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The Adoption of Consumption Technologies under Uncertainty: A Case of Improved Stoves in Nepal

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This paper uses a household model to examine the adoption and efficient use of a consumption technology, improved stoves in Nepal. Improved stoves are a technological substitute for fuelwood. Therefore, they can act as one control on deforestation. Both adoption and efficient use are uncertain events, as is future household income. Our evidence argues that fuelwood and fuelwood substitute prices, the level of stove efficiency, household income, and demographic characteristics indicative of greater information and wealth are the important indicators of adoption and efficiency.

I. Introduction

Improved stoves are a technological substitute for fuelwood in many subsistence economies. Therefore, international development agencies often encourage the adoption of improved stoves in attempts to reduce the pressure on local forests and decrease the serious rate of deforestation observed in many developing countries today. This paper examines the adoption and efficient use of improved stoves in the hills of Nepal.

Knowledge of the characteristics of stove adoption is sparse. While a

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substantial literature characterizes the important features of adopting new agricultural production technologies, there is little empirical evidence on household or rural community adoption of consumption technologies and virtually none on the adoption of new forestry activities (e.g., nurseries, seedlings, planting techniques) — in Nepal or elsewhere.[1] Therefore, evidence on the adoption of improved stoves should be broadly useful for development agencies, particularly as they promote various forest conserving activities.

Improved stoves are enclosed replacements for the traditional open tripods familiar in poor households throughout the world. Enclosed stoves retain heat longer, thereby consuming less fuel and reducing the household fuel budget. They also improve health and nutrition. They improve human health by funneling the smoke discharge, thereby reducing human exposure to a prime cause of the upper respiratory diseases that affect 46 percent of Nepal's population. They indirectly improve nutrition by reducing the time women spend collecting fuel, thereby increasing the alternate use of women's time for food preparation and improving nutrition for the entire household. [Kumar and Hotchkiss (1988) trace these linkages econometrically.]

Nevertheless, each of these gains is uncertain for household decision-makers considering a new technology. These uncertainties contrast with the certain financial cost of an improved stove. The gains also vary with the efficiency of household use of the stove. Thus, both the decision to purchase an improved stove and the choice regarding its efficient level of use depend on household attitudes toward risk and household expectations of the uncertain gains from its adoption.

This paper uses a utility maximization model to explain the representative household's decision to adopt an improved stove. Our model illustrates both the household's decision to purchase the stove and its decision to use the stove efficiently. Increasing efficiency only comes with an increasing expenditure of household resources. The qualitative effects of fuel price, fuelwood production parameters, exogenous income, and household demographic characteristics should be useful guides to policy. Empirical results from households in two hill districts in eastern Nepal suggest the characteristics of households that will accept the risks and lead their communities in adopting improved consumption technologies. This paper differs from other studies of adoption in that a) it examines a consumption technology, b) the technology can vary in efficiency and c) technology adoption has an unknown wealth effect.

1 Feder *et al.*, (1985) is the standard reference for technology adoption in agriculture.

II. The Theoretical Model

Consider a representative household's decision to purchase an improved stove. The household maximizes a utility function with arguments for the consumption of fuelwood and other goods. Both the fuelwood production technology and the household budget constrain consumption. A portion of fuelwood collected may be sold in an existing market.

The household's problem is to select optimal levels of labor and capital inputs and its optimal level of fuelwood consumption, as well as to make a decision regarding the purchase of a stove. Once the household decides to purchase a stove, then it must also choose the efficient level of stove use. The complete household problem is

$$(1) \quad V(p,I;C) = \max E[U(F,X;C)], \\ \text{subject to } \theta(Q,K,K) = 0, \\ p_x X + p_f[(F-\alpha(e,S)] + S + w(R-t) - \pi(w, r) - M = 0 \text{ and} \\ F,X,Q,L,K \geqslant 0.$$

where maximization is over fuelwood cosumed F and fuelwood produced Q, other consumption goods X, and labor L and capital K inputs. V(p,I;C) is indirect expected utility. It depends on the known fuelwood price p_f, other consumption good prices p_x, household income I, and demographic characteristics C. (Household demographic characteristics are exogenous to the wealth maximizing decision, but they still may be important determinants of household behavior.) U(·) is household utility. We assume that U(·) is separable in fuelwood and other goods thus $U(F,X;C) = U^1(F) + U^2(X;C)$. $\theta(\cdot)$ is the production technology that relates labor and capital inputs to fuelwood production.

R is leisure time and t is total time. S is investment in an improved stove, w is the wage, and r is the rental rate of capital. $\pi(\cdot)$ is the profit function for sales of fuelwood and other household production. Household income has a deterministic component M (exogenous income), and an unknown component $[-p_f\alpha(e,S)]$ representing the decrease in fuelwood expenditure when S is invested in an improved stove. Thus, the certain outlay of S introduces a random wealth term into the household budget.

The function $\alpha(\cdot)$ represents two characteristics of the stove adoption decision. First, in order to reduce fuel consumption, the household must invest in (adopt) an improved stove. Second, increasing investments in S imply increasing levels of stove efficiency.[2] The more the household invests in the stove, the greater the deterministic component of household income. The form of $\alpha(\cdot)$ includes most classes of uncertainty and the economic intuition is the same in all classes. The multiplicative form αSe is illustrative.[3] The parameter e is a random variable such that $E(e) = \beta$ and $VAR(e) = z$, where $\alpha(e,S) \geqslant 0$ for all S and $\int \alpha(e,S)dS = 1$ where S is in $[0, \infty)$. We assume that $\partial\alpha(\cdot)/\partial S \geqslant 0$ and $\partial^2\alpha(\cdot)/\partial S^2 < 0$.

We can optimize with respect to the investment in stove efficiency, S, by removing fuelwood consumed, F, from eq. (1). Solving the budget constraint for F and substituting into eq. (1) allows us to restate F in terms of random wealth $W(\alpha,S)$, where

$$W(\alpha,S) = [w(t-R) + \pi(\cdot) + M - p_x X - S]/p_f + \alpha(e,S)$$

Ignoring the non-negativity conditions for now, the new household problem, equivalent to eq. (1), is

$$(2) \qquad V(p,I;C) = \max E\{U[W(\alpha,S),X;C] - \lambda_1\theta(Q,L,K)$$

$$(2a) \qquad = \max E\{U[W(\alpha,S);C] + U^2(X;C) - \lambda_1(\cdot)\}$$

where maximization is now over S, X, L, and K. λ_1 is the Lagrangian multiplier associated with the household's production function. Because utility is separable, $U[W(\alpha,S),X;C]$ is quasi-linear in $W(\cdot)$, and X. The model in eq. (2a) represents the static household decision to adopt an improved stove technology. In reality, the household's decision is intertemporal, since current investment in an improved stove affects future fuel consumption. Therefore, a more appropriate interpretation is that our model represents the discounted value of the infinite stream of reductions in fuelwood consumption due to a one time investment of S.

Household consumption and production decisions are separable in eq. (2a).[4] This means that the uncertainty regarding improved stove adoption has no impact on the household's allocation of its labor and capital in-

2 Improved stoves, in this part of Nepal, are generally similar. S is continuous because some households expend more resources to use similar stoves more efficiently.

3 Fabella (1989) classifies and provides examples of the uncertainties normally encountered in household production models.

4 Separability between consumption and production means that household demand has no effect on household input allocations or household production, although the parameters of household production may determine demand through the household return (profits). The farm household model is separable when complete markets exist for all goods, and the household is indifferent between family labor and hired labor (Singh 1986).

puts. Separability allows us to abstract from the labor and capital decisions and to focus on the fuelwood consumption and improved stove decisions.

The first order conditions for the optimal investment in an improved stove and the optimal level of consumption of other goods are

$$(3) \qquad V_s = EU_w(\cdot)\,[\frac{\alpha(e,S)}{S} - \frac{1}{p_f}] = 0$$

$$(4) \qquad V_x = E[U_w(\cdot)(-\frac{p_x}{p_f}) + U_x^2(\cdot)] = 0$$

We assume the second order conditions hold such that $V_{ss} \leqslant 0$, $V_{xx} \leqslant 0$, and $V_{ss}V_{xx} - (V_{xw}\; V_{wx}) > 0$.

We can use conditions (3) and (4) to examine the two aspects of the households improved stove decision: adoption and the level of efficient use. In order to determine a condition for adoption $(S > 0)$, we can first identify the corner solution $(S = 0)$ and then observe when it is not satisfied. Setting $S = 0$ in conditions (3) and (4), condition (4) becomes irrelevant and condition (3) can be expressed as

$$(5) \qquad V_s = U_w[W(\alpha, 0), X{:}C]\;[E\frac{\partial\, \alpha(e,0)}{\partial S} - \frac{1}{p_f}] \leqslant 0$$

If $S = 0$, the sign of V_s in condition (5) must be strictly negative. Therefore, the household will adopt an improved stove if the expected marginal decrease in fuelwood consumption is greater than the inverse fuelwood price. The probability of adoption $(S > 0)$ approaches one as the fuelwood price approaches infinity. In the particular case where $\alpha(\cdot) = \alpha Se$, the household will adopt as long as $\beta \geqslant 1/p_f\alpha$.

If the household adopts a stove, then $S > 0$ and conditions (3) and (4) simultaneously determine the household's investment in stove efficiency. We can improve our intuition about stove efficiency by holding consumption of other goods X constant. Rewriting condition (3),

$$(6) \qquad E[\frac{\partial\alpha(e,S)}{\partial S} - \frac{1}{p_f}] = -COV(U_w(\cdot), \frac{\partial\alpha(e,S)}{\partial S} - \frac{1}{p_f}]/EU_w^1(\cdot)$$

From condition (5) and the assumption that $U_w(\cdot) \geq 0$, the LHS of condition (6) must be less than or equal to zero when $S \geq 0$. Thus, condition (6) implies that the household chooses a stove such that the expected return from owning it (the reduced household value of fuelwood consumed) equals the covariance between the marginal value of wealth changes (U_w) and the marginal income change [$\partial\alpha(e,S)/\partial S$]. Or, at the chosen level of S, the expected gain from having the stove (LHS) equals the covariance between marginal utility and marginal income. We expect that $COV[U_w(\cdot), \partial\alpha(e,S)/\partial S] \leq 0$, because as the marginal return from investing in a stove increases, the term $\partial\alpha(e,S)/\partial S$ increases, and the marginal utility of wealth must decline if utility is concave.

Once more, if we impose $\alpha(\cdot) = \alpha Se$, then the household optimally invests S^* such that condition (6) becomes

$$(7) \qquad \alpha\beta = -COV[U_w(\cdot), \frac{\partial\alpha(e,S)}{\partial S}]/EU_w^1(\cdot) + \frac{1}{p_f}$$

When stove investment is strictly positive (that is, the household has already chosen to invest), conditions (3) and (4) can be examined simultaneously to determine the effects of exogenous parameters on the level of stove investment.[5] Conceivably, these effects will depend on the household's attitudes toward risk: is it increasingly risk averse, decreasingly risk averse, or risk neutral.

Table 1 summarizes the comparative static results. The first column shows the qualitative effects related to stove adoption as derived by totally differentiating condition (5). The second and third columns of Table 1 show the qualitative effects related to stove efficiency, given adoption, as derived from conditions (3) and (4) (Silberberg 1989) for both households with decreasing absolute risk aversion (DARA) and households with increasing absolute risk aversion (IARA).[6] (An appendix provides the

[5] In practice, the household can adjust its level of stove expenditures continuously. Our data, however, indicate only two levels of stove efficiency. Therefore, our empirical analysis will abstract from the continuous case and explain efficiency as a discrete variable. Household choice between two discrete levels of efficiency can still be represented with expected utilities. (For example, given that the household adopts a stove, the choice between two stove types ($S_1 > S_2$) is described by the expression: Choose S_2 if and only if $EV(p,I|S=S_2) > EV(p,I|S=S_1)$, where $V(p,I)$ is defined as in eq. (1), but is conditional on the level of stove efficiency.)

[6] Using the definition of the Arrow-Pratt coefficient of risk aversion, $A(W) = -U_{ww}/U_w$, DARA implies that $dA(W)/dW < 0$. IARA implies $dA(W)/dW > 0$. These restrictions are

Table 1

THE EFFECTS OF EXOGENOUS PARAMETERS ON
THE PROBABILITY OF IMPROVED STOVE ADOPTION
AND THE EFFICIENT LEVEL OF STOVE USE

Parameter	P(adoption)	Efficient level of use S^*	
		DARA[a]	IARA[b]
change in fuelwood price, p_f	+	+	+
change in price of other consumption goods, p_x	+	+	+
change in wage, w	0	+ /−	−
decrease in fuelwood consumption (mean decrease in $\alpha(e,S)$)	+	+	+
variance in fuelwood consumption (mean preserving spread in $\alpha(e,S)$)	+	+ /−	+ /−
change in household profit, $\pi(\cdot)$	0	+ /−	−
change in exogenous income, M	0	+ /−	−

[a] decreasing absolute risk aversion
[b] increasing absolute risk aversion

proofs.) This qualitative evidence is suggestive of the best household and community targets for development policies that feature improved stoves as a means of reducing the impact of fuelwood collection on deforestation.

All price increases (p_f or p_x) improve the likelihood of adoption because their direct and positive substitution effects outweigh their indirect income effects. Price increases also induce increases in stove efficiency. We expect that, as prices rise, households that are less risk averse (DARA) will invest more in stove efficiency than households that are more risk averse (IARA).

The greater the anticipated mean fuel reduction due to use of an improved stove, the greater the likelihood of adoption, and of more efficient use as well. A change in the variance in expected fuel reduction will be

useful in assessing the comparative static results in Table 1. The assumption of separability in the utility function does not effect the interpretation of the Arrow-Pratt coefficient of risk aversion.

perceived differently by households with different attitudes toward risk. While risk preferring households always prefer an increase in the variance of expected fuel reduction, the qualitative effects on S are ambiguous.

Greater income (household profits or exogenous income) has no effect on adoption. It has an uncertain effect on stove efficiency because risk aversion can change over income levels. If, as generally thought, higher income households are less risk averse, then higher income households may be willing to use a greater share of their income for fuel — or they may be willing to invest more capital in stove efficiency.

In sum, these qualitative results imply that prices and technology-induced fuelwood reduction are the important factors in determining adoption. Predicting efficient stove use is a more complex, and less theoretically certain, issue. It depends on unobservable aversion to a risky investment. For either decision, we may still anticipate that (theoretically unexplained) household characteristics may be important indicators of both adoption and efficiency.

III. Empirical Results

A survey of 99 households from two hill districts in Nepal provides the data to investigate the behavioral postulates derived from conditions (3)-(5). The survey includes observations on fuelwood prices, purchases, and consumption; agricultural residues consumed as a substitute fuel, profits from household production, and exogenous (business and service) income; various demographic characteristics including family size, literacy, education, and ethnic group; and qualitative variables identifying whether the household adopted an improved stove and the efficiency of stove use. The survey also includes observations on the reduction in fuelwood use after a stove was adopted. All households in the sample burned fuelwood.

Households confront the stove adoption and efficient use decisions simultaneously, according to conditions (3)-(5). These decisions can be expressed in a simple probit framework. For the first decision:

(D1) $P(\text{adopt}) = \Gamma(Z)$; $P(\text{do not adopt}) = 1 - \Gamma(Z)$

where, from condition (5), Z is a vector that includes fuelwood price, household demographic characteristics, and other variables that affect the formation of expectations about reduction in fuelwood consumption. $\Gamma(Z)$ is the cumulative density function of a normal random variable. For simplicity in the second decision (from conditions (3) and (4)), consider two levels of stove efficiency, $S_1 < S_2$. Then,

(D2) $P(S_1 \text{ given } S>0) = \Gamma(Z \text{ given adopt})$;

$P(S_2 \text{ given } S>0) = 1-\Gamma(Z \text{ given adopt})$

Table 2 presents the profit estimates for (D1)–(D2).[7] These estimates are generally consistent with the theoretical expectations from Table 1. The survey does not include observations of either wages or variances in

Table 2

PROBIT ESTIMATES OF DECISIONS 1 (adopt) and 2 (efficient use)[a]

Independent Variables	D1 adoption	D2 efficiency
fuelwood price, p_f	0.0641** (1.94)	0.0164 (0.67)
agricultural residues (negative proxy for p_x)	−0.293* (−2.57)	−0.110** (−1.86)
fuelwood reduction, $\alpha(e,S)$	0.143* (1.99)	0.124* (2.27)
profit from household production, π	−0.000567 (−0.22)	−0.00159 (−0.77)
exogenous (non-agricultural) income, M	0.00859* (2.51)	0.00575* (2.15)
Brahmin	1.072** (1.93)	0.663** (2.00)
constant	−2.69* (−3.20)	−1.52* (−3.39)
likelihood ratio test statistic	24.3	15.2
percentage of correct predictions	90	76

[a] numbers in parentheses are asymptotic t ratios
* significant at the .01 level, ** significant at the .05 level

[7] We assume that errors in conditions (3)–(5) are symmetric and uncorrelated. As development agencies and other researchers collect larger data sets, the validity of these assumptions can be tested using bivariate probit methods.

the households' expected fuel reductions. Therefore, we cannot draw conclusions about the wage rate or the mean preserving spread. Furthermore, the survey includes no observations of the prices of other consumption goods. It does, however, include observations on agricultural residue consumption, a substitute for fuelwood. If residue demand is downward sloping, then consumption decreases when residue prices increase, and an agricultural residue proxy for p_x should have the opposite sign from that anticipated for p_x in Table 1.

The adoption equation prices have the anticipated signs and both are significant. Fuelwood reduction is positive and significant, as anticipated. The income terms (π and M) are small and one is insignificantly different from zero, as it should be. The efficiency equation prices both have the anticipated signs and one is significant. Fuelwood reduction is positive and significant, as anticipated. The significant positive coefficient on exogenous income (and insignificant π) may suggest DARA — a reasonable expectation for most populations.

Brahmins are the highest Hindu social caste. They are generally wealthier and better educated. As a group, they are probably more aware of new opportunities and they probably have more capital to use in risky activities than the average household in the general population. A dummy variable identifying Brahmin households performs well in both equations.[8]

The test statistics for both equations are satisfying. The adoption specification predicts ninety percent of all observations correctly. The efficiency specification predicts 76 percent of all observations correctly.

IV. Conclusion

Not all households adopt new stove technologies and not all adopters operate their stoves at the same level of efficiency. Thus, the adoption and

8 Newars are a separate, non-Hindu, ethnic group that uses additional fuel to brew raksi, their traditional alcoholic beverage. We examined, and rejected, econometric specifications including a dummy variable for Newars. We also rejected specifications including years of school and family size.

The two survey districts have substantially different forest endowments. Within each district, farm houses are more likely to be individually constructed than houses in villages. Therefore, farm houses may require more heating. They are also closer to the sources of fuel. Nevertheless, specifications that separate the 99 observations by district, primary income source (agricultural or business-service), or income level do not improve on the statistical results for the full sample.

efficiency decisions imply two levels of potential fuel saving. Policymakers should consider both when evaluating the reduction in deforestation due to introducing improved stoves.

Furthermore, both adoption and efficient use are uncertain events. Neither is a sure thing wherever development advisors desire to introduce the new technology. Rather, both are dependent on the relevant prices, uncertain fuel savings, and household risk preferences. Households in higher price regions, households expecting greater fuelwood savings, and households with demographic characteristics suggesting greater information and more risk capital will adopt the new technology before their less-well-endowed neighbors. Among these households, those with greater exogenous incomes will use the new technology more efficiently.

Appendix

Adoption: The qualitative effects of adoption can be derived by totally differentiating condition (5). From condition (5) and the assumption that $U_w^1(\cdot) \neq 0$, the condition to adopt an improved stove simplifies to

$$\text{(A1)} \qquad E\,\frac{\partial \alpha}{\partial S}(e,0) - \frac{1}{p_f} = 0$$

$$\Rightarrow S = 0 \quad \text{iff} \quad E\,\frac{\partial \alpha}{\partial S}(e,0) < \frac{1}{p_f}$$

It is apparent that, for a given $\partial\alpha(e,0)/\partial S$, an increase in p_f implies an increase in the probability that $S>0$. Similarly, for a given p_f, an increase in $\partial\alpha(e,0)/\partial S$ increases the probability that $S>0$. Because they do not appear in condition (A1), neither p_x, w, π nor M have any effect on adoption.

Efficiency: Using $\alpha(e,S) = \alpha S e$, the second derivatives for conditions (3) and (4) are:

$$\text{(A2)} \qquad V_{ss} = E[U_{ww}(\cdot)\ (\alpha e - 1/p_f)^2]$$

$$\text{(A3)} \qquad V_{xx} = E[U_{ww}(\cdot)\ (-p_x/p_f)^2 + U^2_{xx}(\cdot)]$$

$$\text{(A4)} \qquad V_{sx} = E[U^1_{ww}(\cdot)\ (-p_x/p_f)\ (\alpha e - 1/p_f)]$$

Differentiating conditions (3) and (4) with respect to each exogenous variable yields:

(A5) $V_{sM} = V_{s\pi} = E[U^1_{ww}(\cdot)\ (\alpha e - 1/p_f)\ (1/p_f)] \leqslant 0$

(A6) $V_{sp_f} = E[-U^1_w(\cdot)\ (1/p_f^2) + U_{ww}\ (\cdot) W(\alpha,S)/p_f^2] \leqslant 0$

(A7) $V_{sp_x} = E[U^1_{ww}\ (\cdot)\ (\alpha e - 1/p_f)\ (-x/p_f)]$

(A8) $V_{sw} = E(U^1_{ww}\ (\cdot)\ (\alpha e - 1/p_f)\ (t-R)/p_f]$

(A9) $V_{se} = E[U^1_{ww}\ (\cdot)\ (\alpha e - 1/p_f)\ (\alpha S) + U^1_w(\cdot)\ (\alpha)]$

(A10) $V_{xM} = V_{x\pi} = E[U^1_{ww}\ (\cdot)\ (-p_x/p_f^2)]$

(A11) $V_{xp_f} = E[U^1_{ww}\ (\cdot)\ (-p_x/p_f)\ (W(a,S)'p_f) + U^1_w(\cdot)\ (p_x/p_f^2)]$

(A12) $V_{xp_x} = E[U^1_{ww}\ (\cdot)\ (-X/p_f) - U^1_w(\cdot)\ (1/p_f)]$

(A13) $V_{xw} = E[U^1_{ww}\ (\cdot)\ (-p_x/p_f)\ (t-R)]$

(A14) $V_{xe} = E[U^1_{ww}\ (\cdot)\ (-p_x/p_f)\ (\alpha S)]$

where $W(\alpha,S)$ is defined as in the text.

Standard comparative statics (Silberberg 1989) will show that

$$\frac{\partial S}{\partial Z} = \frac{V_{xz}V_{sx} - V_{xz}V_{xx}}{J}$$

$$\frac{\partial X}{\partial Z} = \frac{V_{sz}V_{xs} - V_{xz}V_{ss}}{J}$$

for any exogenous variable z and where $J = V_{ss}V_{xx} - (V_{sx}V_{xs})^{1/2} \leqslant 0$.

The results in Table 1 can be derived by replacing z with M, π, p_f, p_x, w, and e and using the fact that the coefficient of absolute risk aversion is $\rho(W) = -U_w(\cdot)/U_{ww}(\cdot)$. The complete proofs are lengthy. They can be obtained from the authors.

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