Low demand for nontraditional cookstove technologies

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Biomass combustion with traditional cookstoves causes substantial environmental and health harm. Nontraditional cookstove technologies can be efficacious in reducing this adverse impact, but they are adopted and used at puzzlingly low rates. This study analyzes the determinants of low demand for nontraditional cookstoves in rural Bangladesh by using both stated preference (from a nationally representative survey of rural women) and revealed preference (assessed by conducting a cluster-randomized trial of cookstove prices) approaches. We find consistent evidence across both analyses suggesting that the women in rural Bangladesh do not perceive indoor air pollution as a significant health hazard, prioritize other basic developmental needs over nontraditional cookstoves, and overwhelmingly rely on a free traditional cookstove technology and are therefore not willing to pay much for a new nontraditional cookstove. Efforts to improve health and abate environmental harm by promoting nontraditional cookstoves may be more successful by designing and disseminating nontraditional cookstoves with features valued more highly by users, such as reduction of operating costs, even when those features are not directly related to the cookstoves' health and environmental impacts.

consumer demand experiments | technology adoption | development economics

Biomass combustion with traditional cookstoves is the primary cause in developing countries of indoor air pollution (1), a major global health hazard (1–4). A conservative estimate suggests that exposure to indoor smoke produced by household solid-fuel combustion is responsible for nearly 3% of the global disease burden and 4% of the disease burden in the high-mortality developing regions of the world (5, 6). Beyond health impact, traditional cookstoves have substantial environmental consequences as well. Traditional cookstoves are inefficient, harnessing only 5–15% of biomass energy (7). As a result, users collect large quantities of fuel from surrounding fields and forestlands, potentially decreasing agricultural productivity and contributing to forest degradation (8, 9). Traditional cookstoves also contribute to global warming (10). Incomplete combustion releases heat-trapping pollutants, including methane and black carbon, which have a greater global warming impact than carbon dioxide does per unit of carbon emitted (11, 12). Unsustainable harvesting of biomass fuel compounds this problem because carbon dioxide emitted during combustion is not sequestered by subsequent plant growth.

Despite these negative effects, half of the world's population and 75% of South Asians continue to burn solid fuels in inefficient traditional cookstoves for cooking and heating (13, 14). Many governments and development organizations have attempted to combat indoor air pollution by disseminating cleaner-burning cookstoves (15), but the adoption and use of these nontraditional cookstoves in the developing world has, with few exceptions, remained disappointingly low (16). [The primary exception is China (17, 18).] Low rates of adoption may be attributable to different ideas of what constitutes improvement over traditional cookstove technologies. Cookstove developers typically focus on fuel savings, health improvements, or, increasingly, greenhouse gas emission reductions. However, depending on the technology, the so-called "improved" cookstoves may not bring improvements in all of these dimensions.* Moreover, as our study demonstrates, health improvements and emission reductions may not be prioritized by cookstove users. In fact, across rural Bangladesh, 98% of the population continues to cook with biomass in traditional cookstoves (20) despite years of efforts to promote nontraditional cookstove technologies (21), and 92% of rural Bangladeshi households surveyed in this study had never seen a nontraditional cookstove.In contrast to the vast body of literature on the health and environmental effects of nontraditional cookstoves,† there is a paucity of evidence on the determinants of demand for nontraditional cookstoves. Only a few studies address the determinants of clean cookstove adoption mostly by using qualitative approaches and nonexperimental evidence. Specific factors suggested to explain low adoption rates include expense (24–26), difficulty using cookstoves correctly (24), low levels of formal education (27), lack of knowledge about the benefits of nontraditional cookstoves (26, 28), mismatch between cookstove characteristics and local needs (28), and gender dynamics in household decision-making (29). With the launch of several major international efforts to disseminate cleaner cookstoves—including the United Nations Foundation's Global Alliance for Clean Cookstoves (to coordinate cookstove dissemination efforts across more than a dozen US government agencies), European government and private sector donors (30), and the government of India's National Biomass Cookstoves Initiative—the need for rigorous research on the demand for new varieties of cookstoves and effective distribution strategies has become more urgent.

This paper presents two analyses of underlying preferences for cookstove technologies in the context of rural Bangladesh. First, we report survey evidence on women's stated preferences for cookstove technologies that probes their perceptions about the harm of indoor air pollution, what attributes of cookstoves they value most highly (including health and non-health factors), and how they prioritize cookstoves relative to other basic developmental needs. Second, we present experimental evidence on households' revealed preferences for two types of nontraditional cookstove designs, one that advertises fuel-efficiency gains and

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*Indeed, some cookstoves may reduce fuel consumption by increasing heat-transfer efficiency relative to traditional cookstoves but at the expense of combustion efficiency, causing greater emissions of harmful pollutants and greenhouse gases. One recent editorial challenged the "improved" label placed on many cookstoves and suggested that it always be written with quotes to convey the idea that improvements are subjective and that some improvements in performance may come at the expense of reduced performance in other areas (19). In this paper, we use the label "nontraditional cookstoves" to distinguish these new cookstove designs from the "homemade" traditional clay cookstoves commonly used in rural Bangladesh. We intend to contribute to the discussion of how to best define and market healthier, efficient, and low-emission cookstove technologies that the scientific and policy communities hope to disseminate in the near future.

†For reviews of the health impact of biomass combustion, see Smith (2) on India, Ezzati and Kammen (3) on Africa, and Peabody et al. (22) on China as well as Ezzati et al. (1) and Smith and Ezzati (23). In addition, Bond et al. (11) and Smith and Haigler (15) review the relationship between biomass combustion and climate change.

another that reduces indoor smoke by redirecting emissions through a chimney, by conducting a cluster-randomized trial of prices for these new technologies. Overall, we find a variety of congruent evidence suggesting that rural women in Bangladesh do not prioritize nontraditional cookstoves over other basic developmental needs despite demonstrating awareness of their potential negative health consequences. Because they overwhelmingly rely on a traditional cookstove technology that costs nothing and are accordingly not willing to pay much for a new nontraditional cookstove, non-health considerations are the most salient determinants of cookstove technology choices. Our price experiment confirms negligible adoption rates at full price and despite our very large price elasticity estimates (ranging between −8 and −10). This result implies that large discounts by themselves are unlikely to promote substantial adoption and use. Efforts to promote nontraditional cookstoves may be more successful by developing and emphasizing designs with features valued more highly, even ones unrelated to cookstoves' health and environmental impact.

Background

Traditional Cooking Practices in Rural Bangladesh. As in many developing countries, use of traditional cookstoves for food preparation in rural Bangladesh is highly prevalent. According to the most recent population census, 77% of Bangladesh's 131 million residents live in rural areas (31), and 98–99% of the rural population burns biomass fuels by using traditional cookstoves for cooking and heating (20, 32–34). Households generally construct traditional cookstoves themselves with locally available materials and use biomass fuels that they can gather for free, such as dry leaves and branches, crop refuse, and hay. In our national survey, we found that ~97% of people do not incur any cost related to the construction of traditional cookstoves; however, 37% and 32% of respondents do incur fuel-related costs in wet and dry seasons, respectively. Miah et al. (9) and Alam et al. (8) estimate that heavy reliance on wood and crop residue is responsible for reductions in forest cover and agriculture productivity, respectively, in Bangladesh. Additionally, women bear most of the responsibility for cooking, spending 4–5 h each day in the kitchen. Altogether, the World Health Organization (35) estimates that exposure to smoke from solid-fuel combustion contributes to nearly 50,000 deaths in Bangladesh each year. As in the rest of South Asia, the use of traditional cookstoves in Bangladesh also accounts for a large share of greenhouse gas emissions. Streets and Waldhoff (36) report that combustion of biomass fuels accounted for over 80% of Bangladesh's total energy-based greenhouse gas emissions in 1990.

Clean Cookstove Programs in Bangladesh. Given the substantial health and environmental consequences of traditional cookstoves, both the government and the vibrant nongovernmental organization sector in Bangladesh have made numerous efforts to promote nontraditional cookstove technologies. Since the early 1980s, over 100 national and local nongovernmental organizations as well as the government-affiliated Bangladesh Council of Scientific and Industrial Research have developed and attempted to disseminate a variety of nontraditional cookstove models tailored to the local needs (21, 37). We conducted demand experiments with two of these nontraditional cookstoves. The first is a round "efficiency" cookstove, which improves combustion efficiency and reduces heat loss relative to a traditional cookstove. The second is a "chimney" cookstove, which removes a substantial share of smoke from kitchens via a concrete chimney. The efficiency cookstove and the base of the chimney cookstove are made locally with materials similar to those used for traditional cookstoves, but they are constructed with very precise design specifications.

Results

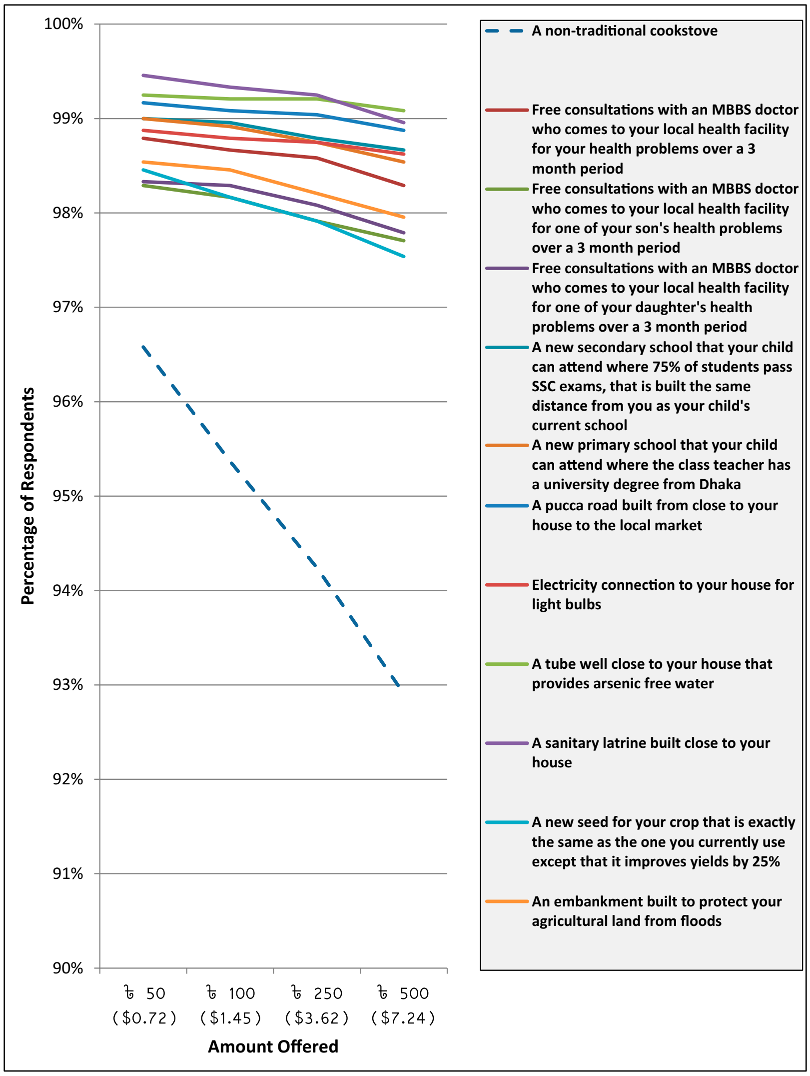
Stated Preferences. We first used a nationally representative survey of women in rural Bangladesh to study perceptions about the risks of indoor smoke relative to other environmental health hazards. Fig. S1 shows the geographic distribution of sampled subdistricts (upazillas) across the country. Our survey collected three major types of data: (*i*) perceptions about the health risks of indoor smoke, (*ii*) the relative desirability of different attributes of nontraditional cookstoves, and (*iii*) the value placed on cleaner cookstoves relative to other basic goods and services. We asked direct survey questions about the first two. For the third, respondents were asked to make hypothetical choices between varying amounts of cash (which we systematically varied between ৳50 and ৳500, roughly \$0.72 and \$7.20) and a variety of important goods and services, including a nontraditional cookstove. This approach allowed us to trace out the demand curve (hypothetical) for each good and service. Table S1 shows descriptive statistics of the national sample.

As Table S2 shows, although the vast majority of respondents (94%) believe that indoor smoke is harmful and 69% correctly believe that indoor smoke is more harmful than dust from sweeping, the majority also believe that smoke is less harmful than polluted water (76%) and spoiled food (66%). These responses suggest that most rural Bangladeshi households are aware that exposure to smoke from traditional cookstoves is associated with some health risk; however, these individuals consider it less serious than other common health hazards.

Table S3 ranks the primary attributes of a nontraditional cookstove in descending order of importance. Overwhelmingly (47% of study participants), households value the ability of nontraditional cookstoves to reduce fuel costs as their most valuable characteristic. (Although only ~35% of respondents report spending money on fuel, there is significant time cost associated with collecting fuel as well, so even those who report no fuel costs may value the reduced fuel consumption of a nontraditional cookstove. Mean and median fuel costs, for those who reported positive costs, were ৳240 and ৳200, respectively, for the dry season, and ৳266 and ৳200, respectively, for the rainy season.)

The next most-valued attributes are the ability to reduce cooking time (21%) and to accommodate a wider variety of biomass fuels (14%). Only 9% of respondents answered that reducing or eliminating household smoke is what they value most about nontraditional cookstoves. Household budgetary concerns (not limited to cookstove price) appear to dominate any health concerns associated with smoke from nontraditional cookstoves.

We investigated households' stated willingness to pay (WTP) for nontraditional cookstoves relative to improvements in other important local goods and services. We followed standard procedures in the contingent valuation literature (38, 39), but the shortcomings of hypothetical WTP questions in demand estimation are well known (40). Therefore, we emphasize that these data are useful for analyzing the prioritization/ranking of goods and services relative to each other, not the cardinal valuations that women place on each (also because we are unable to control for the *size* of each product or service improvement, and each is measured in a different unit). As our revealed-preference data from field experiments demonstrate below, the absolute valuations reported in the stated WTP survey should not be used to make pricing decisions. Fig. 1 shows the share of respondents stating that they would choose a direct cash transfer rather than receiving a good/service against the amount offered, generating the relative demand curve for each good/service. The numbers on which Fig. 1 is based, along with confidence intervals, are available in Table S4. Demand for all goods and services is downward-sloping, which suggests that respondents understood the questions well. Demand for nontraditional cookstoves appears more price-sensitive than demand for any other good or service. Overall, the high degree of price sensitivity for cookstoves relative to other important local goods and services clearly indicates that the perceived benefits of nontraditional cookstoves are not a high priority relative to other basic needs. Reliance on a free alternative cooking technology helps in explaining the low WTP for nontraditional cookstoves.



[α]Demand curves shown are based on hypothetical willingness-to-pay responses in a stated preference survey.

Fig. 1. Relative demand curves for selected goods and services in rural Bangladesh.

Field Experiments Varying Prices of Nontraditional Cookstoves. Given well-known limitations of stated-preference methodologies (40) as well as debate over "sustainable pricing" of environmental health technologies in developing countries,[‡] we also conducted a cluster-randomized trial in two subdistricts of Bangladesh (Hatiya and Jamalpur) to estimate the price sensitivity of demand for two nontraditional cookstove technologies: an efficiency cookstove that improves fuel efficiency and a chimney cookstove that reduces exposure to indoor smoke. Fig. S2 shows the trial profile of the experiment, and key descriptive statistics are reported in Table S5. The chimney cookstove's fuel consumption is roughly comparable to a traditional cookstove. In our field tests with local fuelwood and a standardized amount of food, the chimney cookstove consumed 950 g of fuelwood on average, and the traditional cookstove consumed 900 g. It took, on average, 46 min to cook with the chimney cookstove and 44.5 min with the traditional cookstove. Each study participant had the choice of whether to place an order for the offered cookstove. Project staff then came back to fill the orders and collect payments several weeks later, at which point many households chose to refuse to pay for a cookstove they had previously ordered. Our analysis looks at determinants of cookstove orders, ultimate purchases, and refusal. Placing an order is a necessary condition for purchase, but the respondent then has to produce the cash on the day that the purchase decision has to be made. More information about cookstoves is revealed between the order and the purchase date as villagers observe neighbors and friends who purchase cookstoves. Therefore, cookstove orders, purchases, and refusal jointly provide important information regarding both liquidity constraints and how changes in the information set affect the demand for nontraditional cookstoves.

Orders for Nontraditional Cookstoves. We first estimated the impact of cookstove price on cookstove orders placed with marketers at the time of initial home visits. Table S6 shows cookstove order rates, sample sizes, confidence intervals, and how order rates vary with price. At full price, orders for both types of cookstoves were low: 23% of participants ordered efficiency cookstoves, and 31% ordered chimney cookstoves. Importantly, these orders were placed after study participants received a multimedia health-

[‡]This debate is about appropriate pricing to balance high adoption (favored by low prices) and strong incentives for distributors to supply a good or service (favored by high prices) when prices are not freely set by markets (41). Demand estimates are a primary input into pricing decisions (42).

Table 1. Price experiment estimates

	Efficiency cookstove					Chimney cookstove				
	Initial acceptance		Refusal[†]	Final acceptance		Initial acceptance		Refusal[†]	Final acceptance	
Independent variable	1	2	3	4	5	6	7	8	9	10
Subsidy (50%)	0.252***	0.256*	−0.134*	0.116**	0.079	0.031	0.186**	−0.132**	0.054**	0.065
	(0.085)	(0.136)	(0.070)	(0.045)	(0.083)	(0.062)	(0.071)	(0.054)	(0.024)	(0.041)
Household wealth index[‡]		0.061***	−0.036		0.019**		0.061***	−0.028*		0.002
		(0.013)	(0.022)		(0.008)		(0.016)	(0.016)		(0.003)
Household expenditures		0.000*	−0.000		0.000		0.000***	−0.000		0.000
		(0.000)	(0.000)		(0.000)		(0.000)	(0.000)		(0.000)
Children under age 5 y, *n*		−0.042**	0.004		−0.017*		0.002	−0.001		−0.009*
		(0.019)	(0.031)		(0.009)		(0.026)	(0.014)		(0.004)
Region (Hatiya upazilla)		0.013	−0.070		0.024		−0.016	0.127**		−0.031**
		(0.084)	(0.074)		(0.026)		(0.077)	(0.056)		(0.013)
Subsidy (50%) × household wealth index		−0.009			0.016		0.016			0.027**
		(0.022)			(0.019)		(0.022)			(0.013)
Subsidy (50%) × household expenditures		0.000			0.000		−0.000***			−0.000
		(0.000)			(0.000)		(0.000)			(0.000)
Subsidy (50%) × children under age 5 y, *n*		0.058*			0.029		−0.022			0.014
		(0.033)			(0.025)		(0.042)			(0.012)
Subsidy (50%) × region (Hatiya upazilla)		−0.167			−0.049		−0.066			−0.031
		(0.159)			(0.086)		(0.099)			(0.038)
Constant	0.233***	0.228***	0.866***	0.046***	0.041*	0.314***	0.227***	0.892***	0.020**	0.034*
	(0.041)	(0.033)	(0.059)	(0.013)	(0.020)	(0.044)	(0.059)	(0.056)	(0.009)	(0.017)
Observations	1,184	1,183	410	1,184	1,183	1,096	1,095	360	1,096	1,095
R^2	0.069	0.116	0.037	0.037	0.059	0.001	0.057	0.086	0.016	0.051

Robust SEs clustered by village (the unit of randomization) are given in parentheses below values in all specifications. *Significance at 90%; **significance at 95%; ***significance at 99%. Data on household wealth, expenditures, and number of children under 5 are taken from survey responses given by the male household head.

[†]Dependent variable *Refusal* is only defined for those households who initially accepted the cookstove offer. Note that this is a nonrandom subsample of all households.

[‡]The household wealth index was constructed by using principal component analysis on the basis of five variables: the respondent's self-assessment of the household's affluence on a scale of 1–5 and measures of the four separate categories of household assets—land, vehicles, animals, and cash savings.

education message about the harm of traditional cookstoves and the benefits of the cookstove technologies we marketed.

Table 1 shows the responsiveness of cookstove orders and purchase rates to randomly assigned discounts for efficiency cookstoves and chimney cookstoves by using regression analysis with SEs clustered by village, which was the unit of randomization. We first look at initial acceptance rates. Under each type of cookstove, the first column (1 and 6) shows unadjusted regression estimates, and the second column (2 and 7) reports estimates for a multivariate regression that controls for household socio-economic status and household composition (and includes interactions between subsidies and household characteristics). In both statistical models, reducing efficiency cookstove prices by 50% increases efficiency cookstove orders by 25–26 percentage points (with an implied price elasticity of demand of approximately −2). However, the corresponding estimate for chimney cookstove orders in the overall sample is small and indistinguishable from zero, implying no change in orders accompanying a 50% discount (i.e., we cannot reject perfectly inelastic demand for chimney cookstoves in the cookstove order data). When we add interactions of the randomized subsidy with household characteristics (wealth, expenditures, number of children under age 5 y, and region) to examine whether poorer households or households with greater health costs from indoor air pollution exposure respond differently, we see that chimney cookstove orders are only elastic for very poor households (households that report very low monthly expenditures). Discount interactions with a region dummy variable (for Hatiya) are insignificant, suggesting little regional or ecological difference in orders. If orders are interpreted as reflecting underlying demand, these differential price elasticities by cookstove type imply that participants are less willing to trade off emissions benefits for a lower price than they are fuel-savings benefits of the efficiency cookstove.

Revealed Preferences (Adoption of Nontraditional Cookstoves). After orders were placed, several weeks elapsed before our field team delivered cookstoves and collected payments. In many cases, households that ordered cookstoves declined to accept and pay for them at the time of delivery. Refusal rates were highly correlated with cookstove price, which may suggest that households face liquidity constraints, i.e., households could not take delivery because they did not have enough cash on hand to pay for the cookstove on the date of delivery. Indeed, the majority of households refusing to pay stated lack of cash as the primary reason. The fact that two unrelated treatments with roughly equivalent out-of-pocket costs for households, half-price chimney cookstoves and full-price efficiency cookstoves, led to very similar adoption rates is also consistent with this view.

At full price, actual purchases of both types of cookstoves were very low, i.e., 5% for efficiency cookstoves and 2% for the more relatively expensive chimney cookstoves. These low adoption rates at prevailing prices are consistent with the experiences of Bangladesh's nontraditional cookstove programs to date. We also emphasize their striking discrepancy with the stated hypothetical demand for cookstoves in Fig. 1, which was low in relative terms but high in absolute terms. This discrepancy highlights well-known concerns that stated WTP may poorly reflect real-world choices.

Columns 4, 5, 9, and 10 of Table 1 report the responsiveness of actual cookstove purchases to discounts. For both types of cookstoves, a 50% discount increased adoption, raising efficiency cookstove purchases by 8–12 percentage points and chimney cookstove purchases by 5–6 percentage points. Interactions between discounts as well as both household characteristics and region/local ecology are indistinguishable from zero. These increases are relatively small in absolute terms, suggesting that substantial discounts may be ineffective in achieving high adoption rates; however, they are very large in relative terms (in comparison with adoption rates at full price): 253% and 265% increases (with implied price elasticities of −5 for both stoves). Very low observed adoption rates at any price and high sensitivity of purchase decisions to price are both consistent with the new varieties of cookstoves not being valued relative to alternative uses of household resources. These experimental results are also in line with our survey evidence that household budgetary concerns seem to dominate decision-making and that competing demands for limited funds make nontraditional cookstoves that reduce indoor smoke a low priority for households.

Finally, columns 3 and 8 of Table 1 focus specifically on the households' choice to refuse to purchase a cookstove that they had previously ordered. These data indicate that liquidity constraints are likely a key determinant of a household's decision to purchase: discounted prices (implying that households have to have less cash on hand) significantly reduce refusal rates for both efficiency and chimney cookstoves. (The regression results presented include controls for wealth, expenditures, household composition, and region. These results are robust to the exclusion of these controls and to the inclusion of additional controls for whether the household suffered an economic shock between the time of the cookstove offer and the cookstove delivery.) Moreover, refusal rates were very similar in two unrelated experimental conditions (full-price efficiency cookstove and half-price chimney cookstove) that happened to have the same cash requirement (৳400 or ৳375), which suggests the possibility that lack of cash on hand was the key deterrent to purchase.

Discussion

This paper presents evidence on the underlying determinants of nontraditional cookstove adoption among rural Bangladeshi households. Our analysis of stated preferences yields three key findings. First, women in rural Bangladesh do not perceive indoor air pollution as a high-priority health hazard relative to other risks common in rural Bangladesh. Second, non-health considerations (especially financial and time costs of cookstoves as well as fuel) dominate household decision-making, which may limit a cookstove's marketability on the basis of appeals to health improvements. Few women value reductions in indoor air pollution over monetary considerations. Third, stated demand for nontraditional cookstove technologies is more price-elastic than stated demand for other essential goods and services, implying that nontraditional cookstoves are valued less.

We reinforced these insights through an analysis of revealed preferences by conducting a cluster-randomized trial of cookstove prices. The two main findings from this analysis were that demand for nontraditional cookstoves at both market and highly subsidized prices is very low and that demand is highly sensitive to price (in relative terms). Actual adoption rates at full price were negligible, ranging between 2% (for chimney cookstoves) and 5% (for efficiency cookstoves). Consistent with respondents' not valuing cookstoves relative to competing needs, adoption decisions were also highly sensitive to price, with price elasticities ranging between −8 (for efficiency cookstoves) and −10 (for chimney cookstoves). More elastic demand for chimney cookstoves relative to efficiency cookstoves is also consistent with preferences for lower fuel costs over less indoor smoke. Despite this price sensitivity, large discounts failed to produce quantitatively important gains in adoption: 50% price reductions only led to 12% increase in the adoption of efficiency cookstoves and 5% increase in the adoption of chimney cookstoves.

Existing research suggests that exposure to smoke from household fuels contributes to 4% of all disability-adjusted life years lost in less-developed countries (6). The majority of these health impacts arise from acute respiratory infections, which are a leading cause of illness and death in children under 5 y old worldwide (5). Furthermore, our survey respondents stated, in response to questions that queried their subjective beliefs regarding the health effects of nontraditional cookstoves, that they expected cookstoves to significantly decrease the likelihood of respiratory illness and increase their lifespan. On the basis of these figures, the low valuation our respondents place on nontraditional cookstove technologies appears suboptimal. However, our findings also indicate that price concerns and liquidity constraints are the important deterrents, which may explain the low demand for nontraditional cookstoves despite the large presumed health benefits.

These findings have several implications for future efforts to promote the adoption of cleaner cookstoves in Bangladesh (and possibly in other contexts). First, the design of nontraditional cookstove technologies must focus on attributes that individuals and households value. Even if policymakers are more concerned about the health and environmental consequences of traditional cookstoves, designing cheaper cookstoves or reducing the cost of adoption in other ways (such as introducing fuel-efficient cookstoves in areas with fuels that are not cheaply or easily available) may be the most promising strategies for boosting adoption of nontraditional cookstoves. Second, although not a direct object of our study, education and information campaigns alone may be unlikely to produce important changes in cooking practices. We provided health-education information about indoor air pollution and cooking practices to all participants in our study, so the low adoption rates that we observed capture their impact. Third, in light of the ongoing academic and policy debate about distributing health technologies in developing countries for free or by charging user fees (41), our experiments clearly indicate that cookstove price can be an important deterrent to cookstove adoption. Demand at market price is very low, implying that sustainable pricing of existing cookstoves without addressing the most relevant financial constraints (because of liquidity, lack of credit, or inability/unwillingness to commit funds given the opportunity cost) may dampen cookstove adoption considerably. However, we note that, for existing nontraditional cookstove technologies, any pricing strategy alone is unlikely to achieve high adoption rates.

An important deterrent to adoption of nontraditional cookstove technology may be that many of the technologies currently being marketed around the world are actually not "improved" in terms of fuel savings, emissions reduction, or other attributes that households value most. The analysis we have presented has examined how households trade off budgetary concerns against other desirable cookstove attributes (such as pollution reduction or fuel savings), and a better understanding of these tradeoffs is a necessary first step to developing the optimal marketing schemes, pricing, and engineering designs for the "truly improved" cleaner, healthier, and efficient cookstoves that the scientific and policy communities intend to market in the developing world.

Data and Methods

Nationally Representative Survey of Preferences About Cookstoves. We used stratified random sampling to construct a representative sample of rural Bangladeshi households for a survey we administered in 2006. First, we divided the country into four agro-ecological zones (hilly and forest areas, Barind Tract, coastal and mangrove areas, and plain lands) and then randomly selected 30 upazillas from each zone. Next, we randomly drew one village from each upazilla and randomly selected 20 households from each village. Our final sample included 2,397 households drawn from 120 villages across rural Bangladesh after discarding 3 households with male respondents.

Price Experiment with Two Nontraditional Cookstoves. Our cluster-randomized trial to estimate the price sensitivity of demand for two nontraditional cookstove technologies was conducted in Hatiya and Jamalpur, two ecologically diverse districts of Bangladesh with large differences in rainfall and fuel availability. Within these two districts, we randomly selected 42 study villages. We randomly assigned cookstove prices at the village level to avoid any discontentment that could have been caused by households living in the same village facing different prices. We allocated 11 of the 21 study villages in each district to full cookstove price and the remaining villages to the discounted (50%) cookstove price. We also randomly assigned the type of cookstove technology offered: efficiency cookstoves were marketed in 11 (of 21) villages in each district, and chimney cookstoves were marketed in the other 10. The

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random assignment of cookstove type was orthogonal to the random assignment of price. At full-price condition, we marketed efficiency and chimney cookstoves at ৳400 ($5.80) and ৳750 ($10.90), respectively. These prices reflect some discounts that we received for bulk ordering relative to the cookstoves' retail prices. In the 50% subsidy condition, we marketed efficiency and chimney cookstoves at ৳200 ($2.90) and ৳375 ($5.40), respectively. These cookstoves were offered to households under "real-world" circumstances (generally with both the husband and wife present), so we interpret cookstove orders and purchases as joint household decisions. These circumstances differ from our nationally representative survey of stated preferences in that, in the national survey, all respondents were women. Survey responses indicate that households retained the most salient characteristics of each cookstove as they are advertised: chimney cookstoves reduce indoor emissions by redirecting smoke out of the house, whereas the efficiency cookstove reduces fuel consumption.

After assigning villages to trial arms, we randomly selected 54 households per village on average for experimental marketing. We conducted a baseline survey of all 2,280 sample households between July and September 2008, collecting data on basic demographic and socio-economic characteristics as well as cooking practices, health, and women's status. Table S5 presents baseline descriptive statistics, demonstrating balance on observable characteristics (consistent with successful randomization). At the time of the baseline survey, we provided basic health education about the harm of traditional cookstoves and the benefits of nontraditional cookstoves while offering each respondent the cookstove technology that was randomly assigned to their village at the randomly chosen price. Requests for cookstoves were tallied, cookstove orders were relayed to manufacturers, and cookstoves were delivered between November 2008 and February 2009. We used unadjusted and adjusted linear-regression analysis to estimate the impact of price on both nontraditional cookstove orders and cookstove purchases. The covariates included in our adjusted analysis are a household wealth index, household expenditures, number of children under age 5 y, and region dummy variables as well as the interaction of each with randomized subsidies.

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