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Adoption and use of improved biomass stoves in Rural Mexico☆,☆☆

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ABSTRACT

In households that rely on biomass for a large percentage of their energy needs, adoption of improved biomass stoves can result in significant reduction of indoor air pollutants and emissions of greenhouse gasses with concurrent health co-benefits. To maximize the effectiveness of the stove dissemination process, promoters should choose target populations that are both likely to adopt the new technology and to influence the opinions of other potential adopters within a social group. In the current study a longitudinal analysis of adoption patterns and intensity of use of a Patsari improved biomass cookstove was conducted in 259 randomly selected households of a community intervention study in rural communities of Michoacan, Mexico. Health promoters classified households into one of several stove user groups during a series of monthly follow up interviews after Patsari installation, based on physical traces of use and household self-reporting by questionnaire. Multinomial logistic regression was used develop a model of household and community characteristics associated with early adoption of the Patsari, leading to the development of bi-level model for targeting improved stove dissemination efforts. Factors including community of residence, number of adults in household, suffering from irritated eyes, using wood scraps for fuel, and cooking with certain types of traditional fogons were associated with early adoption of Patsari cookstoves. Maximum saturation of the Patsari in the study population was reached four months after installation; after this point, stove use decreased until eight months but remained relatively steady with 55% of the sample using the Patsari regularly from month eight onwards. Results highlight the importance of utilizing effective targeting strategies to maximize NGO resources and increase the robustness of the diffusion process, resulting in more stoves in actual use. Additionally, results point to the importance of evaluating the success of an improved stove program in terms of stove use over time, rather than the total number of stoves disseminated.

Introduction

Up to 2.4 billion people (approximately 40% of the earth's population) depend on biomass (including wood, charcoal, crop residues, and animal dung) as their main source of energy (Saldiva and Miraglia, 2004). Globally, the poorest households are relying on biomass more now than in the past (Bruce et al., 2000). Worldwide, 4 to 5% of total deaths and disability adjusted life years (DALYs) in less-developed countries (LDCs) can be attributed to indoor air pollution from solid fuel use (Smith and Mehta, 2003).

Improved biomass cook stoves can decrease indoor air pollution (Armendariz et al., 2008), and emissions of greenhouse gasses and black carbon (Johnson et al., 2007), while reducing the amount of time and/or money spent gathering or purchasing fuelwood and decreasing demands on local fuelwood resources (Barnes et al., 1994). Past economic analyses have shown favorable cost–benefit ratios for

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improved cooking stoves in Uganda (Habermehl, 2007) and Malawi (Malinski, 2008) and a recent study conducted in the Purepecha region of Mexico showed that stove adoption results in social, environmental and health co-benefits that outweigh cost by a factor of 10 (García-Frapolli et al., 2010). Unfortunately, however, successful dissemination leading to widespread use of such stoves is not as easy as simply distributing them throughout communities; many programs to promote these improved technologies have failed in the long run because they did not take variations in cultural preferences, local cooking needs, patterns of household fuel use, and other social and economic factors into account (Masera et al., 2005).

Diffusion of Innovation Theory describes the process through which a new *innovation* is *diffused* among members of a *social system* (Rogers, 2003). Innovations have five characteristics perceived by the social system that determine rate of adoption; these are relative advantage, compatibility, complexity, trialability, and observability. In general, innovations that are perceived as low in complexity and high in each of the other categories will be adopted more readily than other innovations (Rogers, 2003).

The Diffusion of Innovation Theory also asserts that individuals, like innovations, have traits that tend to either promote or hinder acceptance of a new innovation. Within a social system, individuals can be grouped into 'adopter categories' according to their level of innovativeness and members of different categories move through the adoption process at different speeds, beginning at different times (Rogers, 2003). According to this theory, improved stove technologies will have a better chance of spreading throughout the general population if they first gain acceptance among 'early adopters,' who are often community 'opinion leaders' who possess the ability to influence other individual's attitudes or behavior informally (Rogers and Scott, 1997). The development of detailed profiles of households likely to be early adopters will allow promoters to increase demand for their product, theoretically resulting in better rates of adoption and thus maximizing the health benefits attained per dollar spent on health promotion programs.

Where the traditional diffusion model is concerned primarily with the initial uptake or time of first use of a new innovation, the Use-Diffusion Model is concerned with both *rate* (the time a person spends actually using a new product) and *variety* (the different ways a new product is used) of use. Over time, new products develop one of four patterns of use: intense use (product has both high rate and high variety of use); specialized use (product becomes a specialized tool that is used at a high rate for only one or two tasks); non-specialized use (product has a high variety of uses but low rate of use); and limited use (product has few if any worthwhile uses and thus rate of usage is also low, possibly to the point of discontinuance) (Shih and Venkatesh, 2004).

Extending the study of adoption of improved technologies to include intensity and variety of use is important for several reasons. Degree of use is an important but often overlooked component in determining the extent of diffusion of an innovation. Criteria for success should be expanded to include the intensity and rate of use of a new technology, rather than a simple count of the number of products that have been disseminated. Additionally, some technologies may have a prolonged trajectory and time scale of diffusion, which may be especially true of 'preventive' innovations that are developed for the purpose of health promotion (Rogers, 2002). Examination of use over time thus helps health promoters more accurately gage the benefits of a new technology. For instance, a better understanding of use patterns can help identify monitoring periods that can be related to chronic health outcomes in epidemiologic investigations. Perhaps more importantly, where binary variables are used in epidemiologic studies relating to the presence or absence of a stove, examination of stove use over time allows for a better quantification of exposure misclassification and bias.

General characteristics of end-users likely to readily adopt a new innovation include integration into the larger social system, prior experience with technology, and a high degree of opinion leadership within a social group (Rogers, 2003; Shih and Venkatesh, 2004). Few studies have examined community and household factors that foster initial adoption of improved stove technologies and lead to sustained use of the stove and there are no reports of detailed tracking of stove adoption and usage patterns over extended time periods through repeated home visits. Without an understanding of the ongoing social and behavioral process of adoption and stove use, the full benefits of stove dissemination programs cannot be realized or estimated. The current paper extends existing research by identifying household and community characteristics associated with early adoption of Patsari stoves (Berrueta et al., 2007; Masera et al., 2005, 2007b), and factors that lead to sustained use over time, through tracking of stove adoption and usage patterns over extended time periods through repeated home visits. Further, a bi-level approach is proposed that may be used by stove dissemination programs to target early adopter communities and households for stove dissemination, in an attempt to increase adoption rates within communities and thus maximize the benefits attained per dollar spent on stove dissemination.

Methods

Patsari stove and dissemination

The Patsari stove was developed by a partnership between the Mexican NGO GIRA AC and the Center for Ecosystems Research of the National University of Mexico (CIECO). GIRA has disseminated a total of 10,000 stoves in Mexico, predominantly in the Purepecha region of Michoacan, Mexico. The population of this area is primarily rural and indigenous. Cooking generally occurs over an open fire with a cooking surface supported by three stones or a horseshoe-shaped "*fogon*" in a kitchen with no chimney. Although various models of Patsaris have been developed, all feature chimneys to vent smoke outside the home and two or more cooking surfaces, including a large surface suitable for cooking tortillas and one or more smaller surfaces suitable for other cooking tasks such as heating food or water (Fig. 1). Wood is placed inside combustion chambers that are overlaid with a ceramic cooking surface called a *comal*. These surfaces are sealed to prevent fugitive smoke emissions. Tunnels inside the stove transport extra heat to secondary surfaces that are used for "low power" tasks, such as re-warming beans (Masera et al., 2005, 2007a).

The Patsari was developed through a participatory approach, with the goal of producing affordable technology that would meet cooking needs, decrease exposure to indoor air pollution, decrease production of greenhouse gasses, and reduce consumption of biomass fuels (Masera et al., 2007a). This approach has produced encouraging

Fig. 1. Making *tortillas* on a Patsari improved cooking stove.

outcomes; households with Patsari stoves that use biomass fuel exclusively achieve an average 67% energy reduction (Berrueta et al., 2007), with an 84% reduction in CO_2-equivalent emissions of greenhouse gasses based on community specific estimates of fuel renewability (Johnson et al., 2007). Furthermore, using a Patsari stove instead of a *fogon* for cooking leads to a median reduction in 48-hour average kitchen $PM_{2.5}$ and carbon monoxide concentrations of 74% and 77% respectively, and a median decrease of personal exposures by 35% and 78% (Armendariz et al., 2008). Users of the Patsari consider it a valuable asset and families that adopt them tend to make other positive changes within their households (Armendariz et al., 2008; Masera et al., 2005; Valencia, 2004). A preliminary evaluation of the Patsari stove program in 2004 found that many users of Patsari stoves cited decreases in fuel wood consumption, the ability to cook multiple things at once, and the benefits to health and physical appearance as positive attributes of the stove (Valencia, 2004).

Data collection

Initial survey-based interviews with the primary cook in the household were completed during the fall and winter of 2004 and 2005. Households completed an initial structured interview consisting of several sets of questions including household demographics, health symptoms, and cooking practices. At each follow-up visit, interviewers classified households into one of several stove "user groups." These classifications were based on visual inspections for physical traces of stove use and reported use. Four categories were used to classify user groups of the stove based on primary cookstove used. These include primary Patsari user, primary open fire user, open fire only (no Patsari) user, and primary gas (LPG) user. An additional survey to assess user satisfaction with the stoves was administered to a subset of household's midway through the study period consisting of questions about frequency of stove use and problems encountered while using the Patsari.

Sample

Based on a community intervention study evaluating the health impacts of cooking with a Patsari stove, 259 households were selected that had at least three months of follow-up surveys conducted within the first 5 months after stove installation at regular monthly intervals. Stoves were installed during every month except November starting in February 2005 and continuing until January 2006. During the study period, the Patsari design was refined from the initial design using mud and cement and later households received a brick Patsari. Households taking part in the health study received the stove in exchange for their participation. Of this sample 26 were non-adopters and 233 reported using the Patsari. Henceforth, we refer primarily to the sample of 233 households who adopted the Patsari since they are the main focus of our analyses. A subset of 112 households for whom 7 or more months of data from follow-up surveys had been collected was compiled in order to assess stove use over an extended time frame. Households in the study were located in five communities in the Purepecha region of Michoacan (Comachuen, La Mojonera, Quinceo, Tanaco, and Turicuaro). All communities are indigenous and rural (see Table 1 for demographics of households from different communities).

Since the majority of households who adopted the Patsari did so by month 3 after installation, households were categorized into one of four adoption groups based on first reported use of the Patsari; month 1 adopter, month 2 adopter, month 3 or later adopter, and non-adopter.

Data analysis

Simple longitudinal analyses were conducted to assess patterns of Patsari adoption and intensity of Patsari use over time. Factors were entered into a multinomial logistic regression model with adoption group (month 1, month 2, or month 3 or later) as the outcome variable. Multinomial logistic regression was chosen since it allows logistic regression analysis where the outcome variable is nominal and has more than two levels (Hosmer and Lemeshow, 2000). The regression analysis had two parts. For the first part, individual factors were entered into univariate multinomial logistic regression models with month of adoption as the outcome variable. For the second part, simple household demographic characteristics and household social and behavioral characteristics that were most strongly associated with time of adoption were entered into a multivariate multinomial logistic regression model in order to develop a model of household characteristics associated with time of adoption of improved stoves. SPSS version 15.0 was used for all analyses.

Table 1
Community demographics.

	Comachuen (n = 39)	Quinceo (n = 39)	Mojonera (n = 23)	Turicuaro (n = 83)	Tanaco (n = 75)
Household income					
<600 pesos/month	12.8%	7.7%	17.4%	10.8%	12.0%
601–1200 pesos/month	41%	35.9%	30.4%	39.8%	44.0%
1201–1800 pesos/month	28.2%	20.5%	30.4%	28.9%	29.3%
>1800 pesos/month	17.9%	35.9%	21.7%	20.5%	14.7%
Own land	17.9%	2.6%	4.3%	17.1%	14.7%
Number of rooms in house (mean)	4.82	4.72	6.00	4.81	4.57
Head of household occupation					
Farmer	48.7%	51.3%	91.3%	36.1%	46.7%
Artisan	5.1%	5.1%	0%	4.8%	4.0%
Laborer	12.8%	10.3%	0%	12.0%	28.0%
Retailer	2.6%	5.1%	0%	1.2%	2.7%
Carpenter	7.7%	15.4%	0%	22.9%	2.7%
Other	23.1%	15.4%	17.4%	24.1%	16.0%
Highest grade completed (mean)	5.1	4.2	6.7	3.1	4.9
Household size					
Total adults (14+)	7.4	6.0	6.1	6.6	6.2
Total children (0–14)	3.3	3.2	3.2	2.9	2.9
Total inhabitants	10.7	9.1	9.4	9.5	9.1
Years in current residence	8.4	8.4	9.4	6.7	6.1

Note: at the time of stove installation (2004) the exchange rate from Mexican pesos to U.S. dollars was 10.86.

Results

Patsari adoption rates

Around 40% of households in the study population adopted the Patsari stove during the first month of the study, immediately following installation. The number of households using the Patsari continued to climb, peaking at around 70% at month 4 and then declined slightly during month 5 (see Fig. 1). Of households who adopted the Patsari, the vast majority began using the stove by the third month after installation.

Factors associated with early and late adoption

Table 2 summarizes multivariable multinomial logistic regression of household characteristics and month of Patsari stove adoption. Community of residence was strongly associated with adoption at month 1. Households living in Quinceo are over 10 times more likely to adopt the Patsari at month 1 versus month 3 or later ($p<0.05$) and over 5 times more likely if community of residence is Comachuen or Mojonera ($p<0.05$) versus Turicuaro. Additionally, those who reported suffering from irritated eyes during the health pre-survey and those who use wood scraps for fuel were more than twice as likely to adopt the stove at month 1 versus month 3 or later ($p<0.05$).

For each additional adult in the household, likelihood of adoption occurring in month 1 and month 2 versus month 3 or later falls by about 10% ($p<0.05$). Households in which the woman works outside the home were 50% less likely to adopt the Patsari in month 1 versus month 3 or later ($p<0.10$) and about 60% less likely to adopt the Patsari in month 2 versus month 3 or later ($p<0.05$). Owning a floor-level horseshoe-shaped fogon is also negatively associated with adoption at month 1 and month 2 versus month 3 or later ($p<0.05$).

Installation of 55 stoves during the rainy season, the vast majority in Tanaco, was negatively associated with adoption due to technical issues with water leaking around the flue. Exclusion of these 55 households did not alter the significance of other predictive variables in the models.

Additional factors were significant in univariate multinomial logistic regression models and may be significant in multivariate models with a larger sample size. Head of household occupation as a farmer and use of pine wood were significantly and positively associated with adoption at month 1 versus adoption at month 3 or later, while total time cooking near the fogon per day and owning a washing machine were marginally significant. Falling into the lowest income category was marginally and negatively associated with adoption at month 1 versus month 3 or later. Households in which members receive money from family in the United States were significantly less likely to adopt the Patsari at month 2 versus month 3 or later, and using kerosene for fuel was marginally negatively associated with Patsari adoption at month 2 versus month 3 or later.

Table 2
Factors associated with month of adoption of Patsari stoves: multinomial logistic regression ($n=233$)[a].

	Month 1 versus month 3 or later (N = 101)	Month 2 versus month 3 or later (N = 62)
	Odds ratio	Odds ratio
Rainy season installation	0.16*	0.82
Community[b]		
Comachuen	6.81*	0.69
Quinceo	10.74*	1.24
Mojonera	5.67*	0.37
Tanaco	3.93†	0.59
Turicuaro	ref	ref
Total adults in household (age 14+)	0.90*	0.90*
Watery eyes in last month	2.65*	2.12†
Woman works outside home	0.459†	0.35*
Use wood scraps for fuel	2.18*	1.55
Use horseshoe stove (floor)	0.35*	0.32*
Likelihood ratio chi-square (df)	90.05 (20)*	

[a] Reference group is adoption at month 3 or later.
[b] Reference group is Turicuaro.
* $p<0.05$.
† <0.10.

Early versus late adopter communities

Community of residence is the demographic factor most strongly associated with month of adoption. Quinceo and Mojonera are positively associated with adoption of the Patsari in month 1 while residence in Turicuaro is negatively associated with adoption in month 1. In order to compare adoption patterns in these two groups, Fig. 2 shows rates of Patsari use over time, defined as any reported use of the Patsari. In "early adopter communities" (Quinceo and Mojonera), rapid uptake of the new technology occurred immediately after stoves were built with a usage rate of approximately 70% during month 1. This rate of usage remained relatively stable and increased slightly over time, resulting in a usage rate of approximately 80% at month 5. Adoption in the "late adopter community" (Turicuaro) is characterized by a more gradual increase in use, with around 20% of households using the Patsari in month 1. Patsari usage peaked at month 4 with around 65% of households using the Patsari and decreased to slightly less than 60% in month 5. Although residence in Comachuen was also positively associated with adoption in month 1, there was a high attrition rate of households due to indoor air and health studies occurring simultaneously in the homes.

Comparison of demographic factors from households in the two early adopter communities ($N=62$) and the late adopter community ($N=83$) reveals a few key possible differences between these groups (Table 3). Fewer households in early adopter communities report owning land (3.2% versus 16.9% in late adopter communities). Fisher's Exact Test obtained by cross-tabulating nominal factors with residence in early or late adopter community reveal significant differences in land ownership ($FET<0.05$) among households in early and late adopter communities. T-tests revealed significant differences for level of education and length of residence in the current household. Women in Quinceo and Mojonera were more highly educated, averaging 5 years of formal education while participants from Turicuaro averaged only 3 years ($t(142)=3.81$, $p<0.005$). Households in early adopter communities are more likely to use a gas stove ($FET<0.005$). Households in early adopter communities reported a higher proportion of household heads were engaged in farming ($FET<0.005$) and less likely to be engaged in carpentry ($FET<0.05$) as their main occupation. Participants reported, on

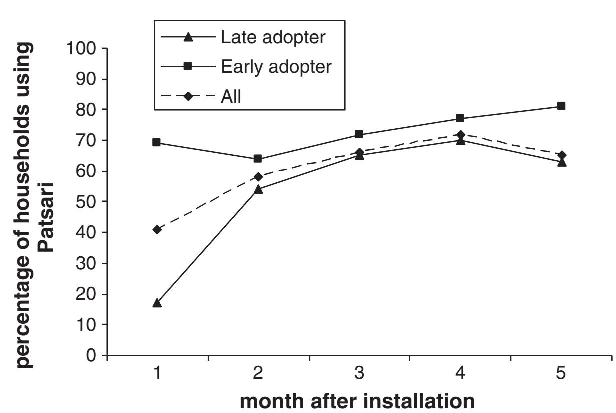

Fig. 2. Households using the patsari over time in early adopter (Quinceo and Mojonera, N = 61), late adopter (Turicuaro, N = 83), and all communities (N = 259).

Table 3
Factors associated with residence in early adopter (Quinceo and Mojonera) and late adopter (Turicuaro) communities (N = 145).

	Early adopter communities (N = 62)		Late adopter community (N = 83)	
	Mean (SD)	N (%)	Mean (SD)	N (%)
Years of education**	5.13 (3.14)		3.11 (3.16)	
HOH occupation: farmer**		41 (66.1)		30 (36.1)
HOH occupation: carpenter*		6 (9.7)		19 (22.9)
Years in current residence†	8.72 (7.55)		6.70 (5.53)	
Own gas stove**		9 (10.8)		22 (35.5)
Own land*		2 (3.2)		14 (16.9)

** $p < 0.005$.
* $p < 0.05$.
† $p < 0.10$.

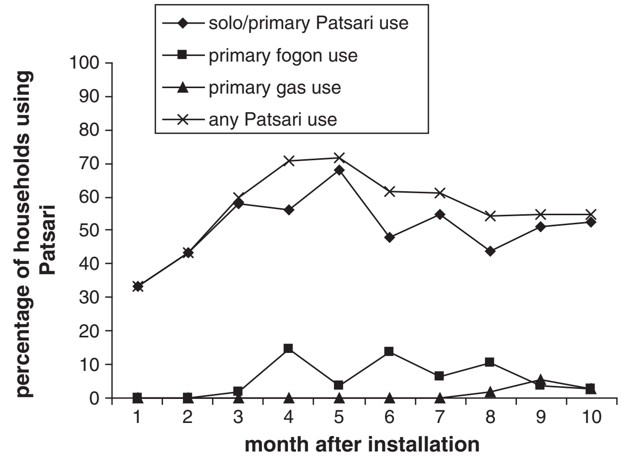

Fig. 3. Patsari use intensity over time (N = 112).

average, more years lived at their current address in the early adopter communities than the late adopter community ($t(103.81) = 1.75$, $p < 0.10$).

An interim survey completed midway through the health study by 168 of the 259 households, shows a striking difference between early adopter community and late adopter community households. 67.5% of early adopter community households reported no problems with their Patsari stoves, while only 47.3% of late adopter community households reported no problems. Households in the late adopter community Turicuaro reported more problems and a greater diversity of problems than did households in the early adopter communities Quinceo and Mojonera.

Intensity of Patsari use

A subset of 112 households had complete data on stove usage for months 1–10 (Fig. 3), which was used to evaluate intensity of Patsari use over an extended period of time.

Patsaris are used most intensely and for the largest variety of purposes around month 5 after installation, when almost 70% of households reported exclusive or primary use of the Patsari stove. Around month 8 the proportion of households using the Patsari exclusively drops to around 15% as the proportion of households who use the Patsari primarily but in conjunction with a second stove increases to around 35%. This pattern remains steady for the remainder of the survey period, indicating that in many households, a secondary stove is used in a limited capacity for some tasks such as heating of bathing water or preparation of *nixtamal* (a tortilla dough). Around month 8 an increase in households using gas stoves primarily is seen with about 5% of households reporting primary use of a gas stove.

Table 4
Demographics for adopter and non-adopter households.

	Adopters (n = 233)		Non-adopters (n = 26)	
	N(%)	Mean (SD)	N(%)	Mean (SD)
Household income				
<600 pesos/month	27 (11.6)		3 (11.5)	
601–1200 pesos/month	96 (41.2)		7 (26.9)	
1201–1800 pesos/mo	61 (26.2)		11 (42.3)	
>1800 pesos/month	49 (21.0)		5 (19.2)	
Use paraffin	36 (15.5)		1 (3.8)	
Wood source				
Collect	163 (70.6)		22 (84.6)	
Buy	49 (21.2)		4 (15.4)	
Collect and buy	19 (8.2)		–	
Highest grade completed		4.5 (3.3)		3.9 (3.8)
Total children (0–14)†		3.0 (1.5)		3.7 (1.9)
Total inhabitants		9.4 (4.4)		10.0 (4.9)
Own washing machine	23 (9.9)		6 (23.1)	
Cough every day**	7 (3.0)		5 (19.2)	
Fogon uses				
Heating the house*	51 (21.9)		11 (42.3)	
Preparing tortillas (min)		103.9 (55.3)		87.1 (37.0)

** $p < 0.005$.
* $p < 0.05$.
† $p < 0.10$.

Non-adopters of the Patsari

Of the 259 households in the sample, 10% or 26 of the 259 did not adopt the Patsari stove at all. Since the sample size is not large enough for robust multinomial logistic regression models, descriptive analyses suggest some differences between non-adopters of the Patsari and the rest of the population (Table 4). Of the non-adopters, 11 of the 26 (42%) reside in Tanaco, while only 64 of the 233 (27.5%) of adopters live in Tanaco. Also, while households from Quinceo comprise about 16% of the population of adopters, only 4% of non-adopters reside there. This suggests that community of residence may have influenced the decision to reject the new stove technology in addition to influencing rate of adoption.

Non-adopters were about twice as likely to report heating their homes with the open fire than were adopters ($\chi^2 = 5.36$, $p < 0.05$). Non-adopters were also significantly more likely to report suffering from a cough daily ($\chi^2 = 13.86$, $p < 0.005$). The average non-adopter household size was larger and included more children (3.7) versus adopter households, who report around 3.0 children per household; this difference was of marginal significance ($t(28.67) = 1.95$, $p = 0.061$). In addition, although not statistically significant, income was skewed slightly higher for non-adopters, with about 62% of the households falling in the top two income brackets (about 47% of adopter households fall in the upper two income brackets). Fuel types used and method of wood collection also seemed to vary between adopter and non adopter households; more non-adopter households reported collecting wood exclusively, and non-adopter households reported spending about 15 min less making tortillas per day than adopter households. Only one of the twenty six non-adopting households reported using kerosene for fuel, while 15% of adopter households reported using kerosene. Fuel and income differences may become more relevant with larger sample sizes.

Discussion

Analysis of Patsari usage patterns reveals that a large proportion of households showed sustained adoption of the stoves. Although some (17%) of the households in our sample ultimately rejected the new technology by the end of the 10 month follow-up period, more than half of the households use the stove for most if not all of their cooking needs and sustain this level of usage over time. Perhaps more interesting is the presence of primary gas users in some homes (3%) toward the end of the 10 month evaluation period. This may indicate that both technologies reinforce each other, and adoption of the Patsari may lead to increased interest in other improved cooking technologies.

Longitudinal analysis reveals a relatively rapid uptake of the new technology (Fig. 1), with the majority of households who adopt the technology beginning to use the stove by month 3 after installation. This adoption pattern is somewhat different to the gradual S-shaped curve described by Rogers (2003) most likely because the process of dissemination was "active" in that participants were selected from a population identified as at-risk for health effects due to indoor air pollution and received a Patsari in exchange for the hours they contributed to a health intervention study. Active promotion of preventive innovations is often necessary to accelerate the diffusion process since this category of innovations tend to diffuse very slowly due to the temporal distance from future perceived health benefits (Rogers, 2002). Due to this dissemination process, our analysis provides insight into adoption processes for programs that utilize active rather than passive promotion methods to facilitate dissemination of new preventive technologies into a population.

Implications for monitoring and evaluation of stove programs

Although the initial adoption–decision process occurred quickly, maximum saturation of the Patsari in the study population was not reached until about 4 months after installation. This indicates that stove promoters should allow some lag time before estimating the rate of uptake of a new stove technology in a population. Reductions in indoor air pollution (IAP) and green house gas emissions may not be evident until households have had adequate time to integrate the new technology into the daily functioning of the household. Current estimates of IAP reductions for households in communities where the Patsari was disseminated (Arnez et al., 2008; Masera et al., 2007b) are likely to be *under*-estimated since they were conducted before peak adoption rates had been reached. Since IAP reductions are typically estimated using the difference between median concentrations in household's pre and post stove installation in approximately 30–50 homes for statistical significance, increased adoption of the Patsari over time would be expected to further lower median concentrations after the stoves were installed.

Stove promoters should be careful to allow significant lag time to pass before assessing total adoption of new stove technologies and thus determining "success" of a dissemination program. In addition, the lag in adoption should be incorporated into assessment of reductions in IAP levels for epidemiologic studies, as taking measurements during the interim period may lead to either an underestimation of the benefits conferred by stove use (if measurements are taken before peak adoption is reached) or an overestimation of IAP reductions (if measurements are taken before households have sufficient time for a "trial period" after which they may reverse their initial adoption decision). Criteria for program success, therefore, should go beyond number of stoves installed and include rate and variety of usage over time.

Additional insight can be gained by examining intensity of Patsari usage over time. Households who reported using the Patsari exclusively or primarily constituted practically all of Patsari users (Fig. 3), with some limited (5–15%) reversion to use of the *fogon* over time with secondary use of the Patsari (Fig. 3). This indicates that over time in some households, Patsaris fell into a "limited use" pattern which was likely characterized by both a low rate of usage and employment in a low variety of uses (Shih and Venkatesh, 2004). For instance, some households reported that the Patsari worked well for tortilla making, but was less well-suited for other common household tasks, including boiling large quantities of water and making *nixtamal.* This is consistent with the phenomenon of "fuel stacking" which describes the process by which households, in the process of switching from one fuel to another, often acquire multiple cooking technologies and employ multiple fuels (Masera et al., 2000). By month 9, this pattern had stabilized and the "any Patsari use" group was again almost completely comprised of primary and solo Patsari users.

The relatively large proportion of households who continued to use the stove indicates that the Patsari adequately performs many of the household tasks required by stove users and that, in the presence of a good fit between the new technology and the needs of the household, more than half of households continue to use the Patsari over an extended period of time. The households who continue to use the Patsari in the long run are those who are able to perform many if not all of their cooking and other stove-related tasks using the new technology. After about 8 months, decisions to discontinue use of the technology tend to occur if the stove has not reached an adequate level of integration with regard to household tasks, with few households continuing to use the Patsari in a limited capacity.

Targeting of stove dissemination efforts

Analyses of household characteristics revealed much potential for improvement in the targeting of households for stove dissemination programs. In particular, a bi-level selection process in which both *community characteristics* and *household characteristics* are used by stove promoters to target communities with characteristics likely to foster early adoption, and select households within those communities who are likely to be early adopters (Fig. 4). This approach would lead to better allocation of time and resources of NGOs and improved stove programs as more stoves in actual use in communities would result. In addition it would foster a more robust diffusion process, since favorable reviews from early adopters should accelerate the adoption–decision process throughout the social system. Early adopters serve as "opinion leaders" in communities who can facilitate diffusion of a new innovation throughout the social system. Additionally, the adoption decisions of early adopters tend to be more robust in that this group is less likely to reverse their initial decision to adopt (Rogers, 2003). This is evident in the time-series analysis of early and late adopter communities. Patsari usage rates in the late adopter community peaks around month 4 after installation and diminishes over time, while in early adopter communities Patsari usage remains steady and continues to increase over the five-month follow-up period (Fig. 2).

Demographic characteristics such as education and length of time at current address are associated with residence in early adopter communities but are not significantly associated with early adoption of the Patsari across households in all communities, indicating that these characteristics operate at a community rather than household level. Education has previously been linked to early adoption of a wide range of innovations by Rogers (2003) and others, and communities with a higher average level of education may foster early adoption of innovations. Communities with a longer average length of time at current address may have a higher degree of connectedness among community members in the social system, which can facilitate diffusion of new ideas and practices (Rogers, 2003). The employment profile of a community is another demographic factor that may create an environment favorable for early adoption, with communities that are heavily employed in agriculture exhibiting a pattern of accelerated adoption. Finally, the presence of households who own other higher-order cooking technologies and fuels (such as LPG) within a community can signal to stove promoters the presence of early adopters who will help ease the way for the new technology.

Identification of households likely to adopt the stove within a community during early stages of a dissemination effort would

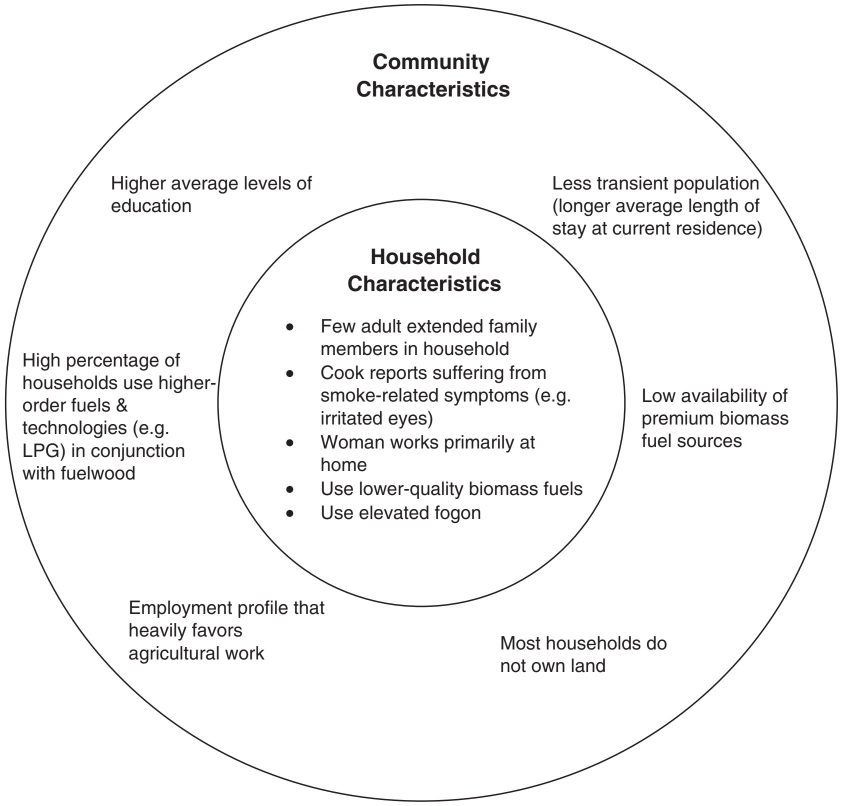

Fig. 4. Bi-level model for targeting improved stove promotion programs.

further improve allocation of time and resources in improved stove programs. Household factors that are strongly associated with early adoption include a lower number of adults residing in the household, women that do not work outside the household, and women reporting suffering from watery, irritated eyes.

The negative association between number of adults in the household and adoption at month one or month two is seemingly counterintuitive, given that more cooking wood be expected with more people in a household and therefore the benefits of adoption are greater. However, the additional adults are likely senior members of the family, for example the mother-in-law, who may be influential in decision-making and technology adoption. Stove promoters should be aware of local customs regarding living arrangements and understand the decision making process for new technologies within households. The negative association between early stove adoption and woman working outside the house may be related to a reduced role as the primary preparer of food or perhaps more food items, such as tortillas, are purchased rather than made at home, which may decrease the need (and thus the relative advantage) of an improved stove.

The association between self-reported suffering from watery, irritated eyes in the past month and early Patsari adoption is an important finding for stove promoters. The design of the Patsari allows for practically instantaneous decreases in indoor smoke levels, which offers quick relief from irritated eyes. The relative advantage of the Patsari compared to open-fire cooking methods is therefore increased for those who experience quick relief from these symptoms, leading to early adoption of the stove. This finding can also be interpreted within the framework of the Health Belief Model (Rosenstock et al., 1988), where stove promoters work to educate potential users about the risks posed by traditional cooking methods and the severity of these risks, but they may not be able to convince people that the benefits of changing cooking methods are worth overcoming the barriers to change. Irritated eyes may serve as an additional "cue to action" that galvanizes potential users and increases readiness to make the change. Stove promoters may increase the effectiveness of their messages if they focus on such cues to action in their outreach efforts.

Careful targeting can help ensure that a new technology will gain a foothold within the population of intended end-users and can help to increase the robustness of the adoption process. If a particular technology acquires a negative reputation then diffusion will likely be hindered; members of a social system tend to observe early adopters and wait for feedback from community "opinion leaders" before making an adoption decision (Rogers, 2003). In communities where the first households to receive a technology have difficulties or otherwise develop negative perceptions of the technology, adoption decisions are impacted by this information and diffusion may be delayed or halted. Although this analysis does not completely delineate factors that result in early adoption of an improved stove, targeting households for adoption highlights an approach that can be a useful tool for health promoters, with an emphasis on targeting populations that will bring about a swift initial uptake of a new innovation. In the absence of site-specific information the variables identified in these models provide a starting point for targeting of communities, but clearly they don't encompass the wide range of stove designs or local customs that may affect adoption rates, and site specific factors to identify early adopter communities are required. Finally, use of an iterative stove dissemination process allows for correction and improvement of stove designs and dissemination techniques to improve adoption rates. Careful targeting that includes consideration of both community- and household-level characteristics that may help or hinder adoption will help to maximize the efficiency of the dissemination process, thus ensuring that each program will result in more working units and the greatest possible health savings. Perhaps more importantly from a policy perspective, however, this paper highlights that evaluation of the success of an improved stove program must be in terms of stoves that continue to be used, rather than the total number of stoves disseminated.

Conclusion

- A large proportion of households showed sustained adoption of Patsari stoves, with maximum adoption after 4 months, where more than half of the households used the stove for most if not all of their cooking needs. Evaluation of stove programs, therefore, should allow some lag time before estimating the rate of uptake of a new stove technology in a population.
- A bi-level selection process in which both community characteristics and household characteristics are used by stove promoters to target communities with characteristics likely to foster early adoption, and select households within those communities who are likely to be early adopters would lead to better allocation of time and resources of NGOs and would result in more stoves in actual use in communities.

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