearing, and financial transactions, this is done by combining current-year income with expected future income from the household's end-of-year holdings of private assets (land, livestock, farm capital, financial wealth). This expected future income is in turn calculated as a normal return to those assets plus a normal return to the labor applied by the household to agriculture or livestock rearing.[11] For incomes derived from resource collection, household enterprise, wage employment, and transfers, we simply extrapolate current-year income. Resource income is then defined as permanent income from common-pool resource collection, and resource dependence as the ratio of permanent income from natural resources to total permanent income.

Our main reason for defining incomes in the above manner is that doing so reduces the noise introduced into current incomes by positive or negative shocks in the survey year.[12] In addition, measuring resource dependence based on the share of resource income in total current income fails to fully capture differences between asset-rich and asset-poor households. All else equal, asset-rich households should be considered less dependent on natural resources, since their assets serve as a buffer to negative income shocks. Our definition of permanent income allows us to account for this buffering capability.

Recall that households also gather one resource, namely fodder, "indirectly," by grazing their livestock in common grazing lands. Since we have no reliable way of converting this resource use to a monetary value, we separately consider the time households spend grazing their livestock.

The independent variables used are those featured in the theoretical model—land, livestock, human capital, household size, biomass availability as a proxy for natural assets, and total income—as well as a vector of prices and two village-level characteristics, namely distance to markets and a dummy for the presence of a Joint Forest Management (JFM) project in the village.

Biomass availability is measured for a 5-km radius around the village center, divided by the number of households in the village, and then converted, for each household, to a per-capita value.

The most interesting price is a wage index for casual off-farm (but in-village) labor, higher levels of which may reduce resource use by increasing the opportunity cost of collection time.

Village remoteness from markets may increase resource use in two ways. First, households in remote villages are likely to have lower opportunities for off-village labor, reducing the opportunity costs of collection time. Second, households in remote villages are also likely to face higher effective costs of purchasing resources or resource substitutes.[13]

Lastly, the presence of a JFM project may affect resource use in a variety of ways.

[10] See Narain, Gupta, and van 't Veld (2005) for a more detailed discussion of our definition of permanent income.

[11] No return to labor is imputed for land or farm capital that is rented out.

[12] Because the survey year was the fifth consecutive drought year in Jhabua, many households in our sample incurred losses from agriculture and livestock rearing, sometimes making their total current income negative.

[13] Although all prices included in the regressions are in-village prices, i.e., market prices adjusted for estimated market-to-village transportation costs, it is plausible that the adjustments are imperfect.

TABLE 2
RESOURCE USE, DEPENDENCE, AND TIME SPENT GRAZING AS A FUNCTION OF TOTAL INCOME

Estimation Method	PROBIT	HECKMN	PROBIT	HECKMN	PROBIT
Dependent Variable	P.RES	P.RES	P.RES	P.RES	P.GRAZE
L.TOT.INC	2.504***	2.690***	2.504***	2.503***	3.070**
L.TOT.INC^2	−0.162***	−0.173***	−0.162***	−0.162***	−0.175**
CONSTANT	−8.797**	−9.600***	−8.797**	−8.793***	−12.467**
Number of observations	536	536	536	536	536
F	10.82***	15.05***	10.82***	6.53***	3.19**
Estimation Method	OLS	HECKMN	OLS	HECKMN	OLS
Dependent Variable	L.RES.INC	L.RES.INC	D.RES	D.RES	T.GRAZE
L.TOT.INC	0.654***	0.609***	−0.654***	−0.659***	6.193**
L.TOT.INC^2			0.039***	0.039***	
CONSTANT	1.898	2.104	2.867***	2.888***	−6.079
MILLSR		0.236**		−0.024	
Number of observations	400	400	400	400	436
F	16.31***	15.05***	6.40***	6.53***	4.86**
R^2	0.06		0.04		0.02
Condition number		38		3,564	

JFM is a government program, initiated in the mid-1990s, under which the state agrees to share forest produce from state-owned forest lands with villagers in return for their participation in the management of these lands (Khare et al. 2000). Villagers are allowed to collect dry and fallen branches for fuelwood, are given access to wood removed during thinning operations, are permitted to collect fodder and minor forest products, and are given a share of the final timber harvest. Collection is meant for domestic needs, however, and not for commercial sale. In return, villagers participate in the development of forest working plans, agree to protect the forests against encroachment and timber smuggling, and agree to restrict their use of certain forest products. Of the 60 villages in our sample, 22 have JFM projects.

V. REGRESSION RESULTS FOR RESOURCE COLLECTION

In this section, we report our regression results for resources collected by hand from the commons, leaving to the next section our results for fodder collected through grazing. We begin by investigating the simple relationship between resource use and dependence on the one hand and total household income on the other.

Relationship Between Resource Use, Dependence, and Total Income

The first four columns in the top panel of Table 2 show our regression estimates of the participation equations for all resources combined, while the corresponding columns in the bottom panel show our estimates for the conditional outcome equations.[14] For comparison purposes,

[14] In all regressions reported in this paper, superscripts *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. Standard errors and *t*-statistics are omitted to conserve space. Also, to correct for the oversampling of households described in Section 3, observations have been weighted by the inverse of each household's probability of being included in the sample. Standard errors have also been corrected to account for our survey design, i.e., for the stratified selection of villages, the oversampling, and the fact that error terms for households within any given village are likely to be correlated. Moreover, although we report results only for regressions run on the whole survey sample, all regressions were also run separately on half subsamples, by way of cross-validation. This cast doubt on the validity of only one coefficient estimate, as discussed at the appropriate point below.

estimates of both the two-part and Heckman models are shown, for resource use in columns 1 and 2, and for resource dependence in columns 3 and 4.

All four participation equations show a clear inversely U-shaped relationship between the probability of collection and the log of total income.[15] A plot of the predicted relationship (not shown) indicates that the very poorest households are somewhat less likely to collect than middle-income households, but richer households are much less likely to collect than either. The turning point of the relationship is at a per-capita income level of Rs. 2,300, about the average income in the bottom income quartile.

Conditional on collection, per-capita income from all resources is found to increase monotonically in total income (columns 1 and 2 of the bottom panel). It is therefore the richest households that are the largest conditional users of common-pool resources.

As for the comparison between the two-part and Heckman estimates, the estimated coefficient on the inverse Mill's ratio term (MILLSR) is positive and significant at the 5% level in the use regression, indicating significant positive correlation between the error terms of the participation and outcome equations. That such correlation should be present is consistent with the prediction from our theoretical analysis above that differences in asset composition between households with the same total income—differences that are absorbed in the error terms—will generally affect their probability of collection and their conditional use in the same direction.

Somewhat surprisingly, transforming the dependent variable from conditional use to conditional dependence appears to remove the error correlation, because the coefficient on the Mill's ratio term in the Heckman dependence regression is not significant. However, the term in the dependence regression is much more collinear with the income terms—the condition number is 3,564, compared to just 38 for the use regression—casting doubt on the precision with which its coefficient is estimated. Because the condition numbers for both Heckman regressions are high, our preferred estimates for both use and dependence are those from the two-part model (columns 1 and 3). Clearly the estimates differ only marginally, however, and for brevity we hereafter report only our preferred estimates.

The notable feature of the dependence regressions is that conditional dependence follows a U-shaped relationship, indicating that in the subsample of households that collect (400 out of 536 total), households at the income extremes are most dependent on resource income. The turning point for the dependence relationship is at Rs. 4,800, about the average income for households in the second income quartile. For households at the income extremes, both resource use and dependence therefore appear to be bimodal: these households tend to collect either no resources at all or a lot of resources. Moreover, both tendencies are stronger than they are for middle-income households.

These results are difficult to interpret, however, because, as noted in Section 2, essentially any relationship between the probability of collection and income, or between conditional use or dependence and income is possible in theory. Explaining the observed relationships requires first examining the effects of private-asset ownership on use, and then combining these effects with the observed distribution of private assets in the sample population.

Relationship Between Resource Use and Private Assets

In this subsection, we explore how private-asset ownership as well as various

[15] Because participation in resource use obviously implies participation in resource dependence, and because the two-part models reported in columns 1 and 3 estimate the participation and outcome equations separately, the estimated participation equations are identical. Because in contrast the FIML Heckman model estimates the two equations simultaneously, the estimated participation equations in columns 2 and 4 differ slightly.

TABLE 3
PROBABILITY OF COLLECTION AND CONDITIONAL USE AS A FUNCTION OF ASSETS

Est. Method Dep. Var.	PROBIT P.RES	PROBIT P.WFU	PROBIT P.DFU	PROBIT P.FOD	PROBIT P.WCO	PROBIT P.ORS
L.LAND	−0.084	−0.240**	−0.049	−0.250**	−0.298***	−0.028
L.LVSTK	−0.173	−0.256**	−0.235**	0.011	0.112	−0.108
HD.EDU	−0.002	−0.047***	0.093**	−0.042*	−0.063*	−0.044**
HD.EDU^2	−0.003		−0.009**			
L.HH.AEU	0.452**	0.385**	0.303*	0.183	0.255	0.317
L.BIO	0.255***	0.291***	1.315*	0.013	0.115	0.128**
L.BIO^2			−0.071			
L.TOT.INC	1.482	3.036**	1.392*	0.643***	0.757***	0.115
L.TOT.INC^2	−0.090*	−0.166**	−0.089*			
L.WAGE	0.318	0.311	−0.411	−0.476	−0.562	0.378
MKTDIS	−0.001	0.033***	−0.024***	0.021*	0.029***	0.019**
JFM	0.048	0.219	−0.391**	0.628**	0.259	0.069
CONST	−38.790***	−31.734***	−25.111**	−1.242	−1.921	−12.425
No. of obs.	536	536	536	536	536	536
F	4.46***	4.20***	2.92***	2.17**	1.91**	4.08***
Est. Method Dep. Var.	OLS L.RES.INC	OLS L.WFU.INC	OLS L.DFU.INC	OLS L.FOD.INC	OLS L.WCO.INC	OLS L.ORS.INC
L.LAND	−0.368***	−0.159	−0.084	0.482	−1.318***	0.220
L.LVSTK	0.021	−0.277	0.151	−0.628**	0.758**	−0.043
HD.EDU	0.115**	0.017	0.006	0.001	−0.064	−0.003
HD.EDU^2	−0.014***					
L.HH.AEU	−0.119	−0.399**	−0.630***	−47.254***	−35.860***	−0.429
L.HH.AEU^2				2.665***	2.123***	
L.BIO	0.223***	0.202*	0.120	−0.439*	0.404*	−0.054
L.TOT.INC	−2.458*	0.588***	0.178	0.925**	1.712***	−12.143***
L.TOT.INC^2	0.204**					0.697***
L.WAGE	−0.962**	−0.899	−0.252	1.837	−2.970***	0.218
MKTDIS	0.041***	0.023**	−0.005	0.014	0.018	−0.001
JFM	0.285	−0.300	0.147	0.744	−2.360***	0.722**
CONST	23.904*	−6.295	7.686	222.121***	156.977***	79.551***
No. of obs.	400	264	265	74	37	111
F	5.51***	4.01***	9.49***	16.55***	n.a.	28.67***
R^2	0.26	0.24	0.26	0.49	0.75	0.34

household and village characteristics affect the income that households derive from resource collection. We focus thereby on resource use rather than dependence because, as is clear from part (2) of Proposition 1, our theoretical predictions for dependence are derivative of those for use.

In Table 3, the top panel again shows our regression estimates of the participation equations, both for all resources combined (column 1) and for fuelwood, dung for fuel, fodder, construction wood, and other resources individually (columns 2–6). The bottom panel shows our estimates of the corresponding outcome equations.

Suppressed from the table are several additional independent variables, namely (1) village-level prices for each of the resources, (2) price indices for crops and for non-labor inputs such as pesticides and fertilizers, and (3) dummy variables for landless households and households with no livestock. The effects of these variables on resource use, while interesting in their own right, are not the main focus of this paper. Note, however, that including the dummy variables implies that the reported coefficients on land and livestock pertain to households that own positive amounts of these assets.

We consider each of the reported variables in turn.

Land. Our theoretical model predicts that if, as is true for most of our sample households, resource collection is mostly for own consumption, then collection of resources for which substitutes can be collected from private land will decrease with land holdings. Consistent with this, we find that the probabilities of collecting fuelwood, fodder, and construction wood decline significantly in land holdings, as does conditional use of construction wood and of all resources combined. Auxiliary regressions confirm that private provision of fuelwood, crop residues used for fuel or fodder, and fodder grown as a crop indeed increase with landholdings. Surprisingly, however, the same is not true of private provision of construction wood. It is unclear what other factors might explain the decline in construction wood collection with landholdings.

Livestock. If livestock is viewed as agricultural production capital, then our model's predictions for land apply to livestock as well. Auxiliary regressions confirm that private provision of dung for fuel increases significantly in livestock holdings. Consistent with this, we find that households with more livestock are less likely to collect both fuelwood and dung for fuel—resources for which dung collected from own livestock serve as substitutes—from the commons. Surprisingly, however, their conditional use of these resources does not appear to be lower.

Conditional use of fodder is found to decline with livestock holdings. We defer discussion of this, and most other results on fodder collection until the next section on grazing, when we can interpret them in light the tradeoff households face between stall-feeding or grazing their livestock.

Lastly, conditional use of construction wood significantly increases with livestock holdings. The likely explanation is that households need animal power to haul construction wood from village forests. For this resource, that is, livestock serves as complementary collection capital.

Human capital. Consistent with our model, the probabilities of collecting most resources decline in the household head's education. The apparent exception is dung for fuel, for which the probability appears to initially increase in education. A non-parametric estimate indicates, however, that the probability is in fact essentially constant up to an education level of about seven years, after which it drops quite sharply. A similar trend is apparent also in the relationship between conditional use of all resources combined and education. For conditional use of the individual resources, however, the estimated coefficient on education is insignificantly different from zero.

It appears, then, that human capital affects resource use mainly through the participation equation: households with more educated heads are less likely to collect resources, but if they do collect, they derive about the same income from the commons as other households.

Household size. Our model predicts that economies of scale in production will cause both the probability of collection and conditional use to increase in household size, but that economies of scale in consumption may cause conditional use to decline. For conditional use, the overall prediction is therefore ambiguous, depending on which source of scale economies dominates.

Our empirical findings are generally consistent with the presence of economies of scale in production, since the probability of collection tends to increase in household size. On the other hand, conditional resource use tends to decline in household size,[16] suggesting that economies of scale in consumption outweigh economies of scale in production.[17]

[16] For construction wood, conditional use is estimated to decline up to a household size of about five adult-equivalent members, and increase thereafter.

[17] Auxiliary regressions of per-capita consumption of fuelwood, dung for fuel, and construction wood on prices, total income, and household size support the presence of such economies of scale in consumption: the estimated coefficient on household size is negative for all three resources, though not significantly so for construction wood.

Biomass. As expected, and consistent with our model, both the probability of collection and conditional use of most resources increase in per-capita biomass availability.[18]

Total income. Although our model suggests that variations in resource use with income are driven by underlying variation in public and private asset holdings, the inclusion of these asset holdings as independent variables in the regressions does not remove the significance of the total income terms. There are several possible explanations for this finding.

First, given that most households consume all the resources they collect, the positive coefficients on most of the linear income terms[19] may simply capture income effects on consumption, which auxiliary regressions[20] estimate to be positive for fuelwood, dung for fuel, and construction wood.

Second, income may be explained partially by forms of human capital not captured by the education variable, such as skill, experience, or personal connections. This unmeasured human capital may help explain why (according to simple tabulations) the very richest households in our sample derive considerably more income from private enterprise and from regular jobs in the public and private sector. If this raises these households' opportunity cost of time, this may in turn explain the estimated decline in the probability of collection at the highest incomes.

Lastly, differential access to resource stocks may be a factor. In many villages in our sample, formal or informal restrictions exist on how much households can collect from the commons, and Angelsen and Wunder (2003) note that in such situations the rich often manage to influence policies and rules in their own favor. In effect, the rich own more "political capital," which acts as a complement to common-pool resource stocks.

Village wages. As expected, higher wages for casual farm labor are found to reduce conditional use of all resources combined. At the individual resource level, however, the effect is significant only for construction wood.

Market distance. Also as expected, increased distance to agricultural markets is found to generally increase both the probability of collection and conditional use.

Joint Forest Management. The presence of a JFM project in a household's village is found to reduce the probability of collecting dung from the commons, but increase the probability of collecting fodder. This may be explained by the fact that, in order to protect young plantations, villages with JFM projects often close off certain sections of village forest lands to grazing (which reduces the amount of dung available in the commons) and instead allocate families plots of communally owned land where they can collect fodder by hand.

Villages with JFM projects are also more likely to enforce restrictions on timber felling, and provide better opportunities for marketing non-timber forest products such as *mahua* flowers and *tendu* leaves. This may explain why the presence of a JFM project is found to reduce conditional use of construction wood, but increase conditional use of other resources.

Relationship Between Resource Use and Total Income Revisited

Having gained some understanding of the relationships between resource use and private-asset ownership, we now return to

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[18] The estimated coefficient on biomass in the conditional use regression for construction wood is somewhat suspect, however. In our cross-validation exercise (recall note 14), this coefficient is estimated to be positive and significant (at the 1% level) in one half subsample, but negative and significant (at the 5% level) in the other. Given the small sample size—just 37 observations—this instability is not surprising.

[19] For use of all resources combined, the positive coefficient on the quadratic income term dominates the negative coefficient on the linear term throughout the sample range.

[20] Recall note 17.

those between resource use and total income reported in Table 2.

Our theoretical model, supported by the estimated outcome equations of Table 3, suggests that the observed increase with total income of conditional resource use can be explained partly by the corresponding increase in livestock holdings (which complement the resource stock of construction wood), partly by income effects on the consumption side, and partly perhaps by an increase with income in "political capital" (which complements the resource stock by improving access to it).

This still leaves the puzzle of the bimodality in resource use at the income extremes. Here our model suggests that variation in asset ownership among households within the same income group may underlie the bimodality. The estimated participation equations of Table 3 suggest more specifically that when comparing collecting households to non-collecting ones, the latter are likely to have higher education levels, more land and livestock, and smaller households. Simple tabulations (not shown) confirm that this is indeed the case. In the lowest income quartile, non-collecting households are significantly more educated, own somewhat more land and livestock, and have significantly fewer household members than collecting households. In the top income quartile, non-collecting households are somewhat more educated, own significantly more land—more than twice as much as collecting households—and somewhat more livestock. These asset holdings appear to give non-collecting households a comparative advantage in deriving income from sources other than resource collection or casual labor; instead, they derive a large share of their income from public-and private-sector jobs, household enterprise, and agriculture.[21]

[21] Auxiliary regressions confirm that the probabilities of deriving income from either public- and private-sector jobs or household enterprise significantly increase in education, as do the conditional levels of income from these sources. The same is not true of income derived from casual in- or off-village labor.

As for households in the middle income quartiles, we find that, compared to households at the income extremes, these households tend to be larger—implying a higher probability of collection but lower conditional use—with a smaller spread in education levels. Compared to households in the top income quartile, the spread of land and livestock holdings is smaller as well. All three findings are consistent with resource use by these households being not as bimodal.

VI. REGRESSION RESULTS FOR TIME SPENT GRAZING

We next turn to our regression results for the time households spend grazing their livestock in the commons, which most households (436 out of 536) in fact do. As with hand-collected resources, we begin by estimating the relationship between this use and total household income alone.

Relationship Between Time Spent Grazing and Total Income

The final column of Table 2 shows the two-part model estimate of this relationship. As with hand-collected resources, the probability of grazing is inversely U-shaped in income (the turning point is at Rs. 6,300, about the average income of households in the third income quartile) while the conditional time spent grazing increases monotonically. Both results reinforce our earlier finding that resource use by the rich is bimodal: they are the largest conditional users of common-pool resources, but also the least likely to use any resources at all.

Interpreting these relationships again requires a closer examination of the relationship between time spent grazing and private-asset ownership, to which we turn next.

Relationship Between Time Spent Grazing and Private Assets

Table 4 reports the expanded regressions, including separate regressions for time

TABLE 4

Probability of Grazing and Conditional Time Spent Grazing as a Function of Assets

Estimation Method	HECKMN	HECKMN	HECKMN
Dependent Variable	P.GRAZE	P.GR.OWN	P.GR.HIR
L.LAND	−0.155***	0.003	−0.073
L.LVSTK	0.632***	0.843***	0.300***
L.LVSTK^2		−0.045***	
HD.EDU	−0.020*	−0.062***	0.044***
L.HH.AEU	0.652***	0.311**	−0.321
L.BIO	−0.156*	−0.131	0.031
L.TOT.INC	0.074	1.087	0.115
L.TOT.INC^2		−0.070	
L. WAGE	−0.540	−0.339	0.183
MKTDIS	0.007	−0.010	0.004
JFM	−0.204	−0.250	−0.047
CONSTANT	−9.739	−7.699	−2.102
No. of obs.	536	536	536
Estimation Method	HECKMN	HECKMN	HECKMN
Dependent Variable	T.GRAZE	T.GR.OWN	T.GR.HIR
L.LAND	−1.357	0.924	−5.903
L.LVSTK	10.588***	8.264***	20.499***
HD.EDU	−0.097	−0.794*	2.796**
L.HH.AEU	−33.285***	−24.730***	−33.024***
L.BIO	2.867*	2.574	9.932
L.TOT.INC	2.681	2.962	1.415
L. WAGE	10.443	2.899	4.366
MKTDIS	−0.066	−0.247	0.667
JFM	3.061	2.764	21.639**
CONSTANT	137.783	67.064	643.669
MILLSR	−0.096	−0.142*	1.008
No. of obs.	436	363	121
F	10.84***	4.38***	5.38***

spent grazing by own household members and by labor hired for that purpose. Suppressed from the table are the same variables suppressed from Table 3, except that that a dummy for households with no livestock is not included in the regressions here.[22]

Heckman rather than two-step results are reported, even though the coefficient on the inverse Mill's ratio terms is not significant in columns 1 and 3. Including these terms in the outcome equation turns out to significantly reduce the standard errors in the participation equation, however, without materially affecting the coefficient estimates themselves. The latter is true also of the regression in column 2, even though the inverse Mill's ratio term in that regression is significant at the 10% level.

Land. Consistent with the fact that stall-fed crop residues or fodder grown as a crop can substitute for grazed fodder, the probability of grazing is found to significantly decrease with land holdings. Recall that the same was true for the probability of collecting fodder from the commons.

Livestock. As noted in Section 2, the fact that grazing typically takes only one person's time strongly favors grazing over stall-feeding for households with large livestock holdings. Consistent with this observation, both the probability of grazing and conditional time spent grazing increase in live-

[22] The no-livestock dummy is excluded because it would perfectly explain non-grazing in the participation equations, and would be perfectly collinear with the constant in the outcome equations.

stock, but in Table 3, conditional collection of fodder decreases.

Human capital. Consistent with our model, the probability of grazing rather than stall-feeding livestock is found to decrease in education. Moreover, consistent also with the model, use of hired labor for grazing is found to significantly increase with education, whereas use of own labor declines.

Household size. The fact that grazing typically takes only one person's time explains also why the probability of grazing increases in household size, but in Table 3, conditional collection of fodder mostly decreases.[23] That conditional grazing time also decreases in household size follows because the time is expressed in per-capita terms: the same full day spent by one person grazing the herd translates into a smaller per-capita time for larger households.

Biomass. In Table 3, we find that conditional collection decreases in biomass. This is consistent with our model if higher biomass increases the marginal productivity of grazing by more than that of collection. Even then, however, the predicted effects on grazing remain ambiguous, as these depend also on the increased total productivities. We find that the probability of grazing declines, while the conditional time spent grazing increases in biomass.

Relationship Between Time Spent Grazing and Total Income Revisited

Returning now to the relationships between grazing time and total income reported in Table 2, it is clear from the estimated outcome equations of Table 4 that the observed increase of conditional grazing time with income is explained by the corresponding increase in livestock holdings.

[23] In the conditional fodder collection regression, the negative linear term on household size dominates the positive quadratic term through most of the sample range.

As for the bimodality in grazing by the rich, the estimated participation equations of Table 4 suggest that when comparing grazing to non-grazing rich, the latter are likely to have higher education levels, more land, less livestock, and smaller families. Simple tabulations confirm this. Compared to grazing households, non-grazing households in the top income quartile are indeed more educated, own significantly less livestock—less than one-sixth as much as grazing households—and have significantly fewer household members. They also own significantly less land, but slightly more land per animal, which is what matters to private fodder provision.

The grazing rich, then, derive their incomes mostly from agriculture, supported by their large land and livestock holdings, whereas the non-grazing rich derive much of their incomes from household enterprise and public- and private-sector jobs, supported by their high levels of human capital.[24]

VII. CONCLUSIONS

Two recent reports on economic development—Pearce (2005), commissioned by a network of more than 30 international development and environment agencies, and WRI (2005), produced by the United Nations Development Programme, the United Nations Environment Programme, the World Bank, and the World Resources Institute—argue for an asset- rather than income-based approach to poverty alleviation, and for viewing natural resources as a particularly important asset for the poor. The central argument of both reports is that poverty results from lack of private assets, but that improving the productivity of natural resource stocks will increase incomes for the poor and allow them to "begin the journey out of poverty" by starting to accumulate their own assets.

Both reports emphasize, however, that without careful policy design, richer house-

[24] Recall note 21.

holds may end up reaping most benefits of the improved productivity. The WRI report stresses the "structural advantage" that the rich have because of their ownership of complementary private assets:

> For example, watershed restoration in arid climates will clearly advantage those with more land, especially if these are low-lying lands where the groundwater captured by the restoration is likely to accumulate most. Likewise, owners of large boats with more efficient gear will be able to harvest more of a healthy fish stock than the poorest fishers paddling small pirogues.

This complementarity in production is just one of many ways in which natural and private assets may interact, however, and Pearce notes that gaining a better understanding of the various links and interdependencies between natural and private assets is an important area for further research.

This paper has attempted to further such understanding by developing and testing a simple theoretical model of optimal resource collection by households from a common-pool stock. The model predicts that if resource collection and sales are unconstrained, then private-asset ownership and household size affect resource collection in very simple ways: resource use (both the probability of collection and the conditional amount collected) decreases in human capital, is invariant to agricultural capital, and increases in resource-collection capital, with household size playing a role similar to the collection capital if there are economies of scale in collection.

When realistic constraints on collection and sales are introduced, however, interactions become considerably more complex. Resource use may then increase in private-asset ownership purely because of income effects on the consumption side, for example, or decrease in household size (in per-capita terms) because of economies of scale in consumption. The tradeoff between private provision of resource substitutes and collection from the commons also becomes relevant, as does, for the specific resource of fodder, the tradeoff between collecting by hand or through grazing.

As for the relationship between resource use or dependence and total income—a focus of much of the existing empirical literature—the model shows that this relationship is inherently unpredictable, as it depends on the empirical asset distribution across as well as within income groups.

Our tests of the model using survey data from Jhabua, India, find considerable support for its predictions. Moreover, when combined with the observed sample distribution of assets and households sizes, our findings can at least partially explain the observed relationships between resource use, dependence and total income in Jhabua.

At the most general level, then, the main conclusion to be drawn from our study is that, conditional on the asset distribution that obtains in any given study area and on any institutional constraints that affect resource collection, household decision-making with respect to such collection can be understood using standard economic analysis of a simple household model.

A more specific conclusion, which reinforces the findings of Adhikari (2005) as well as the observation quoted above from the WRI (2005) report, is that policy makers should be aware of complementarities between private and natural assets. Like Adhikari finds in Nepal, we find that richer households in Jhabua may, to the extent that they own more livestock, end up benefiting disproportionally from policies that improve common-pool resource stocks. Our finding is not clear-cut, however, in that livestock appears to complement for only some common-pool resource stocks, while serving as a substitute for others. Moreover, whereas Adhikari conjectures that land complements common-pool resources as well (but is unable to test for this), we find that in Jhabua, land largely serves as a substitute.

Even more specifically, we find that JFM, the state-initiated forest management scheme, is changing the manner in which households use common-pool forest resources in Jhabua. Households appear to be restricting grazing in favor of fodder collection by hand, possibly to protect young plantations. They also appear to be reducing their collection of construction wood, possibly to a more sustainable level, while increasing their collection of non-timber forest products such as *tendu* leaves and *mahua* seeds, possibly because of better opportunities to market these products. While these findings suggest that JFM is having some of its intended effects in Jhabua, it is as yet unclear whether the program is increasing the forest stock, or in fact improving households' welfare. Nonetheless, our results provide one of the first assessments of the impact of JFM.

It should be emphasized that our analysis of how improvements in natural resource stocks might be used to alleviate poverty is only partial. To arrive at a more complete understanding, at least three sets of questions will have to be addressed that our paper has left for future extensions.

First, how do the institutional constraints on collection that our analysis takes as given come about? What exactly is the nature, for example, of the fixed costs or institutional constraints that induce households in Jhabua to rarely sell collected resources? Why do households rarely hire labor for resource collection by hand, but commonly hire labor for grazing?

Second, how does the distribution of private assets across and within income groups come about, and might this distribution itself change if natural resource stocks improve? Jodha (1986) suggests, for example, that public grazing space and fodder allow small farmers in particular to keep more livestock than they could sustain on their own land. Similarly, Pearce (2005) suggests that having to spend long hours collecting fuel or water interferes with schooling of children.

Lastly, and perhaps most importantly, how can resource management policies be designed to benefit the poor? As noted in Section 5, richer households may influence formal or informal restrictions on access to resource stocks in their own favor, in effect making use of their higher ownership of another private asset, "political capital." Any increase in resource productivity may then merely increase the incentive of the rich to do so, thereby perversely harming rather than benefiting the poor.[25] To prevent this from happening, natural asset-based poverty alleviation policies will have to include measures that improve or at least protect the resource-access rights of the poor.

APPENDIX

Proof of Proposition 1

(1) Since resource income π^r and total income π are both functions of X, and $d\pi/dX$ is positive by definition of X being a productive asset, we have

$$\frac{d\pi^r}{d\pi} = \frac{\frac{d\pi^r}{dX}}{\frac{d\pi}{dX}} \overset{s}{=} \frac{d\pi^r}{dX} = p^r \frac{\partial q^r}{\partial t^r}\frac{dt^{r*}}{dX} + p^r \frac{\partial q^r}{\partial K^r}\frac{dK^r}{dX}.$$

For assets other than resource capital ($X \neq K^r$), the second term in the final expression is zero, and since $\partial q^r/\partial t^r > 0$, we have $d\pi^r/dX \overset{s}{=} dt^{r*}/dX$. For resource capital ($X = K^r$), since $\partial q^r/\partial K^r > 0$, the second term is positive, but from equation [2] in the text, so is the first term. Hence again $d\pi^r/dX \overset{s}{=} dt^{r*}/dX$. The proof that $\partial^2\pi^r/\partial R\partial X \overset{s}{=} dt^{r*}/dX$ is analogous.

(2) Since dependence D is also a function of X, and given again that $d\pi/dX$ is positive, we have

$$\frac{dD}{d\pi} = \frac{\frac{dD}{dX}}{\frac{d\pi}{dX}} \overset{s}{=} \frac{dD}{dX} = \frac{\frac{d\pi^r}{dX}\pi - \frac{d\pi}{dX}\pi^r}{\pi^2} \overset{s}{=} \frac{d\pi^r}{dX}\frac{X}{\pi^r} - \frac{d\pi}{dX}\frac{X}{\pi}$$

It follows that $d\pi^r/d\pi \overset{s}{=} d\pi^r/dX \leq 0$ is sufficient for $dD/d\pi < 0$, while $d\pi^r/d\pi \overset{s}{=} d\pi^r/dX > 0$ is necessary for $dD/d\pi \geq 0$.

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[25] That this perverse effect may occur is sometimes referred to as the "Dove hypothesis," after Dove (1993).

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