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'Oorja' in India: Assessing a large-scale commercial distribution of advanced biomass stoves to households

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ABSTRACT

Replacing traditional stoves with advanced alternatives that burn more cleanly has the potential to ameliorate major health problems associated with indoor air pollution in developing countries. With a few exceptions, large government and charitable programs to distribute advanced stoves have not had the desired impact. Commercially-based distributions that seek cost recovery and even profits might plausibly do better, both because they encourage distributors to supply and promote products that people want and because they are based around properly-incentivized supply chains that could more be scalable, sustainable, and replicable.

The sale in India of over 400,000 "Oorja" stoves to households from 2006 onwards represents the largest commercially-based distribution of a gasification-type advanced biomass stove. BP's Emerging Consumer Markets (ECM) division and then successor company First Energy sold this stove and the pelletized biomass fuel on which it operates. We assess the success of this effort and the role its commercial aspect played in outcomes using a survey of 998 households in areas of Maharashtra and Karnataka where the stove was sold as well as detailed interviews with BP and First Energy staff. Statistical models based on this data indicate that Oorja purchase rates were significantly influenced by the intensity of Oorja marketing in a region as well as by pre-existing stove mix among households. The highest rate of adoption came from LPG-using households for which Oorja's pelletized biomass fuel reduced costs. Smoke- and health-related messages from Oorja marketing did not significantly influence the purchase decision, although they did appear to affect household perceptions about smoke. By the time of our survey, only 9% of households that purchased Oorja were still using the stove, the result in large part of difficulties First Energy encountered in developing a viable supply chain around low-cost procurement of "agricultural waste" to make pellets. The business orientation of First Energy allowed the company to pivot rapidly to commercial customers when the household market encountered difficulties. The business background of managers also facilitated the initial marketing and distribution efforts that allowed the stove distribution to reach scale.

Introduction

Indoor air pollution (IAP) from burning biomass in traditional stoves is a major global health problem, causing an estimated 4 million premature deaths annually from cancer, respiratory infections, and other ailments (Lim et al., 2012; Naeher et al., 2007; Smith and Ezzati, 2005; WHO, 2006). Emissions from traditional stoves, particularly of black carbon and incomplete combustion products, are also increasingly recognized as a serious contributor to climate change (Johnson et al., 2009; Kar et al., 2012; Smith et al., 2000; Zhang et al., 2000).

Government and charitable programs to supplant traditional stoves with cleaner-burning options have struggled over the past 30 years to make a major dent in the problem. China's national stove program reported deploying over 180 million advanced biomass stoves over two decades (Sinton et al., 2004; Smith et al., 1993), while India's national program pushed over 30 million stoves into the market but saw low usage rates (Barnes et al., 1994,2012; Sinha, 2002). A mix of NGO, public sector, and commercial players reports having distributed 8.2 million cleaner-burning stoves since 2006 (GACC, 2012).[1] Given typical stove lifetimes of less than three years (GACC, 2012) and historical usage rates that are uncertain and possibly low (Hanna et al., 2012), efforts to date are nowhere close to providing durable clean cooking solutions to the more than 500 million biomass-using households that need them.[2]

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[1] Because not all stove providers provided information to the Global Alliance for Clean Cookstoves, this figure may understate the actual stove distribution to a certain extent.

[2] The estimate of over 500 million households using biomass for cooking is derived by taking the total biomass-using population of 2.6 billion from the IEA (2012) and assuming an average household size of around five (about that of India, per Census of India (2001)).

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Some in the donor community believe that better results will be achieved by applying a commercial mindset to the problem (Bailis et al., 2009; Hoffman et al., 2005).[3] Commercial stove distribution, whether fully for-profit or part of a hybrid "social enterprise" model with some charitable elements, has two main advantages in theory. First, the need to recover costs provides a strong incentive to supply (and market) a product that customers actually value, with sales figures providing ongoing feedback from the customer base. Second, commercial value chains may create positive cash flow and appropriate incentives from manufacturing through distribution so that stove distributions can be expanded, sustained, and replicated to match the scale of the indoor air pollution problem.[4] As Bailis et al. (2009) point out, the most successful stove efforts to date, like China's national program and the development of the Kenya Ceramic Jiko stove, have indeed incorporated at least some commercial elements.[5] There are, of course, potential downsides to commercial business models, including a lack of incentive to reach the very poorest populations and the possibility that businesses might sacrifice quality to boost profits, especially in a nascent market that lacks performance standards.[6]

In the current work, we assess the benefits and challenges of a commercial approach to stove distribution by studying the experience with the "Oorja" stove in India. Between 2006 and 2010, over 400,000 Oorja stoves were sold in India, initially by BP's Emerging Consumer Markets (ECM) division and then by a spin-off company called First Energy. While the stove business was structured along commercial lines from the outset—in accordance with the idea that serving the "Bottom of the Pyramid" can be profitable (Prahalad, 2005)—our interviews suggest that it functioned as a "social enterprise" within BP. BP managers had expectations for modest returns but not material ones.[7] Several of those whom we interviewed perceived that BP executives all the way up to then-CEO John Browne felt passionately that ECM could represent an opportunity to do significant social good (Author Interviews). The Oorja business was forced to become more purely commercial after BP spun it off. As we will discuss later, this situation illustrates how social enterprises struggling to survive may have to sacrifice either social impact goals or their commercial character.

Two other aspects of the Oorja case make it a particularly valuable object of study. First, Oorja was the first advanced, "micro-gasifier" stove sold at a large scale. By gasifying biomass and burning the resulting gases in a controlled way, such stoves perform more like modern LPG-fueled stoves and offer the potential for dramatic, not just incremental improvements in efficiency and emissions (Jetter et al., 2012; Roth, 2011).[8] Second, the Oorja was fueled by biomass pellets sold by BP/First Energy, so fuel sales data can provide information on usage over time that is unavailable for most stoves. Fig. 1 shows a picture of the Oorja stove and its fuel pellets.

Studying Oorja provides insights not only into the potential of commercial business models in particular but also why households adopt or disadopt modern biomass stoves more generally. In this paper, we identify the household characteristics that were most strongly correlated with purchase of the stove, and then we analyze the reasons for the steep drop-off in Oorja usage that was observed following initial adoption. Because many purveyors of clean-burning stoves—including BP and First Energy—hope to have a positive impact on health, we also assessed the degree to which prospective Oorja customers responded to health-oriented messaging.

Research methodology

Research niche

Many of the existing studies related to advanced biomass stoves fall into one or more of the following categories:

- Technical evaluations measure and compare stove performance, with an increasing reliance in recent years on test protocols that yield efficiency and emissions data reflective of field and not just laboratory conditions (Bailis et al., 2007; Jetter et al., 2012; Johnson et al., 2011; Roden et al., 2009; Vaccari et al., 2012).
- In-depth case studies evaluate the micro-level effects of stove interventions, with more recent efforts incorporating direct emissions monitoring technology (Adkins et al., 2010; Chengappa et al., 2007; Clark et al., 2010; Masera et al., 2007; Ruiz-Mercado et al., 2011).
- Major programmatic evaluations, which are usually based on systematic surveys of stove usage and interviews with the players involved, characterize the functioning and impacts of large government- or donor-funded cookstove programs, such as those in China, India, and Kenya (Bailis et al., 2009; Barnes et al., 1994, 2012; Hyman, 1986, 1987; Ministry of Energy, 2002; Sinha, 2002; Sinton et al., 2004; Smith et al., 1993).
- Diverse studies at both macro- and micro-levels use statistical methods to elucidate and model connections between the physical environment; technology, policy, economic, and energy supply factors; household needs and characteristics; and quantity and type of energy consumed (Biswas and Lucas, 1997; Hosier, 1984; Johnson and Bryden, 2012; Kowsari and Zerriffi, 2011; Victor and Victor, 2002).
- Randomized controlled trials (RCTs) of stove distributions assess with statistical methods whether improved cookstoves achieve the objective of health improvement (Burwen and Levine, 2012; Hanna et al., 2012; Smith et al., 2010, 2011).

[3] A 2005 report from the Shell Foundation, which has been active in the cookstove space, crisply summarizes the view that commercially-oriented distribution of stoves may yield better results than have been achieved thus far by governments, NGOs, and development agencies: "Finally and most germane, the interventions that did get donor funding have not made inroads into the problem on a significant scale. This is partly because of limited funding but largely we believe because the 'solutions' offered were basically subsidized, technical fixes (mostly 'cleaner' stoves) that were often designed elsewhere and bore little relation to what the 'market' (millions of poor households) wanted and could afford or to what overcoming the IAP [indoor air pollution] problem required. In our language, very little business thinking appears to have been applied to tackling the IAP problem by either the donor or the project deliverers. In our view, this resulted in most IDC [International Development Community] IAP interventions being neither financially viable nor scalable. Thus they usually made little sustainable headway in eradicating the IAP problem (Hoffman et al., 2005, p. 15–16)."

[4] A third potential rationale, that charging positive prices enhances perceived value and thus uptake of a health-improving product, is unproven for cookstoves and has been largely discredited for other health interventions (Cohen and Dupas, 2010; Kremer and Miguel, 2007).

[5] China's National Improved Stove Program (NISP) combined central government support with county-level management of rural energy enterprises that manufactured, sold, and serviced stoves (Smith et al., 1993). After 1990 the NISP phased out direct government subsidies to households in favor of support for these rural energy companies (Sinton et al., 2004). The Kenya Ceramic Jiko (KCJ) model of charcoal stove—of which 2 million were reportedly in the field as of 2002 (Ministry of Energy, 2002)—was developed with substantial development agency and NGO funding but evolved over almost two decades into a wholly commercial product (Bailis et al., 2009; Hyman, 1986, 1987).

[6] For example, the authors have observed "spoilage" of markets for solar lights and solar home systems through the influx of low-price and low-quality systems that damage the reputation of these products.

[7] It was also seen as a way to build off of BP's substantial existing presence in India in lubricants, notably Castrol motor oil, and to further develop a positive BP brand in the country (Author Interviews).

[8] To operate the Oorja, a user fills its cylindrical reactor with energy-dense fuel pellets—cylinders about 1 cm in diameter and 4 cm long—that are made from agricultural waste in a conversion plant. After the top surface of the pellets is lit (generally using kerosene), the pellets start to gasify, producing combustible gases that burn with air forced up through the reactor by a fan (Mukunda et al., 2010). The reaction moves progressively down through the pellets, resulting in about a one hour cooking time if the reactor is filled with pellets at the outset. Combustion of gasified fuel is highly efficient. The use of a fan (forced convection) also improves efficiency and minimizes emissions by optimizing the fuel-to-air ratio. While the Oorja's mode of operation enables high efficiency, it remains a batch process, which is a crucial drawback relative to LPG stoves.

Fig. 1. Oorja stove and fuel pellets. Photo: First Energy.

The current work helps extend the literature on programmatic evaluation into the area of commercial stove efforts. Our study may also provide new insights relative to previous programmatic evaluations because of its greater focus on ongoing stove usage and disadoption relative to initial adoption.

By studying the entire adoption/disadoption trajectory of a major commercial product like the residential Oorja stove, our work complements the valuable data from randomized controlled trials (and addresses some of their limitations) in several important ways. First, it allows assessment of impact for a stove which consumers desired sufficiently to purchase in the marketplace of their own accord, at a cost-recovering or near-cost-recovering price.[9] Second, we gain valuable insight into which characteristics of the business model and customers being targeted have the most influence on the scalability and sustainability of the stove distribution. (A finding of positive impact in a randomized controlled trial would be very encouraging but would not necessarily guarantee successful implementation at scale.[10])

Overview of research methods

We used the following quantitative methods in our study. First, we developed a logistic regression (logit) model of Oorja initial adoption based on a survey we performed of 998 households in Maharashtra and Karnataka in April and May of 2011. (The full survey questionnaire is available in the Supplementary materials on the web.) Second, we used data from the survey to create an ordered logit model to explore the effect of BP/First Energy's health-related messaging on perceptions about smoke. Third, we used simple descriptive statistics from the survey data to investigate a variety of relevant aspects of the stove purchase, usage, and disadoption processes, including: 1) how smoke perceptions translated into stove purchases, 2) the perceived strengths and weaknesses of the Oorja stove relative to modern LPG stoves and traditional "chulhas"; and 3) the patterns of stove adoption and disadoption as a function of pre-existing fuel usage. Fourth, we assembled a picture of the overall adoption, usage, and disadoption trajectory for Oorja using the following data provided to us by First Energy: village-resolved stove and pellet sales by month from 2007 through 2008, village-resolved figures for the number of dealers in the distribution network by week over the course of 2008, and aggregate stove and fuel sales data from 2007 through 2010.

Qualitative information provided a crucial complement to our quantitative data, especially by enabling a richer understanding of how the commercial character of the Oorja enterprise affected its operation and results. Interviews with First Energy and BP managers helped us understand the Oorja business model and the rationale behind it, how the business was developed within BP and then First Energy, and then how the enterprise adapted in response to business challenges, especially the escalation in the prices of the raw materials used for making fuel pellets. During field visits before and during the survey, we also interviewed Oorja customers and dealers in an open-ended way about their experiences with the stove. These interviews provided additional perspectives on the Oorja business model and also facilitated survey design and interpretation of survey responses.

Survey sampling

We stratified our sample by district and village/town[11] with two goals in mind. First, we sought to create a generally representative sample from which we could draw conclusions that would be applicable to the overall population exposed to Oorja in Maharashtra and Karnataka. From within the universe of villages and towns where Oorja was marketed, we selected six districts in Maharashtra and four districts in Karnataka to be in our survey sample, reflecting the lesser coverage of Oorja in Karnataka (see Table 1 for a full description of our sample).

Second, in order to maximize the chance of observing an effect in our statistical models, we sought to cover the full range of variation in independent variables that we hypothesized might affect Oorja adoption and use—variables such as geographical location (and resulting economic patterns), intensity of Oorja marketing, and household socioeconomic status, education level, and existing fuel mix. We explicitly chose districts that were geographically dispersed and also that had significant variation in average literacy rate and per capita income according to Indian census figures.

We randomly selected 25 villages and towns[12] from within these districts, with the constraint that the village-to-town ratio be around 2-to-1, in rough accord with the relative stove sales from these different kinds of settlements. Villages or towns with less than 3% Oorja penetration as of the end of 2008 according to BP ECM figures were eliminated from the sample and replaced with alternative randomly-selected settlements due to the concern that it would be too difficult to find households that had purchased Oorja in these locations.

Within each village or town, we chose households to survey through two different methods: random and purposive selection. The goal of the random selection was to obtain a representative set of households that we could use to model Oorja adoption and usage decisions. By dividing each town or village into quadrants and visiting houses in each quadrant according to a specified methodology, we collected a sample from approximately 20 randomly-selected households that had never purchased Oorja, plus whatever number we happened to encounter

[9] When RCTs show low rates of usage of improved stoves (Burwen and Levine, 2012; Hanna et al., 2012), there is always the possible counterargument that consumers in the treatment group may not have valued the new stove in the first place. In considering Oorja we are evaluating the impact of an advanced stove that was intended to be "as good as LPG" (Author Interviews) and indeed appeared to be attractive to prospective consumers at the outset. As a contrasting example, the mud stove used in the RCT conducted by Hanna et al. (2012) was locally produced and arguably optimized on affordability rather than functionality or air quality, leading some to argue that it represented a suboptimal case for measuring the potential impact of improved stoves (Smith, 2012). Smith and Dutta (2011) suggest that cookstove developers should strive for comparable performance to LPG stoves, which are flexible and convenient, rather than an incremental improvement on traditional cooking methods.

[10] Of the two principal long duration RCTs that have been completed, the first—the RESPIRE study in Guatemala—focused on isolating the efficacy of a properly-functioning stove in reducing indoor air pollution and therefore included weekly monitoring of stove operation and repairs if needed (Smith et al., 2010). The second long-duration RCT, which was run in India by Rema Hanna, Esther Duflo, and Michael Greenstone, examined household stove usage patterns as one key outcome and therefore did not incorporate any extraordinary maintenance support (Hanna et al., 2012). (Indeed, rapidly declining stove usage was one of the main reasons that little positive impact from the new stove was observed in this study.)

[11] We use the term "rural" in this paper to refer to a census-identified village and "urban" to refer to a census-identified "town."

[12] One additional town with substantial Oorja penetration (Annigeri) and two additional villages with limited penetration (Kundgol and Nalavadi) were added while the survey was in progress to compensate for slightly lower than expected sampling in some of the original 25 villages and towns.

Table 1
Survey sampling.

State	District	Literacy rate (2001 census)	Per capita income (Rs)	Village/town (towns in italics)	Never purchased Oorja (# of households)	Purchased Oorja (# of households)	Oorja penetration at peak (%)
Maharashtra	Jalna	64.5	19,936	*Ambad*	20	20	10.4
				Sukhapuri	20	20	22.0
	Latur	72.3	20,469	Dhamangaon	20	20	20.5
				Patharwadi	20	20	22.0
	Nashik	75.1	40,924	Bramhan Wade	20	20	17.4
				Nilgavhan	20	20	8.7
				Satana	20	20	22.9
	Pune	80.8	52,811	Dhamani	19	21	10.3
				Rajgurunagar	20	20	18.8
				Thopatewadi	20	20	41.6
	Sangli	76.7	31,181	Bhilwadi	21	19	28.2
				Madhavnagar	19	20	27.2
				Takali	20	20	20.0
	Satara	78.5	33,216	Hol	20	20	8.8
				Pande	20	20	17.5
Karnataka	Bagalkot	57.8	16,109	Kakanur	20	0	5.4
				Kerur	21	10	5.1
	Belgaum	64.4	16,264	*Bail Hongal*	22	18	9.3
				Hanabar Hatti	18	19	5.6
				Raybag	20	20	12.3
				Tarihal	16	2	6.5
	Dharwad	71.9	23,496	*Annigeri*	19	20	7.2
				Betadur	20	15	6.2
				Bhandiwad	20	20	11.0
				Hubli	20	20	42.0
				Kundgol	15	0	<1
				Nalavadi	23	1	<1
	Haveri	68.1	12,323	Hulgur	20	0	9.4

Per capita income data shown are nominal values: 2002–2003 data for Karnataka, 2005–2006 data for Maharashtra.

that had purchased Oorja.[13] The total random selection across all villages and towns ended up consisting of 661 households, of which 553 had never purchased Oorja and 108 had purchased Oorja.

We then added a purposive selection step to increase the number of Oorja-purchasing households in our sample and thereby improve the statistics for this sub-population in analyses that were not focused on adoption decisions. This purposive selection involved asking Oorja purchasers found in the random selection (or people who had heard of Oorja, if purchasers had not yet been found) about the location of other users or of dealers, who could in turn be queried to find additional users. Through this method, we increased the number of Oorja purchasers in our overall sample to 445 (337 found through the purposive selection added to the original 108 that we had located in the random selection).

Table 2 shows basic descriptive statistics for rural and urban households in the random and purposive selections that adopted and did not adopt Oorja. In the random selection, median income and time spent cooking each day varied between rural and urban areas but was constant across adopting and non-adopting groups. The distribution of cooking methods used before exposure to Oorja varied in some noticeable ways between rural and urban areas and within adopting and non-adopting groups. In the following section we describe the regression model we used to explore which of these and other variables had a statistically-significant relationship with Oorja initial adoption.

[13] Each village or town was divided into four quadrants after an initial consultation with the village/town leadership (gram panchayat). Interviewers were deployed by market research firm IMRB International to each of these four quadrants, where they selected households at random (following a specified frequency at which households would be selected and a "right-hand walk" rule where roads forked) and, if both the chief wage earner (CWE) and housewife were present and gave their consent, administered the survey. (In a few cases, the housewife was also the CWE.) Typically, both the CWE and housewife contributed to the responses, with the CWE playing a larger role in answering income and financial questions and the housewife answering cooking-related questions. If survey enumerators were repeatedly unable to find a time when both CWE and housewife were at home, the household was skipped, with the logic that a single one of them would be less able to provide a comprehensive answer for the household. However, this circumstance was rare.

Model of initial adoption

Using the survey data from the random selection only, we developed a multivariate logistic regression (logit) model to characterize the relationship between a household's decision to purchase Oorja and three broad categories of factors: local intensity of Oorja distribution (dealers per thousand people in the town or village), basic household demographics (income and education), and household cooking practices (hours of stove use daily and pre-existing fuel mix). Our estimating equation takes the following form:

$$BuyOorja_i^* = \beta_0 + \beta_1 DealersPerThou_i + \beta_2 Income_i + \beta_3 BelowSecEduc_i + \beta_4 AboveSecEduc_i + \beta_5 CookHrsDaily_i + \boldsymbol{\beta_{Mix}}\mathbf{Mix_i} + \varepsilon_i$$

where $BuyOorja_i^*$ is a latent index indicating the tendency of a household to buy Oorja. (We observe that households actually make this purchase when $BuyOorja_i^*$ is greater than zero.) Because we noticed in our qualitative field research that Oorja adoption appeared to be driven by a different set of factors in villages compared with towns, we performed separate regressions for rural and urban adoption rather than simply using a rural/urban dummy variable.

The density of Oorja dealers (number of dealers at the end of 2008 by BP/First Energy figures per thousand residents in the village or town as reported by the census) controls for the availability of Oorja and the marketing and distribution resources behind it in a particular locale. To assess whether stove affordability was a constraint for lower-income households in our sample, we include household monthly income as an independent variable in the model. Because income questions can elicit unreliable answers—due to both their sensitivity and the difficulty of averaging irregular income flows over the year—we also tested expenditures and appliance holdings as indicators of socioeconomic status. However, the income variable ultimately showed the highest statistical significance and is therefore used in the models shown here.

Because willingness to adopt new cooking methods might plausibly be correlated with general educational background, we characterized

Table 2
Descriptive statistics for households surveyed. (Note that the income means and standard deviations in the purposive selection group are strongly affected by a tail of high earners in the distribution.)

Summary data table		Rural			Urban		
		Random selection		Purposive	Random selection		Purposive
		Did not adopt Oorja	Adopted Oorja	Adopted Oorja	Did not adopt Oorja	Adopted Oorja	Adopted Oorja
Number of households		391	80	217	162	28	120
	Still using Oorja (May 2011)	0	12	12	0	1	13
Income (Rs/month)	Mean	6190	6224	8058	8086	7357	9278
	Median	5000	5000	5000	6000	6000	7000
	Std Dev	3903	3524	12,190	5493	5018	6601
	Min	500	1000	1000	1000	1500	1000
	Max	25,000	20,000	150,000	25,000	25,000	45,000
Maximum education	Less than secondary	22%	11%	13%	20%	29%	12%
(% of households)	Secondary school	54%	50%	56%	44%	43%	44%
	More than secondary	25%	39%	31%	36%	29%	44%
Stove use daily (hours)	Mean	2.6	2.2	2.5	2.9	2.6	2.7
	Median	**2.0**	**2.0**	**2.0**	**3.0**	**3.0**	**3.0**
	Std Dev	1.0	0.6	0.8	1.0	0.6	0.9
	Min	1.0	1.0	1.0	1.0	2.0	1.0
	Max	8.0	5.0	5.0	6.0	4.0	7.0
Pre-existing stove mix	LPG only	5%	13%	9%	33%	32%	41%
(% of households)	LPG + chulha	9%	9%	11%	10%	4%	8%
	LPG + kerosene	5%	8%	6%	10%	18%	8%
	LPG + chulha + kerosene	14%	22%	21%	9%	7%	15%
	Kerosene only	2%	4%	2%	4%	4%	2%
	Chulha + kerosene	21%	32%	21%	18%	14%	13%
	Chulha only	43%	14%	28%	15%	14%	8%
Electric grid connection (% of households)		96.2%	97.5%	99.5%	99.4%	100.0%	100.0%
Appliance holdings	Television	76%	83%	84%	85%	93%	92%
(% of households owning)	Mobile phone	74%	81%	85%	76%	79%	83%
	Motorcycle/scooter	34%	48%	55%	53%	46%	65%
	Refrigerator	13%	19%	22%	30%	32%	35%

the maximum education level achieved by any member of the household using three mutually exclusive dummy variables: education below secondary school (e.g., illiterate, literate but lacking formal education, or having 9 or fewer years of schooling), education through secondary school (this was the mode of the distribution for both rural and urban groups and the omitted variable in our regression), and education above secondary school (e.g., college or professional school).

It may be that households with different cooking needs are more or less interested in the specific cooking attributes offered by Oorja; we sought to capture this variation in a very rough way with a variable representing daily hours spent cooking. Another independent variable that we expected might be significant was the household's mix of cooking methods prior to the introduction of Oorja, which is represented in the equation above by a vector $\mathbf{Mix_i}$ of mutually-exclusive dummy variables indicating all the main stoves that the household reported owning as of December 2006. (Here, the baseline is households without LPG or kerosene, which consist almost entirely of sole chulha users.)

The coefficient estimates for the regression model of the Oorja purchase decision are shown in Table 3 and discussed in the Factors affecting initial adoption section.

Model of smoke perceptions

Oorja marketing channels of various types—including posters, promotional videos, and in-person demonstrations—contained information about the dangers of indoor smoke. We sought to understand whether these messages were absorbed by prospective Oorja buyers (as well as whether they actually affected purchasing behavior). Because our survey was administered well after the Oorja marketing took place, we could not directly compare people's smoke perceptions from before and after they encountered Oorja-related messages. However, a statistically-significant relationship between exposure to Oorja

Table 3
Regression models of Oorja initial adoption in rural and urban areas based on entire random selection of 661 households (see Table 2).

Initial adoption of Oorja in random sample Average marginal effects from logit model with robust standard errors		
	Rural	Urban
	dy/dx (std error)	dy/dx (std error)
Income ('000 Rs/month)	−0.00804 (0.00495)	−0.00075 (0.00574)
Maximum education level is below secondary	−0.0585 (0.0509)	0.0307 (0.0764)
Maximum education level is above secondary	0.0658* (0.0379)	−0.0164 (0.0637)
Hours of stove use daily	−0.0188 (0.0176)	−0.0427 (0.0275)
Pre-existing stove mix: LPG only	0.263*** (0.064)	−0.019 (0.085)
Pre-existing stove mix: LPG + chulha	0.156** (0.068)	−0.158 (0.142)
Pre-existing stove mix: LPG + kerosene	0.109 (0.076)	0.016 (0.094)
Pre-existing stove mix: LPG + chulha + kerosene	0.129** (0.059)	−0.063 (0.120)
Pre-existing stove mix: kerosene only	0.165* (0.097)	−0.092 (0.157)
Pre-existing stove mix: chulha + kerosene	0.103** (0.051)	−0.083 (0.086)
Stove dealers per thousand (average = 1.2 in rural areas/0.6 in urban areas)	0.118*** (0.022)	−0.051 (0.073)
Observations	471	190

Baseline is households without LPG or kerosene (almost all chulha-only) whose most educated member attended secondary school.
*** Significant at 0.01 level.
** Significant at 0.05 level.
* Significant at 0.10 level.

marketing channels and awareness of the impacts of indoor smoke would suggest that smoke-related messages in the marketing were received—whether or not they actually drove Oorja purchases. (Such an inference hinges on the assumption, examined further in the Retention of health messaging and impact on adoption section, that respondents do not self-select in their exposure to Oorja marketing—for example, that people do not choose to attend Oorja demonstrations precisely because of their pre-existing concern about smoke.)

Using the combined survey data from the random and purposive selections, we developed an ordered logit model of respondent perceptions about smoke as a function of relevant household characteristics and exposure to various Oorja marketing channels. We use the following linear equation to model an unobserved dependent variable $SmokeView_i^*$, which represents degree of agreement with the statement "Indoor smoke caused by your cooking appliances is bad for your health or physically bothersome to you and those around you":

$$\begin{aligned} SmokeView_i^* = {} & \beta_1 Town_i + \beta_2 Income_i + \beta_3 BelowSecEduc_i \\ & + \beta_4 AboveSecEduc_i + \beta_5 NoChulha_i \\ & + \beta_6 ChulhaPlusLPGorKero_i + \beta_7 BoughtOorja_i \\ & + \beta_8 OorjaDemo_i + \beta_9 OorjaWordofMouth_i \\ & + \beta_{10} OorjaMedia_i + \varepsilon_i. \end{aligned}$$

We simultaneously estimate the coefficients of this equation along with cutpoints that group values of $SmokeView_i^*$ into the five levels of survey response from "strongly disagree" to "strongly agree." This ordered logit approach is suitable because these five levels are ordered but not necessarily linear.

We believed that income and general educational background might plausibly affect views about the negative health and comfort impacts of smoke, so we included these as independent variables in the same fashion as in our Oorja initial adoption model (see Model of initial adoption section). We also included a dummy variable to indicate whether the respondent was living in a town or village, in case these two populations had characteristically different perceptions of smoke.

We speculated that a household's mix of cooking technologies at the time of the survey could influence perceptions about smoke in several ways. Users of only LPG and/or kerosene, which do not emit significant smoke, should correctly perceive that smoke from their cooking appliances is not a big problem. Users of both traditional chulhas and one of these petroleum-based fuels would observe the negative effects of smoke in stark contrast to the cleaner fuels, and therefore might be expected to be in stronger agreement with the statement that smoke from their appliances is bad for health and/or comfort. Users of traditional chulha only, for whom smoke is objectively the greatest problem, would either be very troubled by smoke or perhaps desensitized to it. To investigate these possible effects, we included mutually-exclusive dummy variables for whether a household used only LPG and/or kerosene (*NoChulhai*) or a mix of these fuels plus chulha (*ChulhaPlusLPGorKeroi*). Chulha-only users were the base case in the regression. Since very few households still used Oorja at the time of our survey (and none as a significant part of their current stove mix), we did not include a variable for current Oorja stove use. (We did include a dummy variable identifying households that bought Oorja, in case these households were inclined to believe—in line with Oorja marketing messages—that they had solved the smoke problem through their purchase of Oorja.)

The final three variables in the estimation equation explore how exposure to each of three Oorja marketing channels—in-person stove demonstrations, word of mouth from acquaintances, and media (e.g., television or radio advertisements)—was correlated with the respondent's perceptions of smoke. Statistically-significant coefficients would suggest that these channels altered perceptions about smoke, subject to the caveat that people who were more concerned about smoke at the outset did not preferentially expose themselves to, or remember, such marketing. We model the effect of exposure to multiple channels as additive.

Results and discussion

In this section we use the quantitative and qualitative methods described in the Research methodology section to investigate the factors that drove adoption and disadoption of the Oorja stove. We also consider the effect of Oorja marketing and the user's current[14] mix of stoves on perceptions about smoke, and in turn the effect of such perceptions on stove purchase patterns. Finally, we address one of the main motivating questions of this work: how the commercial nature of the Oorja enterprise appears to have affected outcomes.

Factors affecting initial adoption

Table 3 shows the results of the regression model of Oorja purchase. For ease of interpretation, average marginal effects are shown. For example, in rural areas, pre-existing use of LPG only is associated with a 26.3 percentage point higher probability that a household adopts Oorja. On average in our sample, being in a village with one additional dealer per thousand population increases the likelihood of Oorja adoption by 11.8 percentage points.

Several main conclusions are evident from Table 3. First of all, the highest rate of rural Oorja adoption is seen in the group that used only LPG, and there generally seems to be a positive correlation between having LPG or kerosene in one's fuel mix and adopting Oorja. BP originally targeted rural households with an electricity connection (to charge the fan batteries) that purchased firewood and earned $2-8 per day (Shrimali et al., 2011; Author Interviews). However, the company was surprised to find that 25–30% of the initial buyers were LPG users; by the middle of 2010, this fraction had grown to 55–60% (Author Interviews). While the original positioning of the stove emphasized health benefits and a more affordable fuel source than purchased firewood, BP realized that the health improvement argument was less compelling to customers than it had hoped (Adler, 2010) and also that there was a strong value proposition vis-à-vis LPG. The 1 kg quantity of pellets needed to cook a meal was initially priced at 5 Rs,[15] putting it well under the 9–11 Rs to cook a meal with subsidized LPG (0.4–0.5 kg at 23 Rs/kg) or the 8–10 Rs to cook a meal with firewood (4–5 kg at 2 Rs/kg) (Author Interviews). Oorja was especially attractive for households whose allotment of subsidized LPG was less than its need, or whose access to it was barred altogether, as in the case for example of migrant workers.

Fig. 2, which graphically depicts Oorja adoption/non-adoption (and disadoption) patterns for our entire random survey sample, illustrates the high fraction of LPG users among the group adopting Oorja. Fifty-three percent of the households that adopted Oorja in our sample had at least some pre-existing access to LPG. In rural areas, the population with LPG access adopted at a substantially higher rate (24%) than the population without any LPG (13%), which mainly relied on the traditional chulha stove for cooking.

Perhaps surprisingly, initial adoption rates for Oorja appeared to be largely independent of income within our sample (Table 3). This may indicate that, for the range of incomes typically found in the villages where Oorja was sold, the upfront cost of the stove was not large enough to pose a significant barrier to initial adoption. Stoves were

[14] As described in the Model of smoke perceptions and Retention of health messaging and impact on adoption sections, it is hypothesized that current (at the time of the survey) stove mix may influence survey responses about how bothersome and unhealthful smoke is. The Oorja purchase decision, on the other hand, is modeled as a function of the user's stove mix prior to the purchase decision (see Model of initial adoption and Factors affecting initial adoption sections).

[15] As we will discuss later, First Energy was subsequently forced to increase pellet prices to 8 Rs/kg, which made the fuel value proposition less compelling.

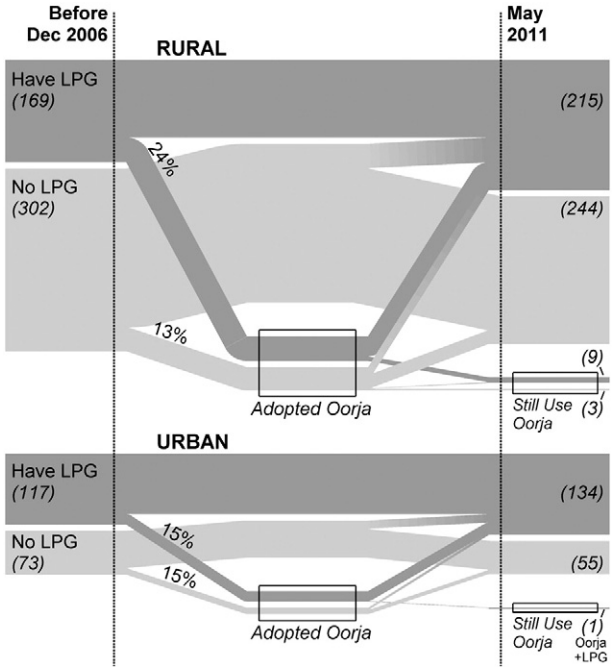

Fig. 2. Stove adoption patterns for households in our entire random selection (including Oorja adopters and non-adopters). Numbers of households with and without LPG stoves in rural and urban areas are given in parentheses. Oorja adoption rates are shown as percentages of the initial (before December 2006) groups.

initially sold to consumers for 675 Rs, or about $15,[16] which was somewhat less than a cost-recovering price; this represented about 14% of the median monthly income of rural respondents in our survey (see Table 2). (Starting in mid-2008, prices were increased to recover costs, and new models sold for around 1200 Rs, or about $27, at the time of our survey.[17]) In order to make their commercially-oriented business model work, BP and First Energy intentionally targeted villages where most households earned at least $2-8/day (Shrimali et al., 2011; Author Interviews). Moreover, because the Oorja requires rechargeable batteries to run its fan, these villages had to have access to electricity. As shown in Table 2, nearly all of the households in our random selection had grid-connected electricity in the home.

Education level had perhaps a modest correlation with Oorja adoption in rural areas, with households whose most educated member had progressed beyond secondary school adopting Oorja at a slightly higher rate (Table 3).

BP originally built out its dealer network with the expectation that villages would represent the main source of demand for its stoves, but the company found within the first year that people in towns wanted to buy Oorja as well (see Fig. 3). Stove dealers in villages told of being surprised at first by customers from towns who had seen Oorja advertisements on television or heard them on the radio and wanted to buy this exciting new product (Author Interviews). Corroborating this greater role of media-based marketing in attracting urban customers is the fact that dealer density was not a significant predictor of Oorja adoption in towns, whereas it was in villages, as shown in Table 3. The steep ramp in stove sales shown in Fig. 3 is a testament to the success of BP in building "buzz" around Oorja through its marketing effort while ensuring that the manufacturing capacity and distribution channel were in place to fulfill the resulting demand.

[16] The US Dollar to Indian Rupee exchange rate varied between 40 and 55 over the period of Oorja dissemination that we considered; here we use a value of 45, which was around the average rate for 2006 and also 2010.

[17] First Energy executives indicate that the current stove price is financially sustainable, there is no need for new capital on the stove side of the business, and the stove price is less of an obstacle to adoption and use than the fuel price (Author Interviews).

Factors affecting disadoption

Fig. 3 illustrates the starkest challenge First Energy ended up facing in its household cook stove business: to recover costs in its fuel supply chain without spurring wide disadoption of the Oorja stove. At the time of our survey the company had been unable to surmount this hurdle (although company managers were exploring innovative business models like distributed pelletization that might improve the fuel situation in the future). As the company increased fuel prices starting in late 2008 and thereafter, it saw the intensity of Oorja stove usage (as indicated in the lower section of Fig. 3) drop accordingly, to the point where very few households were still using the stove as of the spring of 2011 (see right portion of Fig. 2). Survey responses corroborate First Energy's view that increased fuel prices were the single most significant cause of disadoption (see Table 4). As higher fuel prices eroded the value proposition for consumers, dealers also found the stove business to be less attractive, leading to erosion of the distribution network and less convenient fuel availability for household Oorja users.

First Energy's struggles to make the pelletized fuel supply chain work offer useful lessons for other prospective sellers of stoves running on processed "agricultural waste." From the very start, BP ECM knew that its advanced stove design would imply developing and managing two supply chains: for stoves and for fuel. Initially there were some ideas that the enterprise could deploy a "Gillette model" in which the company would sell stoves cheaply and generate profits on sales of fuel. However, the fuel supply chain proved to be the significantly more difficult to execute of the two (Author Interviews). According to First Energy, the cost breakdown for the fuel was roughly 45% for raw materials (which could be bagasse, ground nut husk, corn cobs, cotton stalks, or stalks from other pulse crops like soybeans), 30–35% for conversion into pellets and packaging (in either 5 kg bags or via dispensing machines), and 20–25% for logistics and distribution (including channel margins) (Author Interviews). One of the main conversion plants was located next to a sugarcane processing facility in Maharashtra to have ready access to bagasse, the energy-rich, fibrous material left over after sugarcane stalks are crushed for their juice (see Fig. 4). However, as the company was in the process of developing the Oorja business, it saw demand for the bagasse as an energy source shoot up, pushing prices from $10/ton to $50/ton (Author Interviews). This sharp uptick in raw material cost made the initial pellet price of 5 Rs/kg unsustainable. Prices were increased to 6 Rs/kg in late 2008, and then after BP's exit in 2009 the newly-independent First Energy, lacking deep capital reserves of its own, was forced to boost fuel prices still further to recover costs—to 7 Rs/kg and then 8 Rs/kg. This price increase significantly eroded the value proposition of the Oorja stove relative to alternatives for most household consumers, and particularly relative to LPG, for which the price to households was kept roughly constant over this period by government subsidies.

While fuel price and availability issues were the largest contributors to the decline of household Oorja usage, other factors played a role as well. Twenty-eight percent of households that reduced or eliminated their use of Oorja cited as one reason the fact that other alternative cooking methods had become cheaper or more available (Table 4). An important alternative appears to have been LPG. Between the start of Oorja sales at the end of 2006 and our survey in spring of 2011, there appears to have been appreciable growth in LPG usage within our surveyed population. Among households without previous LPG access, more gained access to LPG during this period than adopted Oorja (see Fig. 2).

Some Oorja reliability concerns emerged in the survey as well, with 23% of those who reduced or eliminated their usage citing unresolved stove problems as one explanatory factor. Oorja was a pioneering design, and it may be that subsequent generations of gasification-type stoves (Jetter et al., 2012; Mukhopadhyay et al., 2012), including newer models of Oorja, will be inherently more robust. The GACC (2012) reports that most advanced stoves have a lifetime of no more

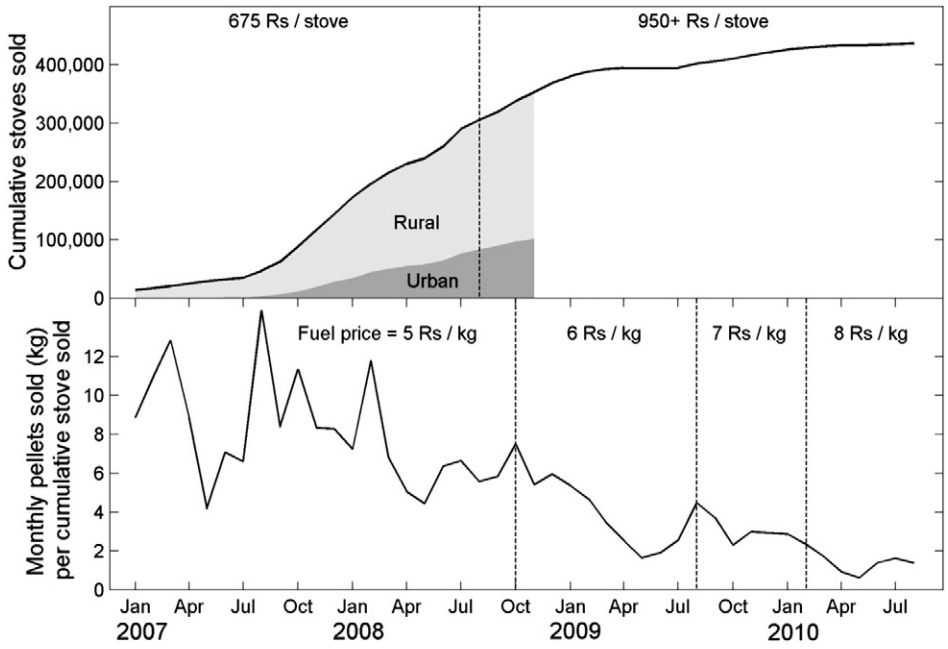

Fig. 3. Adoption and usage trajectories for Oorja stove: cumulative stoves sold (top) and monthly pellets sold per cumulative stove sold (bottom). The plot of monthly pellets sold per cumulative stove sold includes the combined effects of disadoption and reduced intensity of usage. Changes in stove and fuel prices are indicated by dotted lines. Rural/urban distribution of stove sales was estimated from First Energy market penetration data through November 2008, which covered about 80% of total sales to that point. Data source: First Energy.

than three years. Because after-sales support for Oorja was provided through the stove distribution channel, the disintegration of the dealer network due to fuel pricing issues could also possibly have had negative ramifications for the ability of First Energy to support its existing products.

For all the technological sophistication of the Oorja stove, the version we studied ultimately did not achieve its aim of being a cost-effective biomass stove with LPG-like performance. Respondents who had experience with LPG, chulha, and Oorja felt that the Oorja could not quite compete with LPG on convenience, flexibility, prestige, and smoke performance and that it fell short of the traditional chulha on economic criteria, taste, and reliability. Fig. 5 shows the average perceptions of these users, as indicated by degree of agreement with statements about attributes of the three stoves (with responses scaled linearly from 1 through 5). Table 5 applies a Wilcoxon signed-rank test to the matched responses from each of these users to assess which differences in perception of Oorja relative to LPG and Oorja relative to chulha are statistically significant.

Retention of health messaging and impact on adoption

The desire to reduce respiratory disease in the developing world was an important motivation for BP ECM and First Energy, as it has been for most providers of improved cookstoves. Oorja marketing efforts included an educational component describing the dangers of indoor air pollution. However, First Energy managers seem to have become more skeptical over time about whether health education efforts were effective at spurring adoption. First Energy found that measuring the lung function of prospective customers to demonstrate the damage from traditional biomass cooking did not appear to boost stove sales; those shown to have poor lung function requested suitable medicines instead (Adler, 2010). This finding is consistent with studies that have cast doubt on the effectiveness of health education as a spur to adoption of health-improving products in the household (Dupas, 2011; Kremer and Miguel, 2007; Luo et al., 2011; Thurber et al., 2013).

Our survey provided an opportunity to directly measure, first, whether health messages about indoor smoke were retained, and, second, whether they had a noticeable positive impact on Oorja adoption rates. Given that most marketing messages for the Oorja contained information about the dangers of indoor smoke, we used the regression model described in the Model of smoke perceptions section to test whether exposure to different kinds of Oorja marketing affected respondent agreement with the statement: "Indoor smoke caused by your cooking appliances is bad for your health or physically bothersome to you and those around you." We also considered whether basic demographic factors like income and education level as well as the respondent's current stove mix affected their perceptions about smoke being a problem. Table 6 shows the results of an ordered logit model of the influences of these factors on smoke perceptions.

Relative to the baseline respondent (a user of chulha who had not heard of Oorja), those who had been exposed to Oorja stove demonstrations or who had heard about Oorja through word of mouth generally showed higher levels of concern about smoke from their cooking appliances. Highest concern about smoke was found among those who attended in-person demonstrations of the Oorja stove. Marginal effects calculated from the model suggest that having seen an Oorja demo was associated with a 16 percentage point increase in the likelihood of strongly agreeing with the statement that "Indoor smoke caused by your cooking appliances is bad for your health or physically bothersome to you or those around you" and a 4 percentage point decrease in the likelihood of strongly disagreeing with it. For word-of-mouth knowledge

Table 4
Factors cited by Oorja users to explain why they reduced or eliminated Oorja use. Users were allowed to cite multiple factors. (Of 445 adopters of Oorja in our random plus purposive selections, 38 were still using Oorja at the time of our survey in May 2011; only one user reported increasing intensity of Oorja use between initial adoption and the time of the survey.)

Reasons for reducing or eliminating Oorja use	Respondents citing factor
Price of Oorja fuel went up	71%
Oorja fuel became less available	59%
Alternatives became more available and/or cheaper	28%
Oorja broke and was difficult and/or costly to fix	23%
Oorja cooking experience was worse than expected	11%

Fig. 4. First Energy pelletization plant in Maharashtra (left) and bagasse raw materials located on-site (right), December 2009. Photos: Mark C. Thurber.

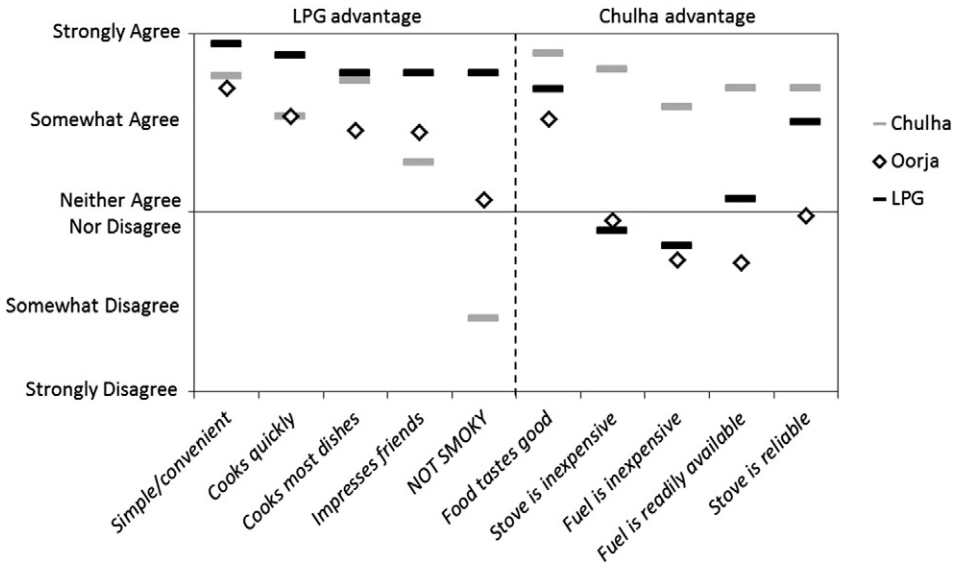

Fig. 5. Average extent of agreement or disagreement with the assertion that chulha, LPG, and Oorja stoves, respectively, possess each of the given attributes, according to the 230 survey respondents who had experience with all three. (Note: It is possible that increased cost and decreased availability of Oorja fuel also influenced other Oorja-related responses.).

about Oorja, the corresponding figures were 9 and 2 percentage points. Media channels, such as television or radio advertisements, showed no statistically-significant correlation with perceptions of smoke, perhaps due to their impersonal nature or the limited amount of information they could communicate. Notably, socioeconomic status and educational attainment showed no direct correlation with smoke perceptions.

There are different possible interpretations of the statistical relationship between smoke perception and exposure to Oorja demos or word-of-mouth communications. The first is that information conveyed through these means indeed raised people's consciousness about the dangers of indoor smoke in a durable way. The second is that there was reverse causation: that those who were already concerned about smoke from their cooking implements (and perhaps ready to change stoves as a result) were more likely to expose themselves to or remember Oorja-related communications that might have included smoke-related messages.

Because we have no data on smoke perceptions from before people were exposed to Oorja marketing, we cannot be certain of which interpretation is correct. However, there is an important reason to believe that the first hypothesis—that Oorja marketing affected perceptions—is more plausible than the second hypothesis of reverse causation. Namely, if smoke concerns drove exposure to or recollection of Oorja marketing exposure, they would also seem likely to drive Oorja purchasing, which would probably result in a positive and significant coefficient on "Household purchased Oorja" in Table 6. This was not observed. One explanation could be that households concerned about smoke preferentially purchased Oorja, and that their smoke concerns were then completely assuaged by the purchase itself, resulting in the negative coefficient seen in Table 6. However, it seems more likely to us that smoke concern was simply not an important driver of either Oorja marketing exposure or the Oorja purchase decision.

Indeed, other data from our survey suggests that smoke concerns were not a principal motivation for purchasing Oorja. Of the 467

Table 5
Statistically significant differences (95% confidence using a Wilcoxon signed-rank test) in perceptions of Oorja relative to LPG and Oorja relative to chulha, according to the 230 survey respondents who had experience with all three.

Attribute	LPG better than Oorja	Oorja better than LPG	Chulha better than Oorja	Oorja better than Chulha
Simple/convenient	✓			
Cooks quickly	✓			
Cooks most dishes	✓		✓	
Impresses friends	✓			✓
Not smoky	✓			✓
Food tastes good	✓		✓	
Stove is inexpensive			✓	
Fuel is inexpensive			✓	
Fuel is readily available	✓		✓	
Stove is reliable	✓		✓	

households in our random selection who were aware of Oorja, 108 (23%) purchased Oorja, and of these, only 39 (36% of purchasers) mentioned smoke concerns as playing any role in their buying decision. Only 10 households (9% of purchasers) cited smoke as a major reason (greater than 30% weight among all factors) for purchasing Oorja, compared, for example, to 32 households (30% of purchasers) who cited convenience of use as a major reason for their purchase.[18] These findings are consistent with other literature suggesting that smoke reduction is rarely a top priority in the stove buying decision (Thurber et al., 2013).

On the whole, our data suggest two main conclusions. First, smoke-related knowledge transmitted during Oorja stove demonstrations was retained to a significant extent by those exposed to it, even though our survey was administered several years after the bulk of stove sales. Second, this information on the negative effects of smoke did not significantly affect stove purchasing behavior. Among the randomly-selected population that was aware of Oorja, having seen an Oorja stove demo with its smoke-related messages was a statistically-significant predictor neither of buying Oorja nor, conditional upon buying, of citing smoke as a reason for doing so (Fig. 6).

The model results in Table 6 also suggest another notable pattern in the perceptions of stove users about smoke. Relative to the chulha-only baseline, users of chulha and a cleaner-burning fuel (LPG or kerosene) agreed more strongly with the statement that smoke from their cooking appliances was problematic. This may indicate a kind of densensitization of chulha-only users to smoke. Since they only cook with a traditional chulha, smoke may be accepted and ignored as a daily part of life. On the other hand, people who use a cleaner fuel some of the time may be more likely to recognize and be bothered by the smokiness of a chulha. (Users who only cooked with LPG and/or kerosene did not show a statistically-significant increase in the perception of smoke being unhealthy or bothersome relative to the chulha-only baseline, perhaps because their cooking appliances truly did not produce significant smoke.) This finding suggests that users with exposure to both clean and dirty stoves may be more responsive to messages highlighting the smoke-reducing character of a new stove than those who only use a dirty stove.

Table 6
Ordered logit regression model of factors affecting agreement with the statement "Indoor smoke caused by your cooking appliances is bad for your health or physically bothersome to you or those around you" (1 = strongly disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = strongly agree). Because the small number of remaining Oorja-using households (see Fig. 2) do not use it as a significant part of their stove mix, Oorja is not included in the current stove mix variables.

Factors influencing perceived effect of smoke on health and comfort Ordered logit with robust standard errors	Effect on "smoke is bad" perception (std error)
Urban	−0.185
	(0.131)
Income ('000 Rs/month)	0.0132
	(0.0117)
Maximum education level is below secondary	−0.056
	(0.159)
Maximum education level is above secondary	0.078
	(0.141)
Use LPG and/or kerosene (no chulha)	0.27
	(0.193)
Use mix of LPG/kerosene and chulha	0.404***
	(0.152)
Household purchased Oorja	−0.239*
	(0.133)
Oorja marketing exposure: demo	0.747***
	(0.134)
Oorja marketing exposure: word of mouth	0.436***
	(0.127)
Oorja marketing exposure: media	−0.076
	(0.173)
Observations	998

Baseline is households with chulha only which are not aware of the Oorja stove and whose most educated member attended secondary school.
*** Significant at 0.01 level.
** Significant at 0.05 level.
* Significant at 0.10 level.

The effect of Oorja's commercial character on outcomes

In the Introduction, we highlighted two possible advantages of commercially-oriented stove distribution: 1) that the imperative of cost recovery encourages organizations to supply and promote stoves that customers actually want, and 2) that the creation of commercially viable supply chains makes stove distribution more scalable, financially sustainable, and replicable. In this section we consider whether and how these possible advantages played out in the case of Oorja.

Lending support to the first argument about the strengths of commercial business models, the BP Emerging Consumer Markets division proved very serious from the outset about providing a product that customers would want. An initial, "desktop" study of energy spending by these consumers was followed by field research in which teams of several people lived in local communities for six to eight months to observe patterns of life and identify possible niches for energy products, especially around cooking (Author Interviews). BP drew several main conclusions from this research: first, that cooking patterns across different countries and markets, while different, could be accommodated to a substantial degree with a single stove design; second, that the very poorest households could not realistically be served by a fully commercial model; and, third, that consumers wanted an entire cooking "solution" that would provide consistent and reliable fuel as well as a stove (Author Interviews).

The fact that BP and First Energy were able to sell so many stoves—even if initial prices for both stoves and fuel were slightly below cost—also suggests that the product had real market appeal, at least initially. Of course, skillful marketing also played a role in the rapid sales ramp of the Oorja stove. This marketing success was itself a reflection of the business savvy of the BP/First Energy management team.

A corollary to the focus of a business on supplying a product that target customers want is a willingness to pivot toward new target customers that might turn out to want the product more. First Energy's behavior in this regard is among the most telling illustrations of the difference between commercial and charitable stove distribution. Despite the strong desire of First Energy management to improve household health outcomes through cleaner-burning stoves, the company was able to pivot toward commercial customers like caterers and restaurants when it became clear that cost-recovering fuel prices were not viable in the household market (Author Interviews; Kowsari, 2013). The Oorja stove remains economically attractive to these customers because of the lack of an LPG subsidy for commercial users. This shift into a new market is what has enabled the company to survive, but it entailed letting go of certain social impact goals, at least for the moment.[19] A nonprofit organization with reduction of indoor air pollution as its mandate would not have had the flexibility to make such a shift. In order to continue to focus on household adoption, it would have had to seek additional donor funding to cover any financial shortfalls. "Social enterprises," which are situated somewhere between fully for-profit businesses and charitable organizations, may need to become either more commercially-oriented or less so when faced with threats to their survival. We suggest that the Oorja business was a

[18] Of course, it is possible that smoke was a major driver of Oorja purchase but that people would not admit this after the fact to avoid dissonance with the fact that they stopped using the stove; however, this possibility seems inconsistent with First Energy's qualitative experience that health benefits were not an effective marketing point (Adler, 2010).

[19] Our interviews suggested that this shift was painful for First Energy managers due to their passionate concern about the negative health consequences of traditional cooking in the household.

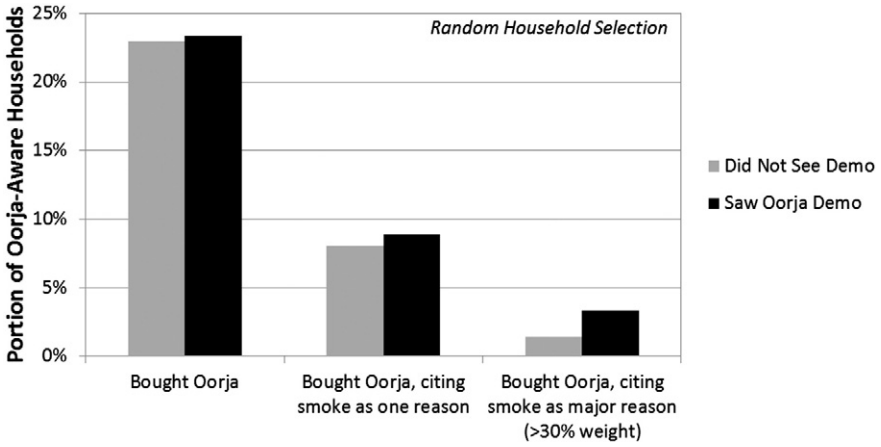

Fig. 6. Portion of Oorja-aware households in the random household sample, divided into groups that saw an Oorja stove demo (180 households) and did not see a demo (287 households), who: 1) bought Oorja; 2) bought Oorja, citing smoke as one reason for doing so; and 3) bought Oorja, citing smoke as a major reason for doing so (at least 30% weight among all factors). Having seen an Oorja stove demo was not a statistically-significant predictor (at a 0.10 or better level) of buying an Oorja stove or, conditional on having bought an Oorja stove, citing smoke as a reason or major reason for doing so.

"social enterprise" (see Introduction) that became more commercial. Kowsari (2013) describes the contrasting case of another cookstove company that maintained its focus on stoves for households but shifted to less market-driven buyers (NGOs and corporations doing CSR projects) in order to survive.

The Oorja case also illustrates how reliance of a "social enterprise" on a profitable parent organization can be a double-edged sword. BP had served as a source of patient capital, facilitating initial research, stove design, supply chain development, and marketing. However, top management changed and the company became impatient with non-core efforts. First Energy was forced to become a truly cost-recovering venture, perhaps sooner than it was ready to do so. The Oorja business was made possible by BP's initial support, but the Oorja experience also suggests that commercialization of marginally profitable businesses aimed at social impact may need to occur over a much longer time horizon. This observation is in line with the conclusions of Bailis et al. (2009), who note that the commercial success of the Kenya Ceramic Jiko stove required nearly two decades of funding support to achieve.

The second main benefit that we expected from the commercial approach was the development of properly-incentivized supply chains that could scale, sustain themselves, and be replicated. This potential advantage was also largely supported by the case of Oorja despite the difficulty in the end of establishing a durable niche among households. BP and First Energy managers were quite meticulous in designing and then monitoring the supply chain for both stoves and fuel. To keep costs down, transport distance was generally limited to 100 km for fuel raw materials and 400 km for finished pellets. Stove costs were minimized by sourcing some components from further away and achieving economies of scale in production (Author Interviews).[20]

The company also built out a sophisticated distribution channel for the stove and fuel pellets. A partnership with SSP (Swayam Shikshan Prayog), a microfinance NGO focused on women's empowerment, and CCD (Covenant Centre for Development), another NGO, helped enable a quick distribution ramp by providing a core of 800 women entrepreneurs to serve as stove dealers (Author Interviews; Kuruganti, 2011; Yadav, 2010).[21] The dealer population, which was supplied with stoves by local bulk distributors, was later diversified to include men and store proprietors, especially as the business expanded to urban areas.[22] A structured, multi-level network of dealers, network coordinators, and business managers allowed the company to collect weekly, village-level data on stove sales, fuel sales, and dealer activity.[23] Maintenance support was also provided through the network, with distributors employing service engineers who would visit dealers in villages or support service centers in towns.

First Energy managers say they did succeed in creating a viable stove supply chain (Author Interviews); it was the fuel supply chain that proved their undoing in the household market, as described in detail in the Factors affecting disadoption section. In retrospect, the company underestimated the difficulty of creating a supply chain based on so-called "agricultural waste." However, its commercial orientation did allow it to reach an impressive degree of scale in both stove and fuel supply in a short period of time. Organizations that have grown out of a charitable rather than business background have often struggled to match this scale (Shrimali et al., 2011).

On the other hand, a purely profit-driven business might never have attempted to invent its own large-scale supply chain for biomass fuel based on agricultural waste. This is a central paradox of the Oorja case. The company's commercial orientation and skill arguably enabled it to get farther along on large-scale biomass pelletization and distribution than anyone ever had before, but its "social enterprise" instincts encouraged it to tackle a problem that may have been too hard. It ultimately was forced to become less of a social enterprise and more of a market-driven business in order to survive.

Conclusions and implications for the dissemination of advanced biomass stoves

We close by highlighting several lessons that may be applicable to other efforts to disseminate advanced biomass stoves and processed biomass fuel. First, the Oorja experience shows that such businesses can indeed achieve scale with sufficient capital backing and smart marketing and distribution strategies. If anything, barriers to change in cooking habits may be overstated. We found little evidence, for example, that attachment to the taste of food cooked on traditional stoves was a significant barrier to adoption of Oorja, or LPG for that matter. Only 2 of the 90 households that used exclusively chulha before December 2006 and became aware of Oorja but did not buy it said that taste considerations played any role in their decision not to buy Oorja.

[20] As of the time of our interviews with First Energy staff, the battery, charger, and circuitry for the stove were imported from China and the fan was produced in Northern India near Delhi. Final assembly of the stove took place in Maharashtra.

[21] SSP and CCD also helped with BP's initial research into possible product niches starting in 2005 (Yadav, 2010).

[22] A village would typically be served by a single dealer; towns could have multiple dealers. BP ECM/First Energy sold stoves and fuel in bulk to distributors, which in turn would sell to dealers within a 60-70 km radius.

[23] The overall health of the network was overseen by network coordinators, of which there were about 60 total, each responsible for 75–80 dealers (Author Interviews). The network coordinators in turn reported to 6 business managers—3 for Maharashtra and 3 for Karnataka.

Second, the market for a new stove is likely to be more sustainable if the stove provides multiple advantages relative to existing alternatives. One of the challenges for Oorja was that its value proposition, which proved to be largely based on fuel cost, was too narrow. Once this economic advantage could no longer be sustained, usage evaporated rapidly. The "holy grail" of advanced biomass stoves would be a product that is low-cost, runs on low-cost and readily-available fuel, has LPG-like cooking flexibility, and does not produce significant indoor air pollution. The gasification design of Oorja, while offering high combustion efficiency, still does not compare to LPG on flexibility, largely because there is no way to start and stop the gasification/combustion process at will without producing heavy emissions. It is unclear whether an affordable gasification stove can be designed that does not need to run as a batch process. If such an innovation proves possible, it would represent a huge step forward.

Third, health benefits appear to have limited marketing appeal, even when efforts are made to educate prospective users. Health-improving attributes did not seem to factor importantly into Oorja purchase decisions despite some evidence that messages about smoke were received. A more effective approach may be to find other value propositions that are more compelling to users than health but coincide with health benefits (Thurber et al., 2013).

Fourth, government policy can have a significant effect on the competitiveness of a given stove/fuel combination relative to alternatives. LPG use at the household level was made significantly more attractive over the period between Oorja's introduction in 2006 and our survey in 2011 by government subsidies that kept the price of LPG to households roughly constant even as prices of other fuels such as purchased biomass and kerosene appreciated (Author Interviews). These LPG subsidies made it significantly more difficult for Oorja to compete in the marketplace. More broadly, they discourage entrepreneurs from developing markets for processed biomass fuels—markets that may yet prove important for segments of the population that cannot be reached by LPG in the near term due to affordability or availability constraints.

At the same time, we should bear in mind that increased LPG use at the household level is a highly desirable outcome that should be a key policy goal in its own right. In fact, our survey indicated significant LPG adoption over the period during which Oorja was widely sold. Among the population that only used chulha at the time Oorja was first introduced—which is the population most at risk from indoor air pollution—more households obtained their first access to LPG by the time of our survey than adopted Oorja (and most Oorja adopters eventually stopped using the new stove). The fact that 18% of rural households and 25% of urban households in our survey gained access to LPG for the first time in the period since 2006 represents a not-insignificant gain for health. Subsidy support for LPG—if it is financially sustainable for government budgets and avoids constraining availability of the fuel—might lead to significant welfare benefits for the population. But for the reasons described in the previous paragraph, there is a good argument for extending equivalent subsidy support to processed biomass fuels that can demonstrate favorable health and environmental characteristics.

Fifth, development of a new ecosystem around processed biomass fuel for household customers is extremely challenging and probably requires more time than the stove business was given by BP. The parent company's departure from the stove business at the same time as the business was struggling with an increase in the price of raw materials for the fuel put First Energy managers in a very difficult position. Businesses hoping to follow in First Energy's footsteps in developing a new fuel supply chain should make sure they have patient capital backing, a product that provides compelling usability advantages, and a favorable policy environment.

A point that cannot be emphasized enough is that "agricultural waste" is no longer waste once someone is paying for it. As First Energy found out with its bagasse feedstock, it can be extremely difficult to predict and control prices in such immature markets for raw materials. Diversification can help in theory but may require more flexibility regarding raw material inputs to the pellet manufacturing process. Collecting raw materials at a more disaggregated level could reduce costs but also implies administration of a complex and extensive gathering operation. Decentralization of the fuel supply chain via village-level pelletization holds promise but might create challenges in maintaining fuel quality. Because the fuel side is so central to efforts to truly match LPG performance with improved biomass stoves, further research on how supply chains can be developed to reliably supply processed biomass would be highly worthwhile.

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