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One-off subsidies and long-run adoption – Experimental evidence on improved cooking stoves in Senegal

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Abstract

Free distribution of a technology can be an effective development policy instrument if its adoption is socially inefficient and hampered by affordability constraints. Improved cookstoves may be such a case: they generate high environmental and public health returns, but adoption is generally low. Based on a randomized controlled trial in rural Senegal, this paper studies whether one-time free cookstove distribution affects households' willingness to pay (WTP) in the long run. Effects might be negative because people anchor their WTP on the earlier zero price (reference dependence) or positive because information deficits about potential benefits are overcome. We find that households who received a free stove six years back exhibit a higher WTP today compared to control households. Potential reference dependence effects are thus at least compensated by learning effects. Our findings suggest that one-time free distribution does not spoil future prices and might even be a stepping stone for future market establishment.

Keywords: technology adoption, cookstoves, willingness to pay, real-purchase offer, energy access

JEL codes: D03, D12, O12, O13, Q41

1. Introduction

A growing body of literature shows that in poor settings positive pricing of socially desirable technologies leads to inefficient underadoption because considerable positive external effects are foregone. This is most notably due to a highly price-responsive demand. Cohen and Dupas (2010) and Tarozzi et al. (2014) observe very high price elasticities for insecticide-treated bednets, Kremer and Miguel (2007) for deworming drugs, Ashraf et al. (2010) for water disinfectants, and Mobarak et al. (2012) for improved biomass cookstoves. Based on this observation, Mobarak et al. (2012) make a case for subsidies or free distribution as obvious policies to overcome this type of underadoption. Bensch and Peters (2015) in fact show that free distribution can be an effective instrument to trigger rapid short-term cookstove uptake among the poor.

In this paper we test whether free technology distribution spoils the prospects of a self-sustaining market for this technology in the future. Next to the fiscal burden of large-scale subsidy programs, a major argument against free distribution is that consumers may anchor their future willingness to pay (WTP) to prices previously paid for the product, a behavioural pattern also known as reference dependence (Köszegi and Rabin 2006). For experience goods, however, the effect of one-time subsidies might even increase future WTP through learning effects. In her seminal paper, Dupas (2014) tests this for the case of insecticide-treated bednets and finds important learning effects from own experimentation but no anchoring around pre-viously subsidized prices. Dupas emphasizes, though, that this finding is very case-sensitive and transferability to other products and circumstances needs to be tested. The present paper builds on this research and extends Dupas' work to the case of improved biomass cookstoves (ICS). More specifically, we study the effect of free distribution on WTP for ICS in the long run.

ICS adoption is desirable from a public-policy perspective because of their negative external effects on deforestation and climate change. Currently, more than 3 billion people worldwide are using firewood or charcoal for their daily cooking purposes, mostly in inefficient traditional stoves or open fires. Uptake of ICS is low because people are chronically short on cash and credit constraint (see Bensch et al. 2015; Lewis and Pattanayak 2012). In addition, some private benefits of ICS such as time savings and health effects remain disregarded by households due to high discount rates or intra-household bargaining patterns (see Pattanayak and Pfaff 2009; Martin et al. 2011; Miller and Mobarak 2013).

Our sample comprises in total 371 households in 18 villages in rural Senegal. The identification strategy mainly relies on the exogenous variation stemming from a randomized controlled trial in 2009 for which we randomly allocated ICS at zero price among 253 households in 12 villages in rural Senegal. ICS have not been available in the villages outside of the experiment. The randomized ICS has a lifetime of two to four years. Hence, when we conducted the follow-up in 2015, treatment group households have had the opportunity to test the ICS over a full lifecycle trial period. In this follow-up survey, we revisited both treatment and control households in order to offer the same type of ICS, now at positive prices. In addition to this experimental sample we visited 118 additional households in six additional villages that had not been exposed to our RCT in 2009 or any ICS promotion activity. We refer to this sub-sample as the non-experimental comparison group, which we then use in a supplementary analysis to explore the existence of spillovers within our experimental sample.

To estimate the WTP in all three groups we use the Becker-DeGroot-Marschak mechanism, an incentive-compatible real-purchase offer procedure (Becker, DeGroot and Marschak 1964; BDM in the following; see as well Plott and Zeiler 2005). This experimental design allows us to estimate the effects of one-off subsidies and a subsequent free life-cycle trial on ICS demand in the long run. Our study area resembles most rural areas in Africa to the extent that firewood is mostly collected, not purchased. Firewood scarcity is high, which is comparable to similarly arid countries in the region. In terms of ICS availability outside our experiment, a vibrant local market for ICS does not exist in these villages, but ICS are available in towns located around 5 to 20 kilometres away. The type of ICS under analysis is adapted to local cooking habits and has been disseminated in other African countries as well, mostly going by the name Jambaar or Jiko (see for example Jetter et al. 2012).

Our paper complements Dupas' (2014) work in three ways: First, we assess the replicability of her findings for another base technology in a different setting. Second, we test the effect of a full lifecycle trial period on re-purchasing the product after it has deteriorated. This is an extension to Dupas, because she essentially assesses adoption of an additional second bednet, given that her follow-on study was carried out one year after the subsidized distribution of bednets with a lifetime of several years. Third, the BDM mechanism allows for individual bids per customer and thereby yields more precise, higher-resolution data on households' WTP as compared to take-it-or-leave-it approaches, where one price is offered to clusters of customers, which eventually provides only WTP bounds.

Our main finding is that even high one-off subsidies do not decrease the WTP in the long-run. The treatment group reveals a WTP that is 14-25 percent higher than in the control group. Although we cannot disentangle the learning effect from the anchor effect, our results confirm Dupas (2014) to the degree that any reference dependence, which potentially hampers future marked-based policies, is at least compensated by a positive learning effect.

In addition, we observe an average WTP of around 11 US$ and more than two thirds of households make bids that exceed the 8.5 US$ that is charged for this ICS on nearby urban markets. This comes as a surprise given that it has so far proven to be extremely difficult for market-based ICS programs in Senegal to reach rural areas. Also in a global context, penetration rates for cookstoves have found to be low even in areas in which people pay monetary prices for fuels (Bensch et al. 2015; Lewis and Pattanayak 2012; Putti et al. 2015).

As we discuss in the concluding section, this finding suggests that barriers and frictions for vendors and thus risk premiums in such rural markets are high. These are costs that have to be covered by the end-user price to make the business attractive and hence the “in town” market price might simply not be high enough.

Taken together, our observation that the free distribution in the past does not harm today’s marketability of improved stoves has important policy implications. The international community via the Sustainable Energy for All (SE4All) initiative of the United Nations envisages universal access to ICS or clean fuels by 2030, as also reflected in the Sustainable Development Goal 7. The prevailing paradigm to achieve this goal is a market-based approach, implying that households are expected to pay cost-covering prices. On this note, our results suggest that one-off free distribution might not be in opposition to such a market-based approach. In contrast to what most proponents of this paradigm think, we find that learning effects at least compensate reference dependence and thus free distribution could even be a stepping stone towards a self-sustaining ICS market in the future.

The remainder of this paper is organized as follows. Section 2 reviews the literature and policy background. Section 3 outlines the research design including the identification strategy and data collection. Section 4 presents the results, Section 5 concludes.

2. Background

2.1 Literature and Policy Background on Improved Cookstoves

In recent years, political support for the dissemination of improved cookstoves (ICS) has grown considerably. The term 'improved' describes a wide range of replacements for traditional cooking methods, with a correspondingly large variation in performance. The major differences are related to costs and the degree to which the stove burns cleaner (see, for example, Jetter et al. 2012). The *World Health Organisation* (WHO) and the *Global Alliance for Clean Cookstoves* mainly combat adverse health effects of biomass cooking and thus endorse the promotion of smoke-free, i.e. 'clean', ICS, mainly electricity and gas. The United Nations initiative SE4All pursues a broader approach in its endeavour to achieve universal access to modern cooking energy. They also count simpler biomass ICS as modern that are not 'clean' according to WHO standards as long as they achieve high enough fuel savings relative to traditional stoves.[1] The ICS used in the present study, called Jambaar in Senegal, qualifies as 'modern' in the SE4All nomenclature but not as 'clean' in WHO's reading (see next section for more details on the Jambaar ICS).

The role of subsidies as an instrument to increase ICS adoption is a matter of an ongoing debate (Simon et al. 2014): Most agencies and national governments reject subsidization of cookstoves, primarily based on concerns about financial sustainability and reference-dependent behaviour of recipients. The latter assumes that subsidization spoils the long-term WTP and thus the establishment of a self-sustaining ICS market. Others count on carbon finance to fund ICS subsidies and some governments use pro-poor arguments to justify free distribution. Another potential financing source is the United Nations REDD+ scheme that foresees direct funding from industrialized countries for developing countries to trigger measurable reductions in deforestation and forest degradation (see for example Beyene et al. 2015*a*).

In the academic literature, evidence on the effectiveness of cookstoves and adoption challenges is growing. Martin et al. (2011) summarize the state of research on improved cooking and emphasize the urgency for addressing the issue of biomass cooking from an environmental and health policy perspective. In general, livelihood and environmental improvements from improved cooking technologies materialize via two channels: first, reduced woodfuel consumption directly reduces workload or monetary expenses, depending on whether fuels are purchased or collected. Environmental benefits stem from mitigated forest degradation and deforestation (Bailis et al. 2015). Ahrends et al. (2010) emphasize the role of woodfuels in tropical deforestation, next to agricultural land clearance. Deforestation is not only problematic for the local environment and economy (see, e.g., Myers et al. 2013),

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[1] See SE4All's Global Tracking Framework for details (World Bank and IEA 2015).

but also contributes an estimated 6 to 17 percent of global anthropogenic carbon dioxide emissions (van der Werf et al. 2009).

The second channel relates to reductions in smoke emissions and smoke exposure. ICS with improved combustion processes or chimneys to channel the smoke outside can achieve health-improving[2] reductions in household air pollution (Grieshop et al. 2011, Jetter et al. 2012). The non-linear particulate exposure–response relation found in medical research suggests that large reductions in smoke exposure are required to ensure positive health effects (see, for example, Burnett et al. 2014, Jamison et al. 2013, or Pope et al. 2011). However, as can be seen in Yu (2011) and Bensch and Peters (2015), even simple ICS may bring about health benefits by facilitating outside cooking (if its portable) and reducing the cooking duration, which both can lead to a considerable reduction of smoke exposure. Beyond its relevance for health, the soot contained in the smoke of cooking fires is the largest source of anthropogenic black carbon, a climate-forcing emission (Gustafsson and Ramanathan 2016; Lacey et al. 2017; Ramanathan and Carmichael 2008; Shindell et al. 2012). There is a growing consensus that black carbon is the second most important source of direct radiative forcing after CO_2 (Gustafsson and Ramanathan 2016; IPCC 2013).

A couple of studies provide evidence for substantial woodfuel reductions as a result of ICS adoption. This branch of literature therefore serves as a proof of the concept for the first impact channel (see Adrianzen 2013, Bensch and Peters 2013, 2015, Bensch et al. 2015, Beyene et al. 2015*a*, Brooks et al. 2016, and Rosa et al. 2014). These studies find that livelihood can be improved and deforestation reduced. In all these studies the positive findings hinge upon the technical design that has to be in fact improved.[3] Moreover, ICS have to be properly adopted and – if necessary –maintained by the users because the partial, diminishing or improper use of ICSs may entail little to no benefits, as it has been observed in Hanna et al. (2016) or Usmani et al. (2017).

2.2 Improved Cookstoves in Senegal

Efforts to reduce the country's heavy reliance on traditional biomass fuels for domestic usage date back to the 1970's when Liquefied Petroleum Gas promotion programs were launched (Schlag and Zuzarte 2008). Later initiatives also worked on the development of low-cost improved biomass stove models, including a program by the Government of Senegal – supported by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) – that

[2] Exposure to particulate matter induced by biomass cooking affects health in various ways and may lead to acute respiratory infections, stunted growth in children, pneumonia, chronic bronchitis in women, chronic obstructive pulmonary disease (COPD), cataracts and other visual impairments, cardiovascular diseases, lung cancer, tuberculosis and perinatal diseases (see for example Po et al. 2011, Ezzati and Kammen 2002, Amegah et al. 2014, Dherani et al. 2008, McCracken et al. 2012, Hosgood et al. 2010, Bruce et al. 2013, or Smith et al. 2014).

[3] This is not necessarily the case for all stoves that are referred to as 'improved', as it is evidenced by Burwen and Levine (2012) who studied a simple mud stove touted as ICS in Ghana, which even in a controlled field lab setting did not perform better than the traditional counterparts.

successfully disseminates a charcoal version of the Jambaar ICS through its program Foyers Ameliorés aux Sénégal (FASEN).[4] Usage of both Liquefied Petroleum Gas and charcoal, however, is mainly limited to urban areas. In rural Senegal, where 57 percent of the Senegalese population lives, the primary cooking fuel of 86 percent of households is firewood, predominantly used in inefficient open fire three-stone stoves or very simple metal stoves (AfDB 2016; ANSD 2014).

As an improved alternative for rural areas, FASEN also developed a firewood version of the Jambaar, which is under evaluation in the present paper and depicted in Annex B. It is a portable, maintenance-free single-pot stove with a fired clay combustion centre enclosed by a metal casing. Owing to these simple design improvements compared to the traditional stoves, the woodfuel burns more efficiently and the heat is better conserved and directed towards the cooking pot. Under day-to-day conditions Bensch and Peters (2015) observe a savings rate of around 40 percent per stove utilisation. This ICS can be considered as well-adapted to the local cooking conditions, which also explains the high usage intensity observed in the same study. Although it is not primarily designed to reduce smoke emissions, study participants exhibit less smoke-related disease symptoms, which may be due to increases in outdoor cooking and reduced cooking duration and thus less smoke exposure. The stove has a lifespan of around two to four years. Bensch and Peters (2015) also show that three and a half years after the randomisation in 2009, half the treatment households still use the randomized ICS, but only half of these ICS were in good condition as wear and tear became noticeable.

FASEN's approach is to train local manufacturers to produce and market the Jambaar stove. ICS are never produced locally in the villages but rather in Dakar and few producers also exist in some secondary towns near the study area. Thus, to reach the rural areas, ICS have to be obtained in town and transported to the villages, either by individual customers or vendors. The ICS price in secondary towns is at around 5,000 CFA F (8.5 US$), which is about thrice the average daily wage for casual agricultural work in the study area. Production costs in Dakar are considerably higher at around 8,500 CFA F (13 US$). Reason for this higher price are that the Dakar producers concentrate on charcoal ICS, while firewood ICS are only produced on demand. Moreover, the Dakar producers employ more and better machinery than those in secondary towns, which also leads to a higher quality. Later in the results section we underpin that the ICS are generally not available directly in villages; as we will show, households have not obtained new ICS to replace the deteriorated stoves randomized in 2009. Therefore, there is also no village price for the ICS. Traditional stoves, in contrast, can be acquired in the villages at considerably lower prices. Traditional metal stoves or open fire grills cost between 500 and

[4] For more details on the Senegalese stove market development, see Dossou Caho (1993) and Bensch and Peters (2013).

2,500 CFA F (0.85 to 4.3 US$) and three-stone stoves are usually homemade at zero cost (stove depictions can be retrieved from Annex B).

3. Experimental Design

The experiment underlying this study was conducted in the Peanut Basin region, located in central Senegal, around 200 kilometres southeast of the capital Dakar. The Basin is Senegal's major agricultural region. Ninety-nine percent of households engage in farming (ANSD 2015) and nearly all land is under cultivation of subsistence and cash crops, mainly peanuts, millet, and cowpeas. In terms of access to basic infrastructure including water, roads, schools and health facilities, the region ranks in the mid-range when comparing it to others in the country (ANSD 2009). Biomass production in this semi-arid zone is low and hence firewood is relatively scarce (Gill 2013).

The data used in this paper was collected in November and December 2015 in two types of villages: an experimental sample and a complementary non-experimental sample. We start with presenting the experimental sample that is used for the main analysis: it comprises twelve villages in which we conducted a randomized controlled trial (RCT) back in 2009, with previous follow-ups in 2010 and 2013 (see Bensch and Peters 2015). Randomization happened at the household level in 2009. Despite a lapse of time of six years since baseline, merely 17 of the originally 253 randomly sampled households could not be re-interviewed in 2015.[5] Just as at baseline stage, the resulting sample of 236 households is composed of 40 percent of households in the experimental treatment arm, i.e. they have received an ICS in 2009. Both treatment and control households were visited individually to conduct the BDM real-purchase offer in order to obtain the WTP.

We adhered to a predefined experimental procedure. In cooperation with a Senegalese survey partner, six local enumerators were trained to act as ICS sales agents.[6] The sample households were informed in advance about a visit of a stove seller including a survey on energy use. The person responsible for taking financial decisions in the household was requested to be present during this visit. Once our team arrived in the household, enumerators started by presenting the Jambaar ICS. Main sales pitches were the same as those that business-as-usual vendors of the ICS program of the Senegalese government are trained to use: quick cooking, safety, woodfuel savings, heat conservation, smoke reduction, cleanliness, and improvements in women's living conditions. We additionally announced that the ICS was produced in Dakar and is thus of supposedly better quality than the ICS produced in towns nearby. Moreover, households were explicitly allowed to make payments for their stove with the village chief

[5] Eight households moved house, two households merged to one, three households deceased, four could not be relocated, and one household was not willing to participate in the interview. We tested for attrition following Fitzgerald et al. (1998), in a first step regressing attrition status on relevant household characteristics. For that purpose, we use the controls presented in Section 0 and extended them by additional controls used in the probit regressions performed in Bensch and Peters (2015) to validate the balancing achieved through the randomization. A slight degree of attrition seems perceivable, but none of the variables turns out to be significant, thus rendering any further attrition adjustment unnecessary.

[6] This rules out foreigner-presence effects as observed in Cillier et al. (2015).

within a timeframe of about two and a half months. This payment period was granted because we visited households in November, just one month before harvest period begins. In this time of the year, households are particularly short on cash. By the time of the payment, target households would have sold at least parts of their harvest to make investments into durable goods.

Our field team then introduced the BDM purchase offer procedure to each interviewee: the bidder is asked to state his or her WTP for the ICS, knowing that the price is randomly drawn only after bidding.[7] Out of fairness considerations, we decided to conduct the draw publicly and at the village level, so that only one effective price applied to the whole village. Only if the participant's bid equals or exceeds the price drawn, the bidder can buy the product for the price drawn. If her bid falls below the drawn price, no transaction takes place. In order to practice the procedure the enumerators first conducted a hypothetical BDM game that involved a purchase offer of a solar lamp (see Annex C).

During pre-tests, we noted that households were well able to grasp the bidding game and its rules and are hence able to confidently express their WTP. There is thus no indication that the BDM elicitation approach would impose unrealistic cognitive demands, a common problem with stated WTP approaches for environmental non-market products (Gregory et al. 1993).[8] The WTP elicited by BDM is widely seen as a very precise approximation of a real-life WTP because of its incentive-compatible features (see Berry et al. 2015 for a discussion of the BDM method).[9]

After bidding for the stove, a structured questionnaire was administered using a tablet-based data collection application. Later the same day, all survey participants came together to attend the public draw of the price. The draw balls contained prices between 4,500 and 6,000 CFA F (7.5 to 10 US$); this price range was not communicated to the participants. Successful bidders received the stove after signing contracts. Again for fairness reasons we informed households about the "in town" price of ICS of 5,000 CFA F and also provided the contact details of vendors in town. Households were then allowed to withdraw from the contract (which only happened in five cases, see next section).

[7] The random price determination makes the BDM mechanism a variant of the Vickrey (second-price) auction where the final price is determined through competition between bidders (Vickrey 1961). Beltramo et al. (2015), for example, applied Vickrey auctions to study the effect of marketing messages and payment over time on the uptake of improved cookstoves in Uganda. A simple analysis of WTP for ICS in Bangladesh using the Vickrey auction is conducted by Rosenbaum et al. (2015). Alternatively, van der Kroon et al. (2014) and Jeuland et al. (2015) studied cookstove adoption preferences based on discrete choice methods that involved hypothetical decisions.

[8] Also note that villagers are not unfamiliar with paying for cookstoves: while the widely used three-stone stove is free of any monetary charge, around 82 percent of sampled households have paid for a stove in the past.

[9] The mechanism has already been widely used in laboratory settings, but also in field experiments to elicit consumer preferences for such diverse items as meat quality, rice origin, mosquito nets, water and hygiene, and rainfall insurances (Guiteras et al. 2016; Lusk et al. 2001; Morey 2016; Hoffmann 2009; Cole et al., 2014).

The survey in 2015 included an additional set of six villages that had not been part of the 2009 RCT, where we applied exactly the same BDM and interview procedure with a random sample of 118 households. The villages were selected from the same department, located sufficiently remote from the twelve villages of the original sample. We refer to this group as the “non-experimental comparison group”. It will provide complementary information on villages without any previous local exposure to ICS. The composition of the entire sample is depicted in the participant flow in Figure 1.

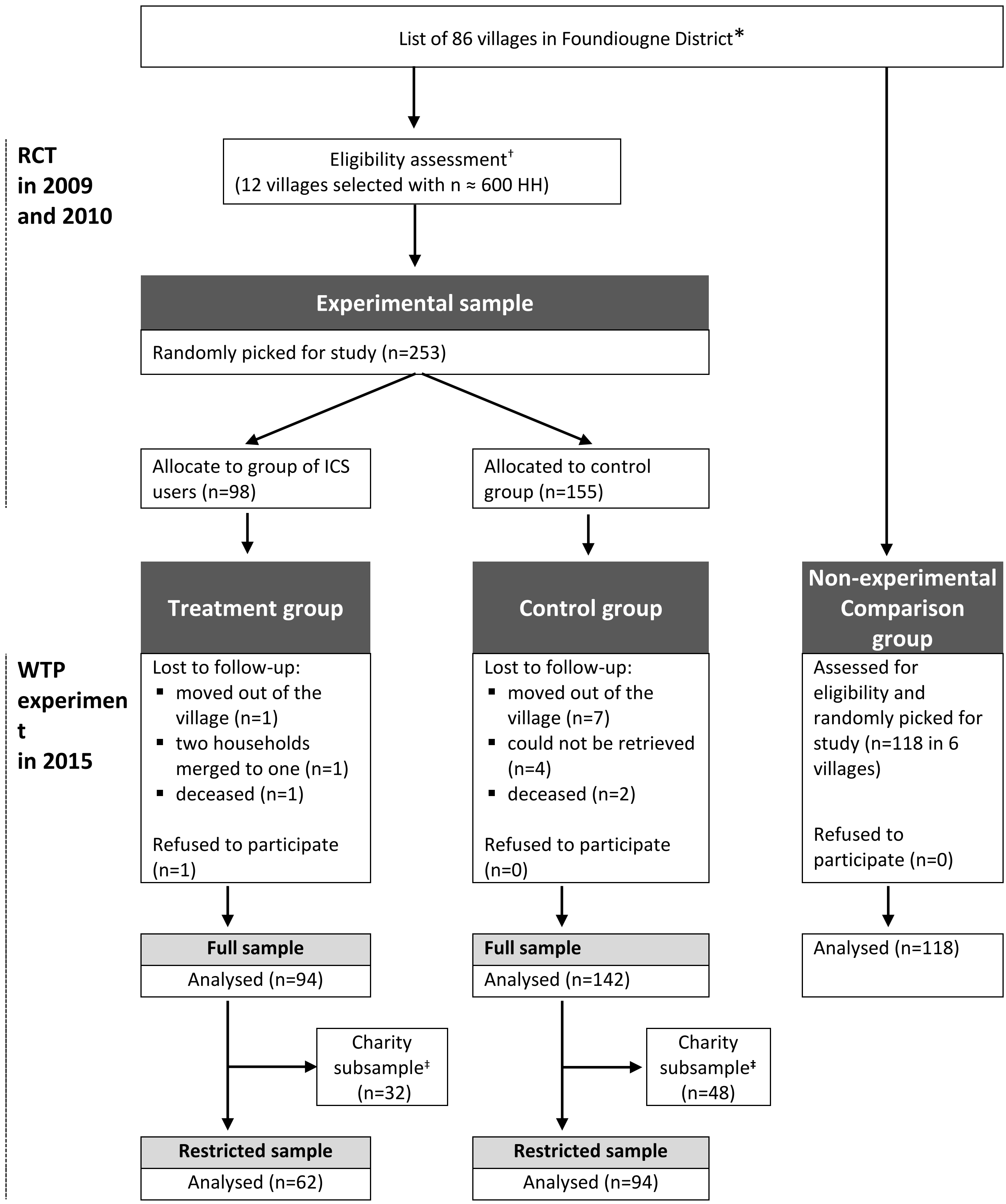

Figure 1: Participant Flow

Note: * Foundiougne is a district of 3,000 km² size in the South of the Peanut Basin region. All villages on the list were originally envisaged for an electrification intervention, which, however, was mostly abandoned such that to date none of the surveyed villages was electrified. † Eligibility criteria included the ecological zone, population size, main livelihood activities, infrastructure availability as well as the absence of access to ICS. ‡ Charity subsample refers to three sampled villages that were targeted by a recent intervention, which offered ICS at highly subsidized prices, see Section 0.

4. Results

4.1 Basic descriptives

As a result of a low attrition rate between the randomization in 2009 and the 2015 survey, we retrieved 236 households in our experimental sample, 94 in the treatment group, 142 in the control group (see Figure 1). The sample composition and balancing is depicted in Table 1. We show household characteristics for four sets of controls: respondent-specific characteristics on the individual level as well as socio-demographic, economic, and cooking-related household variables.

Table 1: Descriptive statistics and randomization test

	2015 data					*2009 data*
	Treatment		Control		Difference	Difference
	mean	sd	mean	sd	*p*-value	*p*-value
Respondent Controls						
Age difference respondent to interviewer	16.86	(16.38)	16.11	(16.81)	0.73	-
Person taking financial decisions in HH present during stove purchase experiment (share)	0.67		0.63		0.56	-
Person responsible for cooking in HH present during stove purchase experiment (share)	0.51		0.57		0.33	-
Sociodemographic Controls						
Head of HH is female (share)	0.14		0.14		0.96	0.68
Head of HH attended koranic or Arabic school (share)	0.83		0.85		0.65	0.73
HH size	13.91	(8.59)	14.57	(10.28)	0.61	0.86
Economic Controls						
HH possesses tile or zinc roofing (share)	0.66		0.66		0.97	0.69
HH owns sheep (share)	0.47		0.47		0.96	0.88
HHs monthly telecommunication expenditures (CFAF)	16,400	(21,450)	14,340	(17,130)	0.43	0.19
Cooking Controls						
HH owns firewood ICS (share)	0.21		0.20		0.77	0.87
HH mostly uses open fire for cooking (share)	0.62		0.56		0.36	0.69
HH buys firewood (share)	0.50		0.52		0.75	0.93
Number of observations	94		142			

Note: Expenditures are outlier-corrected by trimming figures that deviate more than three standard deviations (sd) from the mean to the value equalling the mean plus or minus three standard deviations. *p*-values refer to *t*-tests on the bivariate difference between treatment and control observations. In the very right column, this test is also conducted with the 2009 baseline data.

For all variables, *t*-tests confirm similarity between treatment and control observations both for the 2009 baseline and the 2015 follow-up wave. We see that, in line with our planning to conduct the follow-up with the person responsible for financial decisions in the household, two-thirds of respondents are actually the members taking financial decisions in the household. This is highly correlated with the sex of the interviewer being male in 63 percent of the cases (not shown in the table). Households are typically large in rural Senegal, which is also reflected in an average household size of 14.4. The table also shows telecommunication expenditures as a proxy for income and two wealth proxies, roofing and sheep ownership.

About half the households sometimes buy their firewood and thus have a monetary incentive to invest in a fuel-saving stove, unlike those households that only collect wood. For this latter group the return on an ICS investment is of non-monetary nature. Finally, a fifth of households already possess an ICS, half of which were (mostly worn-out) ICS received in 2009. The other half are all households located in three of our twelve villages in which – as we learned during the survey – small-scale initiatives have recently sold, out of charity, highly subsidized ICS ("charity subsample" in the following). In the remaining nine villages, only one percent of households own an ICS that had not been distributed in our 2009 randomization. In other words, in spite of the exposure to the new ICS technology induced by our previous study virtually no household has made an effort to re-invest into ICS by obtaining one from the towns nearby or from vendors in Dakar. At the time of our 2015 survey ICS are not used in the area, except for households in the charity subsample. Later in our analysis, village fixed effects and a dummy on firewood ICS ownership will control for the particularity of this subsample (see also balancing tests in Table A1 in Annex A). In addition, we test in Section 0 for the sensitivity of results to excluding the charity subsample completely.

The same descriptives and balancing tests as in Table 1 have also been compiled for the non-experimental comparison group, in that case compared to the entire experimental sample. They can be taken from Table A2 in the Annex. The non-random allocation into the two groups likely explains the few observed statistically significant differences. For example, the comparison group households have better roofing on average, whereas the experimental group exhibits higher shares of livestock ownership. There is, thus, no indication for structural differences in the overall socio-economic conditions that would advise to abstain from comparing the two groups in the supplementary non-experimental analysis in Section 0.

4.2 Impacts of free lifecycle trial period

Results on the impacts of the free distribution treatment, free lifecycle trial period in the following, are presented in Table 2. We show specifications that use the raw WTP in the local currency CFA Francs as outcome, for which the exchange rate to the US$ is about 590:1. The table additionally differentiates between results for a limited and extended set of controls and for the full sample as compared to the restricted sample, where we exclude the charity subsample with recent ICS interventions.

We find that the free lifecycle trial increases household's WTP. The effect size is considerable at 25 percent and statistically significant at the 8 percent level once we look at the restricted sample only and if we increase precision by adding the extended set of controls (Column 4).

The effect size is somewhat smaller and non-significant for the full sample that includes the charity subsample (14 percent, Column 2). This is intuitive because the utility of a second ICS is obviously smaller.

Table 2: Willingness to pay impact estimates

outcome:	Willingness to pay (in CFAF)				
estimation method:	OLS				
village sample:	full sample		restricted sample		full sample (treatment only)
	(1)	(2)	(3)	(4)	(5)
Free lifecycle trial treatment	837.15	839.70	1239.76	1661.70*	
	(723.87)	(691.63)	(1089.19)	(935.58)	
	[0.27]	[0.25]	[0.29]	[0.08]	
ICS usage intensity					3090.90
					(2486.35)
					[0.24]
Constant	7456.69***	7082.25***	7329.55***	7648.90**	8846.49
	(228.59)	(2608.53)	(343.96)	(3797.38)	(8971.05)
Observations	234	234	154	154	93
Adjusted R-squared	0.04	0.06	0.00	0.06	0.04
Controls:					
Village	Yes	Yes	Yes	Yes	Yes
Respondent	-	Yes	-	Yes	Yes
Sociodemographic	-	Yes	-	Yes	Yes
Economic	-	Yes	-	Yes	Yes
Cooking	-	Yes	-	Yes	Yes

Note: The restricted sample refers to those nine of the twelve villages where no recent ICS interventions took place. ICS usage intensity refers to share of meals cooked on an ICS in the total number of meals cooked in the household; it ranges between 0 and 1. Standard errors in parentheses and *p*-values in squared brackets. Standard errors are clustered by village; * p<0.10, ** p<0.05, *** p<0.01.

Among the controls not shown in the table, a main significant correlate of WTP is whether the respondent is responsible for financial decisions in the household, which clearly is in line with expectations. The explanatory power of these controls does not seem to be strong, though. Overall, while the precision of estimates may not be high enough to take the effect sizes at face value, it is certainly safe to reject the hypothesis of strong reference dependence in people's WTP. The results rather hint at considerable direct learning effects in the treatment group. This presumption is further corroborated by a variant of our estimations that assesses the effect of a variable that more closely reflects learning: the share of meals cooked on an ICS in the 2010 follow-up. This indicator taken as a continuous (linear) treatment variable for the sample of treatment observations shows a positive correlation between usage intensity and WTP (Column 5 of Table 2); yet, with a once more reduced sample size the coefficient is insignificant (*p*-value of 0.24). What remains to be examined is whether reference dependence and learning spill over from the treatment to the control group exist. This we explore in Section 0 by including the non-experimental comparison group without previous exposure to ICS in the analysis.

Beyond the treatment effect, a very notable result is the mere level of the willingness to pay (see also the ICS demand curve depicted in Figure 2). The means (without controlling for the covariates) are 6,300 and 7,000 CFA F for the full and restricted sample, respectively, and thus clearly above the 5,000 CFA F price charged by ICS producers in towns nearby. In the full and restricted sample, 69 and 75 percent of households make a bid that is higher than this “in town” price, respectively. Even if we take the higher Dakar price of 8,500 CFA F, still remarkable shares of 16 and 19 percent make high enough bids. This is a surprising result given that commercial ICS programs that charge cost-covering prices both in Senegal and elsewhere in Africa are having tremendous problems with low adoption rates. We will therefore discuss the viability of a rural market or reasons for its absence in the concluding section.

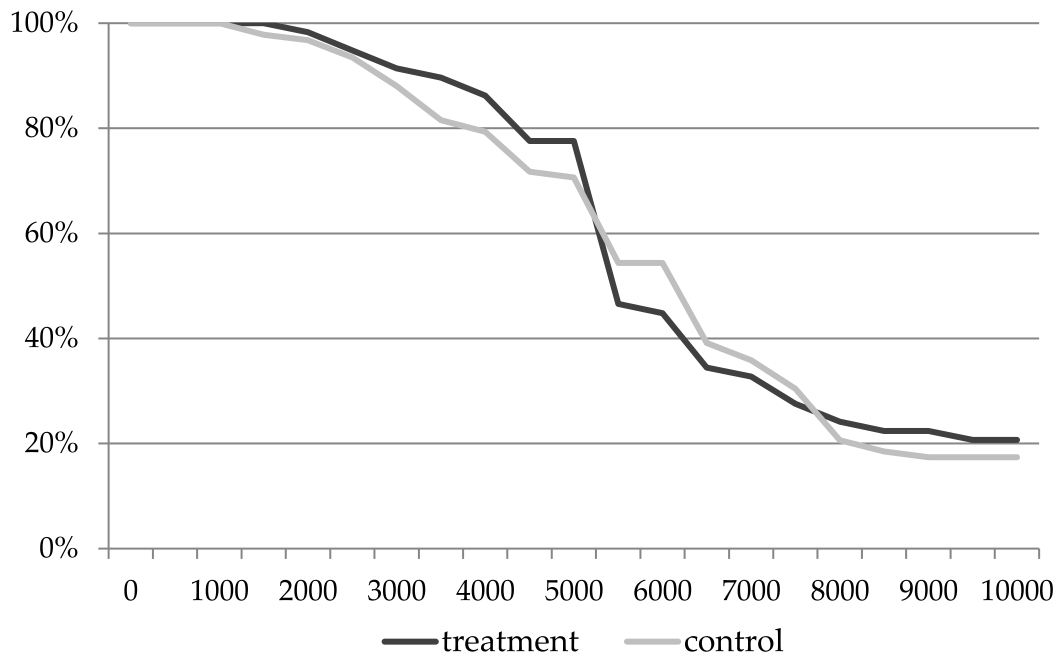

Figure 2: ICS demand curve according to bids in BDM purchase offer

Note: This figure refers to the restricted sample excluding the charity subsample.

4.3 Robustness checks

The main analysis so far has focused on direct learning and reference dependence effects among the treatment group. Yet, the two effects may also be at work in the control group in the form of spillovers. Control households may have learnt about ICS’ benefits from treated neighbours in their village, but likewise information about the free distribution may have triggered reference dependence among them. Our study design does not allow for disentangling these two spillover effects, but by including our non-experimental comparison group in the sample we are able to indicatively explore their net effect. Households in these comparison villages have never been exposed to an ICS intervention and were visited by our study team in 2015 for the first time. Spillover effects can thus be ruled out for these villages.

As can be seen in Figure 3, the revealed WTP in the non-experimental comparison group is quite similar to the WTP observed in our experimental control group. Interpreting the comparison group's WTP as the genuine WTP in the absence of a previous experimental free-distribution intervention, this suggests that there are at least no strong spillovers from the treatment to the control group.[10] The lower WTP in the control group as compared to the comparison group would further suggest some subtle reference dependence spillovers in the experimental sample that are more pronounced than potential learning spillovers. It is the direct learning effect in the treatment group that makes the WTP exceeding the baseline level.

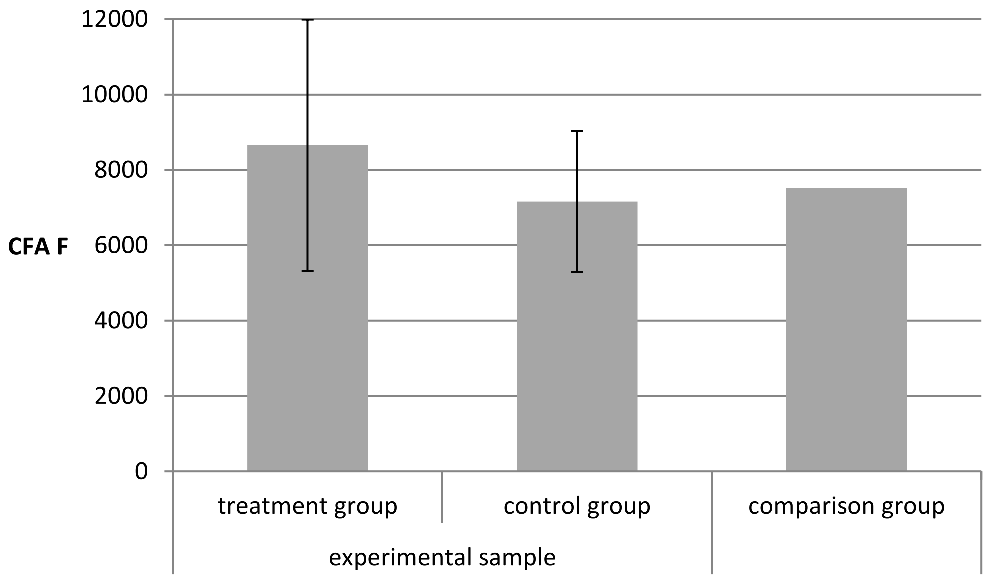

Figure 3: Willingness to pay in experimental groups and comparison group

Note: The WTP shown in this figure is derived from a regression model with the same specification as in Table 2 that now includes a polytomous categorical treatment variable with the comparison group as the base case. The marginal WTP mean for the comparison group (on the right) is calculated at the mean of the control variables. In order to derive the WTP means for the two experimental subsamples on the left, we simply adjusted the comparison group value by the point estimates of the respective coefficients in the same regression model. The lines indicate the 95%-confidence intervals for these two coefficients (not available for the comparison group as the base case).

[10] Another observation that supports our interpretation of little spillover learning effects is that only few control households have ever tried using an ICS (16 percent).

The data underlying Figure 3 comes from estimating the same specification as in Table 2 using the restricted experimental sample, now including a polytomous categorical treatment variable accounting for the three different groups: experimental treatment group, experimental control group, and the newly added non-experimental comparison group. The regression results presented in Table A3 in Annex A underpin what can already be taken from the graph: there is basically no difference between control and non-experimental comparison group as indicated by a *p*-value of 0.69. The WTP of the treatment group is higher compared to the non-experimental comparison group, yet the estimates are too noisy to reveal any statistically significant difference (point estimate of 1,134 CFA F, *p*-value of 0.48). The results thus support the claim that the direct reference dependence effects are at least compensated by direct learning effects.

We conduct another robustness test to check the effect of dropping those households that opted out. A small share of households was not willing or able to make a bid at all (two households), did not sign the contract after making a successful bid (five), or did not pay after having received the stove (six)[11]. In the above analyses we set the WTP of the two households not willing or able to make a bid to zero and considered the other eleven households as normal bidders. We test how sensitive our results are to the exclusion of these households by running the same regression as in Table 2. Given their small number it is in line with expectations that removing those households has little effect on the estimates, none of which changes in quality. If at all, they increase in size, such as, for example, the full sample estimate with controls (column 2) from 840 to 1,015 CFA F (not shown in the table).

Finally, in case households had a strong prior about the price charged for the ICS in town, the WTP could be downward biased because of strategic bidding. During the interview, households were asked whether they are aware of the market price in town and if so to come up with an estimate. Only a small minority (17 percent of households) stated that they are aware of this price and half of them, in turn, gave an estimate that was at least 40 percent higher or lower than the actual price.

[11] As in a business-as-usual marketing approach our team members returned to the villages in order to take back the ICS from those households that did not pay the full price. The advance payments made for the ICS were returned to these households (as it is stipulated in the contract).

5 Discussion and conclusion

This paper studied whether give-away distribution of improved cookstoves (ICS) affects willingness to pay (WTP) six years after the ICS were randomized among a sample of households. It is thus the first to examine this effect after a full life-cycle trial period, in which households were given ample time to learn about the stoves, enabling them to make a well-informed repurchase decision. We find that treatment households reveal a 14 to 25 percent higher WTP in the repurchase offer than control households who have never used an ICS. This effect size is considerable and also statistically significant, though not across all specifications (*p*-value of 0.08 in the main regression). Potential reference dependence effects are hence at least compensated by learning effects. By comparing our experimental sample to a comparison group that had never been exposed to ICS before, we furthermore provide indications for subtle reference dependence effects in the control group that outweigh potential learning spillovers. The product's valuation among non-beneficiaries of a free distribution intervention may thus not only be affected through learning spillovers, as suggested by Dupas (2014), but also through reference dependence spillovers.

Dupas explicitly discusses the transferability of her findings to improved cookstoves. She expects that people "may underestimate the returns to switching" and thus hypothesizes that "one-time subsidies for cookstoves […] have the potential to boost subsequent adoption through learning effects". Overall, we confirm Dupas' prediction to the degree that free distribution does increase adoption in the long run. The fact that the vast majority of households did not acquire an ICS themselves between the follow-ups in 2010 and 2015 calls attention to the need for guaranteeing easy access to the technology. The policy implication of this finding is striking: free cookstove distribution emerges as a policy option that is not only effective in triggering high uptake in the short run (Rosa et al. 2014; Bensch and Peters 2015; Beyene et al. 2015*b*) but also in the long run. We thereby complement the branch of literature on the validity of one-time subsidies and cost-sharing related to important products for the poor (see also Bates et al. 2012).

It is also the absolute level of WTP revealed by households in our study that is remarkable. With an average of around 11 US$, clearly exceeding "in town" market prices, it is very high compared to previous cookstove WTP studies (Beltramo et al. 2015; Mobarak et al. 2012). Given a repayment rate of almost 100 percent, participants took the offer and their bids serious.[12] In Bensch and Peters (2016), we examine different reasons for this high WTP in more detail. We argue that the high wood scarcity in the region plays an important role as well as specific features of our BDM approach, notably its implicit door-to-door marketing feature: Because of the individual household visits and the lottery situation, customers probably

[12] This cannot be taken for granted. See, for example, Grimm et al. (2017) and Tarozzi et al. (2014) who use payment targets similar to ours and observe repayment rates of between 60 and 70 percent.

dedicate more attention to the offer than they would in the case of regular shop offers. This is particularly true for products that attract less attention in every-day life, as it is the case for cookstoves. The typically male financial decision maker in the household tends to neglect them, also because of many competing pressures. Not least, the two months payment target in the harvest period may have increased adoption rates. Among others, it helped households aware of being present biased to commit themselves to buy the cookstove. This commitment device character has also been observed by Duflo et al. (2011) for time-limited fertilizer discounts in Kenya. To the contrary, Hawthorne effects are quite unlikely, since the randomization was done six years ago. Still, these factors should be taken into account when interpreting the WTP levels and their transferability to other settings.

The absence of a vibrant local ICS market despite the relative high WTP points at a variety of barriers and frictions that make rural market exploration a highly risky endeavour. Vendors in such a market environment would have to price in risk premiums, leading to rural end-user prices that exceed "in town" prices. Having said this, strong external effects of ICS as well as the poverty alleviation effects on the private level provide economic arguments to subsidize cookstoves even on a permanent basis. To the extent that climate-relevant emissions are reduced through a reduction of deforestation or black carbon emissions, carbon finance could be an additional funding source. This would also considerably increase the political feasibility of long-term subsidy schemes.

Beyond concerns about funding sources and reference dependence, what are further main arguments against subsidies and free distribution? It is sometimes argued that cost sharing helps targeting of users with highest marginal benefits. This so-called screening effect, however, is clearly competing with credit and liquidity constraints that hamper adoption, in particular if poorer households are targeted (Tarozzi et al. 2014). A related concern about free distribution is that positive prices not only induce screening effects, but also sunk cost effects. After having paid a positive price for a product people might feel committed to also using it (see Arkes and Blumer 1985). For various products, however, this concern about underutilization has been rebutted (see, for example, Ashraf et al. 2010, Cohen and Dupas 2010, and Grimm et al. 2017). For the particular case of cookstoves, Bensch and Peters (2015) and Rosa et al. (2014) observe very high usage rates in free cookstove distribution programs. Beyene et al. (2015*b*) show in an RCT in Ethiopia that households who received a stove for free use it even more than those that paid positive prices.

The paradigm that today's subsidies induce detrimental effects on tomorrow's markets has for long suffocated the subsidization discussion at early stages. Evidence is growing that these categorical concerns are not justified. Indeed, if our findings on high adoption intensities and long-run appreciation are confirmed in future research, subsidization (including free distribution) of technologies generating positive external effects can be a cost-effective tool to tackle many grievances in developing countries. The calibration of this subsidy policy may rely on a step-wise approach, where in a first step the market potentials and purchasing power in new intervention areas are examined using a methodology similar to what this study has done. In a second step, the region-specific evidence is then used to inform the roll-out at scale in this region, which may involve sustainable subsidy schemes. One crucial aspect is to communicate clearly that a one-time free distribution today is no entitlement for a subsidy tomorrow. Shaped in such a way, subsidies might even facilitate self-sustaining markets by mobilizing long-term demand through learning effects.

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Annex A

Table A1: Balancing test for the charity and non-charity subsample

	2015 data					*2009 data*
	Non-charity		Charity		Difference	Difference
	mean	sd	mean	sd	*p*-value	*p*-value
Respondent Controls						
Age difference respondent to interviewer	15.15	(16.06)	18.84	(17.47)	0.11	-
Person taking financial decisions in HH present during stove purchase experiment (share)	0.69		0.56		0.04	-
Person responsible for cooking in HH present during stove purchase experiment (share)	0.52		0.59		0.34	-
Sociodemographic Controls						
Head of HH is female (share)	0.12		0.17		0.27	0.01
Head of HH attended koranic or Arabic school (share)	0.83		0.87		0.40	0.85
HH size	14.08	(9.29)	14.75	(10.30)	0.62	0.51
Economic Controls						
HH possesses tile or zinc roofing (share)	0.62		0.75		0.04	0.40
HH owns sheep (share)	0.50		0.41		0.20	0.88
HHs monthly telecommunication expenditures (CFAF)	13,820	(18,270)	17,850	(20,140)	0.13	0.07
Cooking Controls						
HH owns firewood ICS (share)	0.04		0.51		0.00	0.05
HH mostly uses open fire for cooking (share)	0.58		0.58		0.90	0.00
HH buys firewood (share)	0.59		0.36		0.01	0.29
Number of observations	156		80			

Note: Expenditures are outlier-corrected by trimming figures that deviate more than three standard deviations (sd) from the mean to the value equalling the mean plus or minus three standard deviations. *p*-values refer to *t*-tests on the bivariate difference between treatment and control observations. In the very right column, this test is also conducted with the 2009 baseline data.

Table A2: Balancing test for the experimental and non-experimental sample

	2015 data				
	Experimental (restr. sample)		Non-experimental		Difference
	mean	sd	mean	sd	*p*-value
Respondent Controls					
Age difference respondent to interviewer	15.14	(16.06)	15.42	(13.38)	0.89
Person taking financial decisions in HH present during stove purchase experiment (share)	0.69		0.81		0.03
Person responsible for cooking in HH present during stove purchase experiment (share)	0.52		0.47		0.35
Sociodemographic Controls					
Head of HH is female (share)	0.12		0.14		0.72
Head of HH attended koranic or Arabic school (share)	0.83		0.74		0.07
HH size	14.08	(9.29)	11.89	(7.34)	0.04
Economic Controls					
HH possesses tile or zinc roofing (share)	0.62		0.77		0.00
HH owns sheep (share)	0.50		0.38		0.04
HHs monthly telecommunication expenditures (CFAF)	13,480	(16,370)	10,420	(10,260)	0.08
Cooking Controls					
HH owns firewood ICS (share)	0.04		0.02		0.20
HH mostly uses open fire for cooking (share)	0.58		0.50		0.15
HH buys firewood (share)	0.59		0.51		0.21
Number of observations	156		117		

Note: Expenditures are outlier-corrected by trimming figures that deviate more than three standard deviations (sd) from the mean to the value equalling the mean plus or minus three standard deviations. *p*-values refer to *t*-tests on the bivariate difference between treatment and control observations.

Table A3: Willingness to pay impact estimates

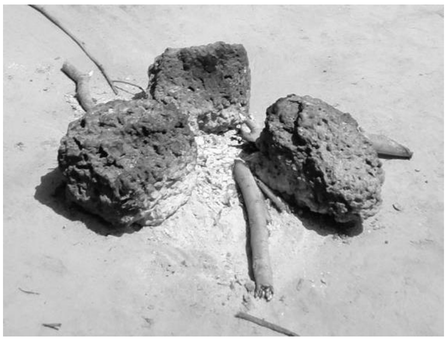
outcome:	Willingness to pay (in CFAF)		
estimation method:	OLS		
village sample:	restricted sample + comparison group		
	Coeff.	95% Conf. Interval	
	(1)	(2)	(3)
treatment	1134.37	-2199.39	4468.13
	(1554.36)		
	[0.48]		
control	-358.51	-2232.01	1514.98
	(873.51)		
	[0.69]		
Constant	4566.15		
	(2244.22)		
	[0.06]		
Observations	272		
Adjusted R-squared	0.05		
Controls:			
Village	Yes		
Respondent	Yes		
Sociodemographic	Yes		
Economic	Yes		
Cooking	Yes		
Marginal mean for comparison group	7521.53		

Annex B: Stove types used in the survey area

Stove type/ model name	Combustion chamber type	Fuel type	Feed type	Chimney	Portability	Approx. cost (US$)
Three-stone stoves	none	biomass	continuous	no	yes	-
Os	none	biomass	continuous	no	yes	1-2
Cire khatach	metal	crop residues	batch fed	no	yes	3-5
Cire wood	metal	wood	continuous	no	yes	3-5
Malagasy stove	metal	charcoal, (wood)	continuous	no	yes	3-5
Jambaar Wood	ceramic	wood	continuous	no	yes	10

Open fire stoves

Three-stone stoves



Os

Traditional metal stoves

Cire khatach (crop residues)

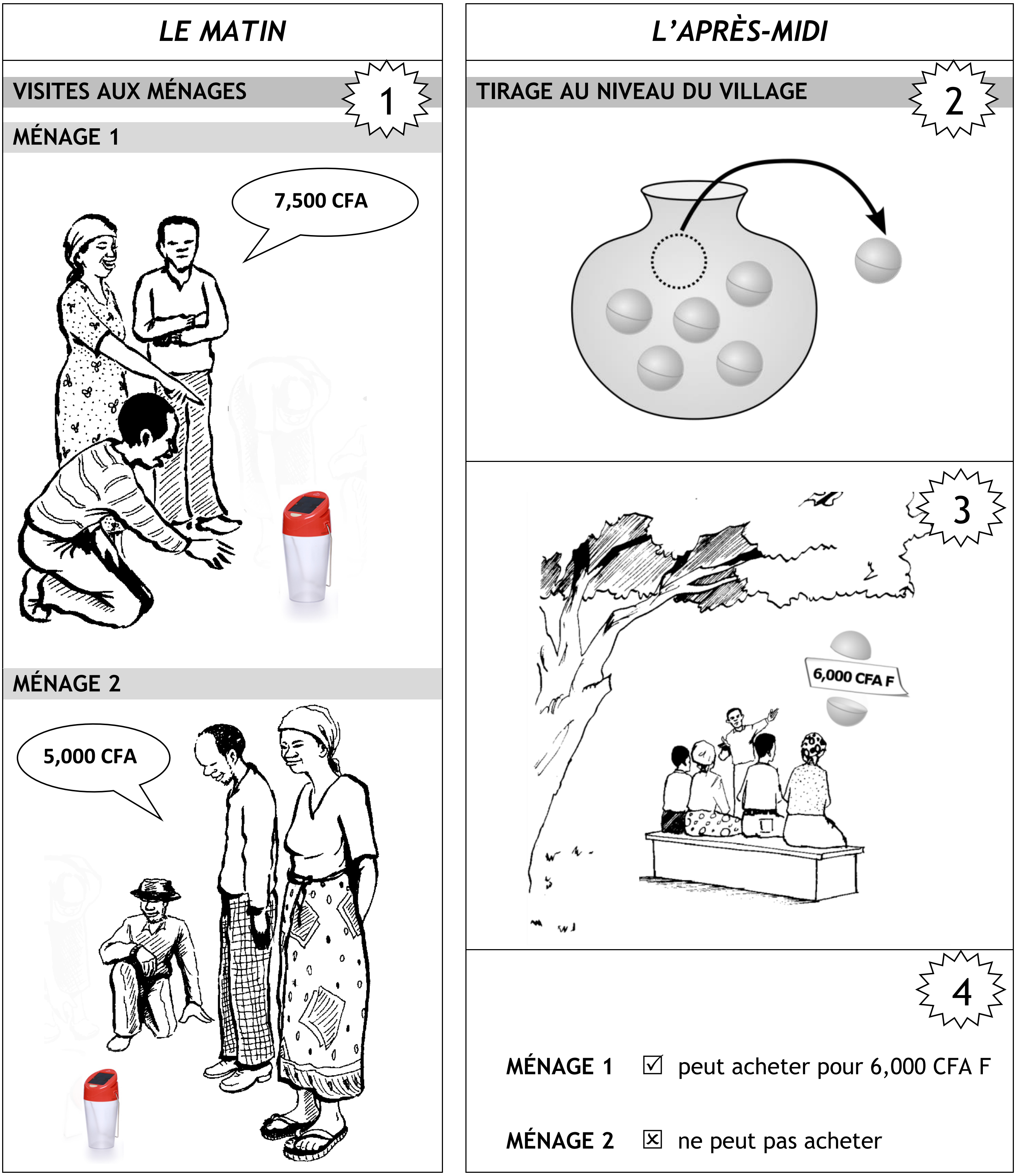
Cire wood

Malagasy stove

Improved Cooking Stove (ICS) Jambaar

Sources: author's own photographs

Annex C: Showcard used to practice the BDM procedure



Note: The showcard explains the four steps in our BDM procedure for the exemplary case of a solar lamp. On the left (step 1), two households bid for the solar lamp in the morning. On the right, the subsequent village lottery in the afternoon is shown (step 2 and 3) and the lottery results are confronted with the households' bids (step 4): household 1 can buy the lamp, household 2 cannot.

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