ONE-OFF SUBSIDIES AND LONG-RUN ADOPTION—EXPERIMENTAL EVIDENCE ON IMPROVED COOKING STOVES IN SENEGAL

GUNTHER BENSCH AND JÖRG PETERS

Free technology distribution can be an effective development policy instrument if market-driven adoption is socially inefficient and hampered by affordability constraints. Yet, policy makers often oppose free distribution, arguing that reference dependence lowers the willingness to pay (WTP) and thus hinders market potentials in the long run. For improved cookstoves, this paper studies the WTP six years after a randomized one-time free distribution in 2009. We demonstrate that the cookstoves were intensely used by the treatment group households in the years after randomization until they reached their designated lifetime. Using a real-purchase offer, we find that both treatment and control households reveal a remarkably high WTP in 2015. The estimated confidence interval suggests that we can exclude a substantial negative effect on the treatment group. The policy implication is that one-time free distribution does not necessarily undermine future market establishment, and thus can be an effective policy instrument if rapid dissemination is the objective.

Key words: Energy access, real-purchase offer, reference dependence, supply chains, technology adoption, willingness to pay.

JEL codes: : C93, D12, O12, O13, Q41.

A growing body of literature shows that positive pricing of socially desirable technologies in poor settings leads to inefficiently low levels of adoption, in that positive externalities are forgone. This is most notably due to a highly price-responsive demand. For example, 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, Berry, and Shapiro (2010) for water disinfectants, and both Mobarak et al. (2012) and Pattanayak et al. (2019) observe the same for improved cooking stoves (ICS). Based on this observation, Mobarak et al. (2012) make a case for subsidies or free distribution as policies to overcome this type of under-adoption. In fact, Bensch and Peters (2015) and Pattanayak et al. (2019) show that free distribution can be an effective instrument to trigger rapid short-term ICS uptake among the poor.

In this article, we study the effect of a one-time free ICS distribution on the revealed willingness to pay (WTP) for the same ICS technology six years later, a period that exceeds the free stove's lifetime. We thereby test whether a free distribution spoils longer-term prospects of a self-sustaining market for this technology. Next to the fiscal burden of large-scale subsidy programs, a major

---

Gunther Bensch is a researcher at the Leibniz Institute for Economic Research, Essen, Germany. Jörg Peters is a researcher at the Leibniz Institute for Economic Research and Professor at University of Passau, Essen, Germany. The authors are grateful for valuable comments and suggestions by Cyndi Berck, Pascaline Dupas, Katja Fels, Michael Grimm, Guillaume Hollard, Marc Jeuland, Luciane Lenz, Lise Masselus, and Colin Vance. The authors also thank research seminar participants at GIGA in Hamburg, the University of Passau, the University of Connecticut, the University of Göttingen, ZEF in Bonn, École Polytechnique in Paris, the 10th Annual Meeting of the Environment for Development (EfD) initiative in Pucón, the 23rd Annual Conference of the European Association of Environmental and Resource Economists (EAERE) in Athens, the Causal Inference, Program Evaluation, and External Validity Workshop in Luxembourg, and the Annual Conference of the European Economic Association in Cologne, Germany, for valuable comments. Financial support of the Federal Ministry for Economic Cooperation and Development (BMZ) via the Centre for Development Research in Bonn (ZEF) is gratefully acknowledged. Peters gratefully acknowledges the support of a special grant (Sondertatbestand) from the German Federal Ministry for Economic Affairs and Energy and the Ministry of Innovation, Science, and Research of the State of North Rhine-Westphalia.
Correspondence may be sent to: bensch@rwi-essen.de

Amer. J. Agr. Econ. 0(0): 1–19; doi: 10.1093/ajae/aaz023

argument against free distribution is that consumers may anchor their future WTP to prices previously paid for the product, a behavioral pattern also known as reference dependence (Köszegi and Rabin 2006). For experience goods, learning effects from a free trial may also influence future WTP, which is increasing in case of positive learning and decreasing if learning is negative (Fischer et al. 2014; Levine et al. 2018).

In her seminal paper, Dupas (2014) tests these two forces of learning and reference dependence for the case of insecticide-treated bednets, and finds important learning effects from own experimentation, but no anchoring around previously subsidized prices. Fischer et al. (2014) study these factors for the free distribution of consumable drugs. These authors observe a statistically insignificant decrease in the adoption of a drug with positive learning potentials, whereas adoption significantly decreases for products with no or negative learning potentials. While we cannot disentangle reference dependence and learning effects as done by Dupas and Fischer et al., we extend their work on the net long-run effects of a free distribution policy for the case of ICS.

The adoption of ICS is desirable from a public policy perspective as reflected in the United Nations Sustainable Development Goal 7 on universal access to affordable and clean energy by 2030. Currently, more than three billion people worldwide are using firewood or charcoal for their daily cooking purposes, mostly in inefficient traditional stoves or open fires (World Bank 2017). Improved cooking is high on the policy agenda because of positive external effects on deforestation and climate change (Martin et al. 2011; Shindell et al. 2012; Bailis et al. 2015). It is partly due to those non-internalized benefits that uptake of ICS is mostly low (Lewis and Pattanayak 2012; Putti et al. 2015). Other reasons stretch from cash and credit constraints to high discount rates or intra-household bargaining patterns (see, e.g., Bensch, Grimm, and Peters 2015; Alem, Hassen, and Köhlin 2018; Levine et al. 2018).

The data used in our study was collected in 2015 by surveying 371 households from 18 villages in rural Senegal. The identification strategy mainly relies on the exogenous variation stemming from a randomized controlled trial (RCT) in 2009 for which we randomly allocated ICS at zero price among 253 households from that sample. The ICS has a lifetime of two to four years. Hence, when we conducted the follow-up in 2015, treatment group households had had the opportunity to test the ICS over a full lifecycle trial period. In this follow-up survey, we offered both treatment and control households the same type of ICS, now at positive prices, in order to elicit their WTP. On top of this experimental sample, we visited 118 households in six additional villages that had not been exposed to our RCT in 2009 or to any ICS promotion activity. We use this non-experimental comparison group to explore the existence of spillovers within our experimental sample, for example, through social network effects and learning from neighbors (see Maertens and Barrett 2012; Krishnan and Patnam 2013).

To estimate the WTP in all three groups, we use the Becker-DeGroot-Marschak (BDM) mechanism, an incentive-compatible real-purchase offer procedure (Becker, DeGroot, and Marschak 1964; Plott and Zeiler 2005). This experimental design allows us to estimate the effects of one-off subsidies and a subsequent free lifecycle trial on ICS demand in the long run. Our study area resembles most rural areas in Africa to the extent that firewood is the dominant cooking fuel and 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, ICS are not available in the villages, but can be obtained in some towns located around five to 20 kilometers away, something that many villagers, however, are not aware of. The type of ICS under analysis is adapted to local cooking patterns and has been disseminated in other African countries as well, mostly going by the name Jambaar or Jiko (see, e.g., Jetter et al. 2012; Bensch and Peters 2015).

Our paper mainly complements Dupas' (2014) work in two ways. First, we assess the replicability of her findings for another base technology in a different setting. Second, our study pushes further in that we test the effect of a free full lifecycle trial period on demand, as the new ICS is offered after the first ICS has exceeded its expected durability. This is an extension to Dupas because a household needs several bednets and she assesses adoption of a second product, given that her follow-on study was carried out one year after distribution of the subsidized bednet with a lifetime of several years. We furthermore complement Fischer et al. (2014) by providing evidence on a durable product. Compared to both products, learning effects and reference dependence can be expected to differ for our case of an ICS.

Our main finding is that even a free distribution does not lead to a sizable decline in the WTP in the long run. The treatment effect point estimates are positive, yet only borderline statistically significant for certain specifications using a conventional two-sided test. To assess the concern that free distribution spoils future WTP, we additionally apply a one-sided test and can rule out negative effects at the 8% to 11% significance level. The 95% confidence interval indicates that the worst-case decrease in the WTP at the interval's lower bound is between 8% and 15%.

Our results confirm Dupas (2014) to the extent that any reference dependence is at least compensated by a positive learning effect. Explorative analysis of a comparison group outside the experimental villages suggests that no sizable spillovers from the treatment to the control group are at work. Our results also confirm the finding of Fischer et al. (2014) inasmuch as free trials do not decrease future demand for a product that entails positive learning.

In addition, we observe an average WTP of around \$11 and find that more than two-thirds of households make bids that exceed the \$8 that are usually charged for this ICS on markets in towns nearby. This is noteworthy given that it has so far proven to be extremely difficult for market-based ICS programs in Senegal (as elsewhere in the developing world) to reach rural areas. 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. To make the business attractive, these costs have to be covered by the end-user price, and hence the in-town market price might simply not be high enough for rural areas (see Adams et al. 2016). Our results provide a proof of concept that if rapid adoption is a policy goal, subsidization of free distribution does not hamper the establishment of future market-based distribution.

The remainder of this article is organized as follows. The following section reviews the literature and policy background. The section on *Experimental Design* outlines the research approach, including the identification strategy and data collection. The subsequent section presents the results with a supplementary analysis of potential spillovers, and the last section concludes and discusses the implication of our findings for ICS support policies.

Background

This section summarizes the literature on ICS and the international policy debate as well as the Senegal specific background on improved cooking policies.

Literature and Policy Background on Improved Cookstoves

In recent years, political support for the dissemination of ICS has grown considerably. The term "improved" describes a wide range of replacements for traditional cooking methods, with a correspondingly large variation in performance. Major differences are related to costs and the degree to which the stove burns cleaner (see, e.g., Jetter et al. 2012). The World Health Organization (WHO) and the Clean Cooking Alliance endorse smoke-free ICS, mainly electricity and gas, to combat adverse health effects of biomass cooking. The United Nations initiative SE4All pursues a broader approach in its endeavor to achieve universal access to modern cooking energy. The United Nations also count simple biomass ICS that are not "clean" according to WHO standards as "modern", as long as they achieve high enough fuel savings relative to traditional stoves (World Bank 2017). The ICS used in the present study qualifies as "modern" in the SE4All nomenclature but not as "clean" in WHO's reading (see next section for details on the Jambaar ICS).

The role of subsidies in increasing ICS adoption is a matter of ongoing policy debate (Simon et al. 2014; Kumar, Rao, and Reddy 2016). Most agencies and national governments reject subsidization of cookstoves, primarily based on concerns about financial sustainability and the assumption that subsidization spoils the long-term WTP and thus the establishment of a self-sustaining ICS market. Others count on carbon finance, including the United Nations REDD+ scheme, to fund ICS subsidies (see, e.g., Beyene et al. 2015a), and some governments use pro-poor arguments to justify free distribution.

In the academic literature, evidence on the effectiveness of cookstove dissemination and adoption challenges is growing (Martin et al. 2011). The livelihood and environmental improvements from improved cooking technologies generally materialize via two channels. First, reduced woodfuel consumption directly reduces workload or monetary expenses, depending on whether fuels are purchased or collected. It also brings about environmental benefits that stem from mitigated forest degradation and deforestation and, in turn, climate change mitigation (van der Werf et al. 2009; Ahrends et al. 2010; Myers et al. 2013; Bailis et al. 2015).

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[1] reductions in household air pollution (Grieshop, Marshall, and Kandlikar 2011; Jetter et al. 2012). The non-linear particulate exposure-response relationship found in medical research suggests that large reductions in smoke exposure are required to ensure positive health effects (see, e.g., Jamison et al. 2013; Burnett et al. 2014; or Pope et al. 2011). However, as can be seen in Langbein, Peters, and Vance (2017), Yu (2011), and Bensch and Peters (2015), even simple ICS may bring about health benefits from reduced smoke exposure by facilitating outside cooking and shorter cooking durations. Beyond its relevance for health, the soot of cooking fires is the largest source of anthropogenic black carbon, an important climate-forcing emission (Ramanathan and Carmichael 2008; Shindell et al. 2012; Lacey et al. 2017).

A number of studies provide evidence for substantial woodfuel reductions as a result of ICS adoption (see Adrianzén 2013; Bensch and Peters 2013, 2015; Rosa et al. 2014; Bensch, Grimm, and Peters 2015; Brooks et al. 2016; Gebreegziabher et al. 2018). In all these studies, the positive findings hinge upon the effective and perceptible improvements of the ICS compared to the baseline stove. More precisely, consumers will only use the new stove if it fits into their cooking habits and if it yields reductions in fuel consumption or smoke exposure at manageable adaptation costs. Indeed, ICS have to be properly adopted and—if necessary—maintained by users because the partial, diminishing, or improper use of ICS may entail few or no benefits, as observed in Hanna, Duflo, and Greenstone (2016) and Usmani, Steele, and Jeuland (2017).

Improved Cookstoves in Senegal

Efforts to reduce the country's heavy reliance on traditional biomass fuels for domestic usage date back to the 1970s, when Liquefied Petroleum Gas (LPG) 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 successfully disseminates a charcoal version of the Jambaar ICS through its program Foyers Ameliorés aux Sénégal (FASEN).[2] Usage of both LPG and charcoal, however, is mainly limited to urban areas. In rural Senegal, where 57% of the Senegalese population lives, the primary cooking fuel of 86% of households is firewood, predominantly used in inefficient open-fire three-stone stoves or very simple metal stoves (Agence Nationale de la Statistique et de la Démographie 2014; African Development Bank 2016).[3]

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 online supplementary annex A. The Jambaar is a portable, maintenance-free single-pot stove with a fired clay liner inseparably bound to a metal cladding with a mix of cement and ashes. Owing to simple design improvements compared to traditional stoves, the woodfuel burns more efficiently and the heat is better conserved and directed toward the cooking pot. Bensch and Peters (2015) observe a savings rate of around 40% per stove utilization under day-to-day conditions. This ICS can be considered as well-adapted to the local cooking

[1] 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, e.g., Ezzati and Kammen 2002; Dherani et al. 2008; Hosgood et al. 2010; Po, FitzGerald, and Carlsten 2011; McCracken et al. 2012; Bruce et al. 2013; Amegah, Quansah, and Jaakkola 2014; Smith et al. 2014).

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

[3] See Wiedinmyer et al. (2017) for urban-rural differences in Ghana.

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 fewer smoke-related disease symptoms, which may be due to increases in outdoor cooking and reduced cooking duration and thus less smoke exposure. Bensch and Peters (2015) also show that three and a half years after the randomization in 2009, half the treatment households were still using the randomly distributed ICS. Half of these ICS were in good condition as wear and tear became noticeable, which is in line with expectations since the stove has a lifespan of around two to four years according to the FASEN program.

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; a 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, by either individual customers or vendors. The ICS price in secondary towns is around 5,000 CFA Francs, for which the exchange rate to the U.S. dollar is about 590: 1. This sum, equivalent to $8, is about three times the average daily wage for casual agricultural work in the study area. Prices in Dakar are considerably higher, at around $14. Various reasons explain the higher prices in Dakar compared to secondary towns. To start with, labor costs are higher. In addition, the Dakar producers concentrate on charcoal stoves and produce firewood Jambaars only on demand and mostly in smaller quantities, which leads to higher unit costs than in secondary towns. Moreover, the Dakar producers employ higher-quality inputs and more and better machinery than that used in secondary towns, again leading to higher costs but also higher quality. Later, in the *Results* section, we emphasize that the ICS are generally not available directly in villages and not readily available in nearby towns; as we will show, households did not obtain new ICS to replace the deteriorated stoves provided in 2009. Hence, there is also no village price for the ICS. Traditional stoves, in contrast, can be acquired in the villages at low prices. Traditional metal stoves or open fire grills cost between $0.8 and $4.30 and three-stone stoves are usually homemade at zero cost (stove depictions can be seen in online supplementary annex A).

Experimental Design

The experiment underlying this study was conducted in the Peanut Basin region, located in central Senegal, around 200 kilometers southeast of the capital Dakar. The basin is Senegal's major agricultural region, where 99% of households engage in farming and nearly all land is under cultivation of subsistence and cash crops—mainly peanuts, millet, maize, and cowpeas (Agence Nationale de la Statistique et de la Démographie 2015). 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 (Agence Nationale de la Statistique et de la Démographie 2009). Biomass production in this semi-arid zone is low and hence firewood is scarce (Gill 2013).

The data used in this article was collected in November and December 2015 in two types of villages: an experimental sample and a complementary non-experimental sample. We start by 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 was done at the household level in 2009, where treatment was stratified by village. Despite a lapse of six years since baseline, merely 17 of the original 253 randomly sampled households could not be reinterviewed in 2015.[4] Just as at baseline stage, the resulting sample of 236 households is composed of 40% of households in the experimental treatment arm, that is, they received an ICS in 2009.

We adhered to a predefined experimental procedure to conduct the BDM real-purchase offer in order to obtain the WTP. In cooperation with a Senegalese survey partner, six local enumerators were trained to act as ICS

[4] Eight households changed location, two households merged into one, three households' respondents were deceased, four could not be located, and one household was not willing to participate in the interview. We tested for attrition following Fitzgerald, Gottschalk, and Moffitt (1998), in a first step regressing attrition status on relevant household characteristics. For that purpose, we use the control variables presented in the *Results* section and extended them by additional control variables 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.

sales agents.[5] The sample households were informed in advance about a visit of a stove seller, including a survey on energy use. The person responsible for making financial decisions in the household was requested to be present during this visit. Both treatment and control households were visited individually. Once our team arrived in the household, enumerators started by presenting the Jambaar ICS. Stove prices were not revealed. 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 within a timeframe of about two and a half months. This payment period was granted because we visited households in November, a time of year when households are particularly short on cash because the harvest period has only just started. By the time of the payment, target households would have sold at least part of their harvest and thus would be able to make investments in durable goods.[6]

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 conducted the draw publicly and at the village level after all bids had been made, so that one effective price applied to the entire village. The bidder could buy the product for the price drawn only if his or her bid equaled or exceeded the price drawn. If the bid fell below the drawn price, no transaction took 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 supplementary annex B). All but two respondents then followed the invitation to make a bid.

During pre-tests, we noted that households were well able to grasp the bidding game and its rules and were hence able to confidently express their WTP. There is thus no indication that the BDM elicitation approach imposed unrealistic cognitive demands, a common problem with stated WTP approaches for environmental non-market products (Gregory, Lichtenstein, and Slovic 1993).[8] The WTP elicited by BDM is widely seen as a precise approximation of a real-life WTP because of its incentive-compatible features (see Berry, Fischer, and Guiteras 2019 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.[10] 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); this price range was not communicated to the participants and can thus not have affected the bidding of households.[11] For reasons of

[5] This rules out foreigner-presence effects as observed in Cillier, Dube, and Siddiqi (2015).

[6] The delayed payment period potentially offers an opportunity to game the system. Given that participants did not need to pay right away, they could have made a higher bid than their own ad hoc valuation in order to find out more information about the usefulness of the ICS or potentials to resell and default in the event the ICS turned out to be useless. One would expect this strategic bidding to be higher in the control group since the treatment group is already fully informed. Yet, there is no indication for this; default rates are extremely low in both the treatment and the control group.

[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, Derby, and Dutta (2015). Alternatively, ICS adoption preferences have been studied based on discrete choice methods by van der Kroon, Brouwer, and van Beukering (2014) and Jeuland et al. (2015), who used hypothetical decisions, and by Jagger and Jumbe (2016), who faced participants with a real choice between an ICS and a package of dry goods including sugar and salt of equal monetary value.

[8] Also note that villagers are familiar with paying for cookstoves; while the widely used three-stone stove is free of any monetary charge, 82% of sampled households have paid for a stove in the past.

[9] The mechanism has already been widely used in laboratory settings, and also in field experiments to elicit consumer preferences for such diverse items as meat quality, solar kits, rice origin, mosquito nets, water and hygiene, and rainfall insurance (Lusk et al. 2001; Hoffmann 2009; Cole, Stein, and Tobacman 2014; Guiteras et al. 2016; Morey 2016; Alem and Dugoua 2018; Grimm et al. 2018).

[10] The experimental procedure also included the same BDM procedure for another ICS type, the so-called Sakkanal, after the Jambaar stove purchase offer was finalized. The clearly demarcated sequence ensured that the second stove offer could not affect the bids for the Jambaar stove analyzed in this article, since, when the Jambaar was offered, households were not aware that they would be offered a second stove.

[11] Later in figure 2 we show the entire distribution of bids. There is no indication for an effect of the price range on the bidding behavior of households such as a kink in the distribution

fairness and transparency, we then informed households that the ICS is available at around \$8 in towns nearby (the "in-town price" in the following) and provided the contact details of vendors. Successful bidders could withdraw from the commitment to buy the ICS or otherwise received the stove after signing contracts. Withdrawals happened in only five cases, implying very strong compliance among participants and thus reliability of the bid amounts. The same can be said about the subsequent actual payment behavior; all but six households paid the full price via their village chief before the end of the payment period.[12]

The survey in 2015 included six additional villages that had not been part of the 2009 RCT, where we applied the same BDM and interview procedure with a random sample of 118 households. The villages were selected from the same department, at a location 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 participant flow in Figure 1 presents the composition of the entire sample and depicts another division of the sample at the bottom of the figure into the restricted sample and the charity subsample. As we learned during the survey, small-scale initiatives recently sold ICS, out of charity, at highly subsidized prices in three of our twelve villages (80% of buyers of the Jambaar in these villages paid less than \$0.3). These were taken up more by control households, simply because many treatment households still had the ICS they received in 2009 at the time of the charities' visits. This can have various implications for the WTP, for example because these households bid for a second ICS, but also because the charity ICS itself might have induced reference or learning effects. Therefore, later in the analysis we explore how excluding this "charity subsample" affects the results in the remaining nine villages ("restricted sample" in the following).

below 4,500 or above 6,000 CFA F. This is furthermore confirmed by the fact that 30% of participants made bids below 4,500 CFA F.

[12] As in a business-as-usual marketing approach, our team returned to the villages in order to take back the ICS from those households that did not pay the full price. In the case households made (non-predefined) advance payments for the ICS, these were returned to these households as stipulated in the contract.

Results

We first present the descriptive statistics on the balancing of the three groups (treatment, control, and comparison) and the ICS usage prior to our real-purchase offer in 2015, followed by results on the WTP and the effects of the lifecycle trial period.

Basic Descriptive Statistics and Balancing

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 and 142 in the control group (see table 1). In table 1, we show descriptive statistics for those variables that we include as controls in the impact analysis in the next subsection. These variables either refer to the characteristics of the household member who participated in the WTP bidding game or were elicited before the randomization in 2009. In line with expectation, treatment and control group are balanced in 2009.

As for the respondent-specific variables, 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 financial decision makers within the household. This is highly correlated with the sex of respondents, who are male in 63% of the cases (not shown in the table). Similarly, the age difference between the respondent and the enumerator, which reflects the specific interview situation, is highly correlated with the respondent age, which averages 47 years. Households are typically large in rural Senegal; the average household size is 14.4 people. Table 1 also shows telecommunication expenditures as a proxy for income and two wealth proxies: flooring and sheep ownership.

The same descriptive statistics and balancing tests as in table 1 can be seen in table C1 in online supplementary annex C for the restricted sample and the non-experimental comparison group. For the restricted sample, it does not come as a surprise that the sample is similarly well-balanced as the full sample, given that we stratified the randomization by village. Despite a careful selection of non-experimental comparison sites, they exhibit statistically significant differences to the whole experimental sample for a couple of variables. Taking into account other household

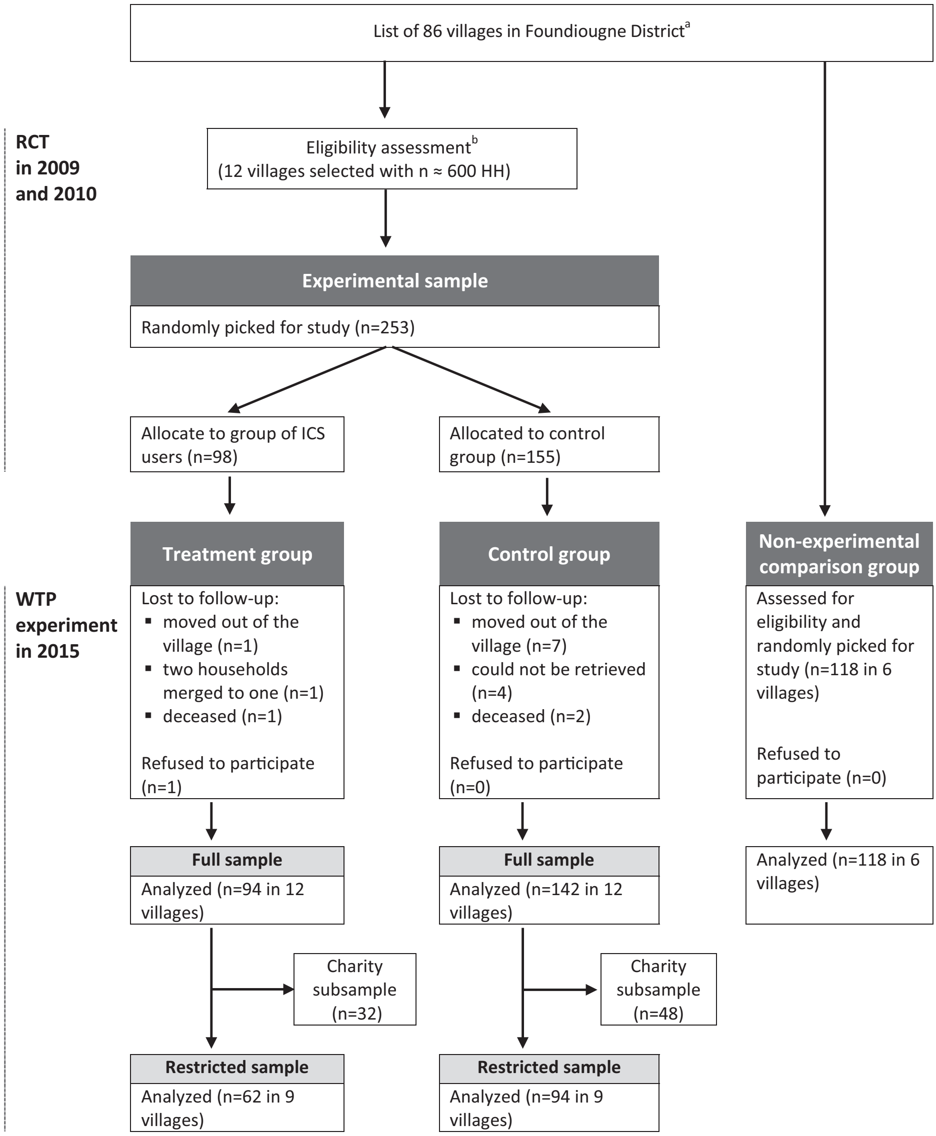

Figure 1. Participant flow

Note: [a] Foundiougne is a district of 3,000 km^2 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 were electrified. [b] Eligibility criteria included the ecological zone, population size, main livelihood activities, infrastructure availability, and absence of access to ICS.

variables not shown in the table, there is, however, no indication of clear structural differences in the overall socio-economic conditions that would cause us to abstain from comparing the two groups in a supplementary non-experimental analysis below. For example, the comparison group households have better roofing on average, whereas the experimental group exhibits higher shares of livestock ownership. Expenditures are higher in the experimental group; per-capita expenditures are not.

Cookstove Usage and Intermediate Outcomes

The impact of the free lifecycle trial treatment on households' WTP critically depends on the imprint the treatment had on people's cooking habits, especially with regard to learning. We therefore discuss ICS ownership and usage after 2009 and a variety of cooking-related variables from 2015 in table 2.

The ICS ownership rate in 2015 is at 20%, fairly equally distributed across the treatment

Table 1. Descriptive Statistics on Control Variables

	Treatment mean (sd)	Control mean (sd)	Difference *p*-value
Respondent-specific characteristics at time of stove purchase experiment (elicited in 2015)			
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 baseline variables (elicited in 2009)			
Male head of household with more than one wife (share)	0.36	0.32	0.48
Head of HH attended Koranic or Arabic school (share)	0.78	0.76	0.78
HH size	14.90 (13.58)	15.25 (15.79)	0.86
Economic baseline variables (elicited in 2009)			
HH has cement flooring (share)	0.32	0.30	0.70
HH owns sheep (share)	0.64	0.65	0.88
HH's monthly telecommunication expenditures (CFAF)	4,780 (5,160)	5,880 (8,160)	0.25
Improved firewood stove baseline variable (elicited in 2009)			
HH owns woodfuel stove other than open fire	0.36	0.43	0.30
Number of observations	94	142	

Note: See Bensch and Peters (2015) for a comprehensive set of balancing tests. Expenditures are outlier-corrected by trimming figures that deviate more than three standard deviations (sd) from the mean to the value equaling the mean plus or minus three standard deviations; *p*-values refer to *t*-tests on the bivariate difference between treatment and control observations.

Table 2. Intermediate Outcomes on Cookstove Usage

	Treatment mean (sd)	Control mean (sd)	Difference p-value
HH owns firewood ICS (share)	0.21	0.20	0.77
HH owns firewood ICS given out in 2009 (share)	0.10	0.00	0.00
HH owns firewood ICS from charity (share)	0.11	0.17	0.18
HH owns woodfuel stove other than open fire (share)	0.59	0.63	0.45
Usage duration of firewood ICS given out in 2009 (share)			
up to two years	0.14	–	–
at least two years	0.86	–	–
at least three and a half years	0.51	–	–
at least six years	0.10	–	–
HH mostly uses open fire for cooking (share)	0.62	0.56	0.36
HH buys firewood (share)	0.50	0.52	0.75
Firewood collection time (hours per week)	9.23 (11.57)	10.71 (12.69)	0.37
HH ever had a firewood ICS (share)	1.00	0.39	0.00
Any HH member ever cooked on a firewood ICS (share)	1.00	0.47	0.00
Number of observations	94	142	

and control groups. The reason for this is that uptake of the charity ICS is higher in the control group, where 17% own a charity ICS. In the treatment group, 11% own a charity ICS and 10% still have the 2009 ICS. ICS purchases other than those from the charity have virtually not taken place after 2009: in both the 2013 and the 2015 survey, only one household from the restricted sample reported owning a (self-purchased) Jambaar ICS that had not been distributed in our 2009 randomization. Other free distribution activities have

Table 3. Willingness to Pay Impact Estimates

Outcome:	Willingness to Pay (in CFA F)					
Estimation method:	OLS					
Village sample:	Full sample			Restricted sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Free lifecycle trial treatment	863.48 (733.27) [0.26]	910.34 (625.27) [0.17]	1,298.17 (691.41) [0.09]	1,283.93 (1,105.98) [0.28]	1,335.51 (1,006.53) [0.22]	1,668.66 (1,103.71) [0.17]
HH still owns randomized ICS in 2015	–	–	−4,152.81 (726.88) [0.00]	–	–	−5,108.87 (1,466.06) [0.01]
Controls:						
Village	Yes	Yes	Yes	Yes	Yes	Yes
Respondent variables	–	Yes	Yes	–	Yes	Yes
Baseline covariates	–	Yes	Yes	–	Yes	Yes
Marginal mean for control group[a]	5,987.17	5,968.67	5,815.53	6,586.04	6,565.81	6,435.17
WTP increase	+14.4%	+15.3%	+22.3%	+19.5%	+20.3%	+25.9%
Maximal WTP drop according to 95% CI lower bound	−12.5%	−7.8%	−3.8%	−19.2%	−15.0%	−13.6%
Observations	233	233	233	153	153	153
Adjusted R-squared	0.04	0.07	0.09	0.00	0.07	0.09

Note: [a]Calculated at the mean of the control variables. See table C2 in online supplementary annex for coefficients of the full set of control variables. Standard errors clustered by village are in parentheses and *p*-values appear in squared brackets.

not taken place. Table 2 thus conveys the intermediate finding that virtually no household had made an effort to (re-)invest into ICS by obtaining one from towns nearby or from vendors in Dakar. Cross-selling between treatment and control households had not happened either.

As described in Bensch and Peters (2015), adoption of the randomized ICS was high at the extensive and the intensive margin. In 2010, virtually all treatment households used the ICS regularly and the vast majority of meals were prepared on the new ICS: the ICS was the primary cookstove in 85% of households with ICS. In line with the expected lifetime of two to four years, ownership declined over time. Only about 14% stopped using the ICS within the first two years, and in 2013, almost four years after the randomization, still 51% were using the ICS (see table 2 and Bensch and Peters 2015). Even those 10% of treatment households that still own a randomized ICS in 2015 use it regularly, on average twice a day.

Table 2 also presents other key cooking-related household characteristics: 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 materializes in terms of time savings. The share of households that have at least one member who has ever tried some type of improved stove is relatively high, although this also includes other stoves that tend to be less improved than the Jambaar ICS, such as fixed mud stoves.

Impacts of Free Lifecycle Trial Period

Results on the impacts of the free lifecycle trial treatment period are presented in table 3. The *free lifecycle trial treatment* coefficient in the table corresponds to β_1 in the following OLS regression setup:

$$(1) \quad WTP_i = \beta_0 + \beta_1 Treatment + \boldsymbol{\beta}_2' \boldsymbol{X}_\mathrm{i} + \mu_\mathrm{i}$$

where the raw *WTP* is the outcome, i refers to the individual household, $\boldsymbol{X}_i$ to the vector of control variables, and μ_i to the error term. Standard errors are clustered by village for being our primary sampling unit. We run the regressions for the full sample and for the restricted sample in which we exclude the three charity villages. For both samples, we estimate a parsimonious model in which we only control for village fixed effects (columns 1 and 4) and a standard model in line with equation (1) which we control for the variables presented in table 1, that is, the 2009 covariates and the respondent-specific characteristics elicited during the 2015 survey (columns 2 and 5). The point estimate in the full sample (column 2) suggests that the free lifecycle trial increases household WTP. The effect size is at 15%, but not statistically different from zero at conventional levels. Coefficients of control variables are not shown in the table, but can be taken from table C2 in online supplementary annex C. Significant positive correlates of WTP are financial responsibility status of the respondent, a younger age of the respondent (reflected in the age difference to the interviewer) and, for the restricted sample, baseline ownership of a stove other than open fire.

Columns (4–6) depict the results for the restricted sample, that is, after dropping the charity villages. The free lifecycle treatment effect is higher (at 20%), but less precise. The difference in point estimates between the full sample and the charity subsample portends the important role that existing ICS in a household have for the WTP revealed in the bidding game. Note that we interpret this only as a robustness check. It is difficult to tell what is driving this change in effect size because of the unpredictable mechanisms that might be at work: many households in the charity subsample bid for a second ICS, which decreases their average WTP. At the same time, the charity ICS itself could have induced reference and learning effects, which increases noise because the stove is a similar make but may be of a different quality than the one offered in our experiment.

As discussed in the previous subsection, a notable fraction of treatment households in the restricted sample also still owns and uses the 2009 ICS. It is likely that their WTP is affected as well. In our main specifications in columns 2 and 5, we do not account for this and thereby evaluate the real-world effect of a free-distribution ICS program on the adoption of the same ICS six years later. In this real-world interpretation, we treat people who still own an ICS as a natural part of the policy population, including their downward effect on the average WTP since this is also what a real market would face if it reaches out to the region sometime after the free distribution intervention.

Yet one might also be interested in the treatment effect of a free distribution on the WTP when all ICS have deteriorated, that is, on a green field. Such a treatment effect gives us a better idea of the net effect of learning and reference dependence since for this we ideally want to know each household's WTP for a new stove, and not a second one. For this purpose, in an exploratory analysis we include a further control variable for whether the household still owns the 2009 ICS. As can be seen in columns (3) and (6), this leads to a higher average treatment effect. These estimations, however, must be interpreted with care since the additional control variable is endogenous. The survival of the randomized ICS may also be due to household characteristics that are correlated with unobservable WTP determinants: those households who still use the 2009 ICS might have a particularly high (or low) valuation of the ICS, which also drives the WTP.

Overall, while the precision of estimates is not high enough to establish a clearly positive treatment effect, the estimations consistently indicate that it is safe to reject a negative effect. A one-sided test on a negative impact, equivalent to half the *p*-value shown in table 3, is significant at the 8% and 11% levels in our main estimations in columns (2) and (5). As a very conservative estimate of the free lifecycle effect, table 3 also shows the lower bound of the 95% confidence interval. Even at these lower bounds, the WTP does not go down by more than 8% in the full sample and 15% in the restricted sample. We conclude from this that free distribution is very unlikely to have substantial negative effects on adoption in the long run; negative effects of reference dependence (if they exist) seem to be largely compensated by positive learning effects.

Given that we did not randomize subsidy levels in the 2009 RCT and do not avail of any other exogenous variation in determinants of learning and reference dependence, unlike Dupas (2014) and Fischer et al. (2014) we cannot dig deeper empirically into these mechanisms. We do have some potential proxies from the survey data for an exploratory assessment, but they show too little variation: ICS usage intensity in 2010 may serve as a proxy for learning (although it would also be endogenous to the valuation of the ICS), but virtually all treated households (88%) used the ICS at least twice per day, so we cannot expect differences in learning for them. We furthermore asked questions on *beliefs about returns*, which could be related to learning. Yet the answers do not show any exploitable variation either: In both the treatment and the control group, 99% of households stated in 2015 that they expected the new ICS to reduce their expenses on energy.

Beyond the treatment effect, a very notable result is the level of the WTP. The simple means are 6,300 and 7,100 CFA F ($11 to $12) for the full and restricted sample, respectively, and are thus clearly above the $8 price charged by ICS producers in nearby towns. A convenient feature of the BDM mechanism is that—contrary to simple take-it-or-leave-it approaches—it allows for individual WTP estimates per customer and thus yields higher-resolution data that can be depicted as a demand curve (see figure 2). It can be derived from this curve that 68% and 75% of households in the full and restricted samples, respectively, make a bid that is higher than the in-town price. Even if we take the higher Dakar price of $14 shares of 16% and 19% still make high enough bids. This is a remarkable 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 also suggests that WTP among treatment households may not always be strictly above the WTP of control households. We run quantile regressions to compare treatment and control units more thoroughly across different WTP levels. Point estimates of the impact coefficient remain positive across the entire conditional WTP distribution (see figure D1 in online supplementary annex D), thus supporting the results on the mean impact found above. Moreover, in online supplementary annex D, we conduct some robustness checks on outlier sensitivity, since 12% of households in the treatment group and 7% in the control group make bids higher than 10,000 CFA F ($17). Results on point estimates and confidence intervals are very similar. In another sensitivity analysis we drop the few households that opted out of the purchasing process (see online supplementary annex D as well).

Spillover Effects

Because ICS were randomly distributed within villages in 2009, treatment and control group households are likely to be in contact so that spillover effects are possible, both for learning and for reference dependence. Control households may have learnt about ICS benefits from treated neighbors in their village, but likewise they might anchor their WTP to the zero price ICS that treatment households received in 2009. This would be especially problematic if the null effect observed in the previous section was driven by reference dependence in the treatment group that spilled over to the control group households (indirect reference dependence). In this case, our conclusion of no negative effects of free distribution would be false.

We explore aggregate spillovers by including the non-experimental comparison group in the estimation sample. Remember that these are six additional villages that had never been exposed to ICS before our visit. As can be seen in figure 3, the WTP in these comparison villages barely differs from the WTP in the experimental control group (restricted sample). The data underlying this figure comes from estimating a variant of the specification presented in table 3, column 5 (see table C3 in online supplementary annex C for the regression results). Three changes are made: first, instead of the treatment-control dummy, the specification now includes 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. Second, since we do not have 2009 data for the non-experimental sample and in order to account for the slight imbalances described above, we now include control variables measured in 2015. Third, in order to only include those variables that are plausibly non-responsive to the 2009 treatment, we do not include an ICS ownership variable (summary statistics are shown on the right side of table C1 in online supplementary annex C).

Suppressing concerns about a selection bias for a moment and interpreting the comparison group's WTP as the counterfactual WTP in the complete absence of a previous free-distribution RCT, the similarity between the comparison and the control group suggests that there are no strong aggregate spillovers from the treatment to the control

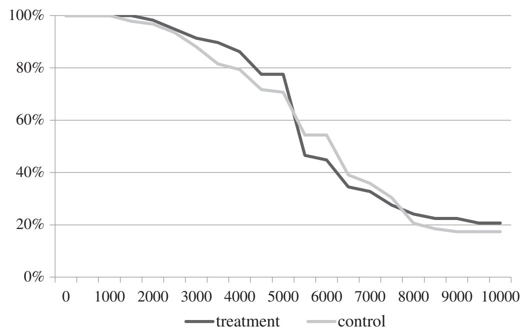

Figure 2. ICS demand curve according to bids in BDM purchase offer

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

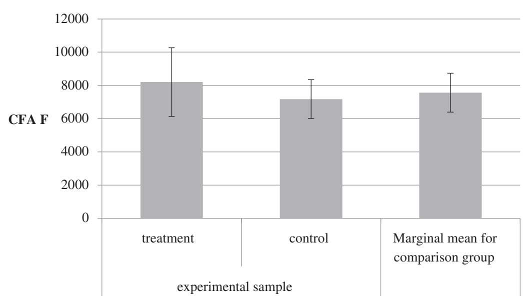

Figure 3. Willingness to pay in experimental groups and comparison group

Note: The values in this figure are derived from a regression model with the same specification as in table 3, column (5), which now includes a polytomous categorical treatment variable with the comparison group as the base case. Moreover, all 2015 variables listed in table C1 in online supplementary annex C are included as control variables—except for the ICS ownership variable. First, the marginal WTP mean for the comparison group (on the right) is calculated at the mean of the control variables. Second, the WTP means for the two experimental subsamples on the left are calculated by adjusting the comparison group mean by the point estimates of the respective coefficients in the same regression model. The lines indicate the 95% confidence intervals for these two coefficients. Third, the confidence band for the comparison group is derived from the same regression, using the control group as the base case. Applying wild bootstrap inference (Cameron, Gelbach, and Miller 2008) yields only marginally different confidence intervals than the ones depicted in the graph, which are based on conventional clustered standard errors.

group. In addition, this observation eases concerns about survey effects, which might have been induced by reciprocity and our repeated presence in the experimental villages, for example.

Discussion and Conclusion

Our empirical analysis has shown that free distribution of improved cookstoves (ICS) is very unlikely to substantially decrease the willingness to pay (WTP) for the product in the long run. Even the worst-case WTP decreases determined at the lower bound of 95% confidence intervals might be politically acceptable in light of the high adoption rate triggered by the free distribution and the strong external effects of ICS. We thereby follow up on Dupas' (2014) seminal work on how one-off subsidies for malaria bednets affect adoption. Dupas explicitly discusses the transferability of her findings for ICS, arguing 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." We tentatively confirm Dupas' prediction to the degree that point estimates for the net effect are positive, although not statistically significant. While we cannot disentangle reference dependence from learning effects, it seems that the former is at least compensated by the latter after free distribution. These results are also consistent with what Fischer et al. (2014) observe for products with positive learning.

A further notable result of our study is the absolute level of WTP revealed by both treatment and control households. With an average of around \$11, the WTP is very high compared to previous cookstove WTP studies (Mobarak et al. 2012; Beltramo et al. 2015) and considerable fractions also pay prices above what vendors charge in town. Participants took these expressions of their WTP seriously, as evidenced by a repayment rate of over 95% among those households who were allowed to buy the stove.[13] One plausible reason for the high WTP is the firewood scarcity in our study region, which is representative for other Sahelian places as well, but might differ from more biomass-abundant regions, for example, more tropical parts of Africa.[14]

Despite the high WTP there is no vibrant local ICS market that reaches the villages. Virtually no household acquired an ICS between the distribution in 2009 and our 2015 survey. Why has the market not reached these villages? The reasons likely relate to very high transaction costs on rural markets

[13] This cannot be taken for granted. See, for example, Grimm et al. (2018) and Tarozzi et al. (2014), who use payment targets similar to ours and observe repayment rates of between 60% and 70%.

[14] In Bensch and Peters (2017), we qualitatively explore different explanations for this high WTP in more detail.

that have to be added to the in-town market price. Likewise, while generally the BDM method is found to be a very accurate reflection of the true WTP (see Berry, Fischer, and Guiteras 2019), one might speculate that the WTP observed in our set-up is higher than what people reveal on regular markets. More specifically, due to the door-to-door marketing feature that is implicit to the BDM method, especially male household members (oftentimes the financial decision makers) probably dedicated more attention to the offer than they usually do to regular market offers. Importantly, the two-month payment target in the harvest period served as an interest-free short-term loan and commitment device. Financing components proved to increase the WTP in similar contexts, for example, for latrines in Cambodia (Ben Yishay et al. 2017) and improved cookstoves in Uganda (Levine et al. 2018), but not for solar kits in Rwanda (Grimm et al. 2018). Private vendors could replicate all this, but it obviously increases transaction costs. This bespeaks a variety of barriers and frictions that make rural market exploration a highly risky endeavor. Vendors in such a market environment would have to price in risks and logistics, leading to rural end-user prices that exceed urban prices considerably (see also Adams et al. 2016; Barriga and Fiala 2018; Grimm et al. 2018; Levine et al. 2018).

In sum, this paper and our previous study (Bensch and Peters 2015) have shown that households are eager to use the ICS even if it is received as a gift, which is in line with Bates et al. (2012) as well as Grimm et al. (2017). More specifically, our study shows that households reveal a high valuation when being offered an ICS for purchase—but do not make a pro-active effort to obtain one in town. This suggests that policy interventions should increase the salience of ICS, for example, through vigorous marketing approaches (including a strengthening of supply chains) that reach out into the villages. In addition, because this would further increase transaction costs, partial subsidies are probably required to make the ICS business attractive in rural areas. The strong positive livelihood and environmental effects provide the necessary economic arguments to subsidize ICS. Carbon finance could be a long-term funding source as long as the respective ICS effectively reduces climate-relevant emissions. Moreover, in some areas like very arid regions, fuelwood scarcity might call for an urgent policy intervention. Especially in such contexts, free distribution could be an effective instrument to achieve a rapid increase in ICS adoption, and our analysis provides a proof of concept that this does not necessarily spoil future markets.[15]

That being said, some external validity concerns apply (see Peters, Langbein, and Roberts 2018). It is important to emphasize that adoption is case-specific and likely to vary across regions and product types, including ICS types. Subsidization might decrease the future WTP if no learning or even net negative learning is involved (Luoto et al. 2012; Fischer et al. 2014). This is likely to hold true for ICS types that involve high non-fuel usage costs, for example, because they are not convenient to use or imply intensive maintenance work (see, e.g., Beltramo and Levine 2013; Hanna, Duflo, and Greenstone 2016). Moreover, while we observed a high usage intensity despite the free distribution, concerns about screening and sunk cost effects reducing usage intensity in give-away programs might be stronger in other settings (see Arkes and Blumer 1985; Ashraf, Berry, and Shapiro 2010; Cohen and Dupas 2010; Beyene et al. 2015b; Cohen, Dupas, and Schaner 2015). Such heterogeneities in behavior and product features call for region- and product-specific experimentation similar to what this study has done before rolling out any subsidy policy (see also Berry, Fischer, and Guiteras 2019; Lybbert et al. 2018).

Supplementary Material

Supplementary materials are available at *American Journal of Agricultural Economics* online.

References

Adams, K.P., T.J. Lybbert, S.A. Vosti, and E. Ayifah. 2016. Using an Economic Experiment to Estimate Willingness-to-Pay for a New Maternal Nutrient Supplement in Ghana. *Agricultural Economics* 47 (5): 581–95.

[15] Omotilewa, Ricker-Gilbert, and Ainembabazi (2019) come to a very similar conclusion in their study on one-time subsidies for hermetic grain storage bags that have been newly introduced among smallholders in Uganda.

Adrianzén, M.A. 2013. Improved Cooking Stoves and Firewood Consumption: Quasi-Experimental Evidence from the Northern Peruvian Andes. *Ecological Economics* 89: 135–43.

African Development Bank. 2016. *African Statistical Yearbook 2016*. Abidjan: African Development Bank.

Alem, Y., and E. Dugoua. 2018. Passive Learning and Incentivized Communication: A Randomized Controlled Trial in India. University of Gothenburg Working Paper in Economics, No. 723.

Alem, Y., S. Hassen, and G. Köhlin. 2018. Decision-Making within the Household: The Role of Autonomy and Differences in Preferences. University of Gothenburg Working Paper in Economics, No. 724.

Agence Nationale de la Statistique et de la Démographie. 2009. *Enquête Villages de 2009 Sur L'Accès Aux Services Sociaux de Base*. Dakar: Ministry of the Economy and Finance.

———. 2014. *Recensement Général de la Population et de l'Habitat, de l'Agriculture et de l'Elevage 2013. Rapport Définitif*. Dakar: Agence Nationale de la Statistique et de la Démographie.

———. 2015. *Situation Économique et Sociale Régionale 2013*. Fatick. Dakar: Agence Nationale de la Statistique et de la Démographie.

Ahrends, A., N.D. Burgess, S.A.H. Milledge, M.T. Bulling, B. Fisher, J.C.R. Smart, G.P. Clarke, B.E. Mhoro, and S.L. Lewis. 2010. Predictable Waves of Sequential Forest Degradation and Biodiversity Loss Spreading from an African City. *Proceedings of the National Academy of Sciences* 107 (33): 14556–61.

Amegah, A.K., R. Quansah, and J.J.K. Jaakkola. 2014. Household Air Pollution from Solid Fuel Use and Risk of Adverse Pregnancy Outcomes: A Systematic Review and Meta-Analysis of the Empirical Evidence. *PLoS One* 9 (12): e113920.

Arkes, H.R., and C. Blumer. 1985. The Psychology of Sunk Cost. *Organizational Behavior and Human Decision Processes* 35 (1): 124–40.

Ashraf, N., J. Berry, and J.M. Shapiro. 2010. Can Higher Prices Stimulate Product Use? Evidence from a Field Experiment in Zambia. *American Economic Review* 100 (5): 2383–413.

Bailis, R., R. Drigo, A. Ghilardi, and O. Masera. 2015. The Carbon Footprint of Traditional Woodfuels. *Nature Climate Change* 5 (3): 266–72.

Barriga, A., and N. Fiala. 2018. The Supply Chain for Seed in Uganda: Where Does It All Go Wrong? Ruhr Economic Papers, No. 754.

Bates, M.A., R. Glennerster, K. Gumede, and E. Duflo. 2012. The Price Is Wrong. *Field Actions Science (FACTS) Report, Special Issue* 4: 30–7.

Becker, G.M., M.H. DeGroot, and J. Marschak. 1964. Measuring Utility by a Single-Response Sequential Method. *Behavioral Science* 9 (3): 226–32.

Beltramo, T., G. Blalock, D.I. Levine, and A.M. Simons. 2015. The Effect of Marketing Messages and Payment over Time on Willingness to Pay for Fuel-Efficient Cookstoves. *Journal of Economic Behavior & Organization* 118: 333–45.

Beltramo, T., and D.I. Levine. 2013. The Effect of Solar Ovens on Fuel Use, Emissions and Health: Results from a Randomised Controlled Trial. *Journal of Development Effectiveness* 5 (2): 178–207.

Bensch, G., and J. Peters. 2013. Alleviating Deforestation Pressures? Impacts of Improved Stove Dissemination on Charcoal Consumption in Urban Senegal. *Land Economics* 89 (4): 676–98.

———. 2015. The Intensive Margin of Technology Adoption—Experimental Evidence on Improved Cooking Stoves in Rural Senegal. *Journal of Health Economics* 42: 44–63.

———. 2017. Enablers of Strong Cookstove Sales through a Purchase Offer Approach in Rural Senegal—An Explorative Analysis. *Boiling Point* 69: 6–9.

Bensch, G., M. Grimm, and J. Peters. 2015. Why Do Households Forego High Returns from Technology Adoption—Evidence from Improved Cook Stoves in Burkina Faso. *Journal of Economic Behavior & Organization* 116: 187–205.

Ben Yishay, A., A. Fraker, R. Guiteras, G. Palloni, N.B. Shah, S. Shirrell, and P. Wang. 2017. Microcredit and Willingness to Pay for Environmental Quality: Evidence from a Randomized-

Controlled Trial of Finance for Sanitation in Rural Cambodia. *Journal of Environmental Economics and Management* 86: 121–40.

Berry, J., G. Fischer, and R.P. Guiteras. 2019. Eliciting and Utilizing Willingness to Pay: Evidence from Field Trials in Northern Ghana. *Journal of Political Economy*. in press.

Beyene, A.D., R.A. Bluffstone, S. Dissanayake, Z. Gebreegziabher, P. Martinsson, A. Mekonnen, and M. Toman. 2015a. Can Improved Biomass Cookstoves Contribute to REDD+ in Low-Income Countries? Evidence from a Controlled Cooking Test Trial with Randomized Behavioral Treatments. World Bank Policy Research Working Paper, No. 7394.

Beyene, A.D., R. Bluffstone, P. Martinson, and A. Mekonnen. 2015b. The Improved Biomass Stove Saves Wood, But How Often Do People Use It? Evidence from a Randomized Treatment Trial in Ethiopia. World Bank Policy Research Working Paper, No. 7297.

Brooks, N., V. Bhojvaid, M. Jeuland, J. Lewis, O. Patange, and S. Pattanayak. 2016. How Much Do Alternative Cookstoves Reduce Biomass Fuel Use? Evidence from North India. *Resource and Energy Economics* 43: 153–71.

Bruce, N., M.K. Dherani, J.K. Das, K. Balakrishnan, H. Adair-Rohani, Z.A. Bhutta, and D. Pope. 2013. Control of Household Air Pollution for Child Survival: Estimates for Intervention Impacts. *BMC Public Health* 13 (Suppl. 3): S8.

Burnett, R.T., C.A. Pope, M. Ezzati, C. Olives, S.S. Lim, S. Mehta, H.H. Shin, et al. 2014. An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. *Environmental Health Perspectives* 122 (4): 397–403.

Cameron, A.C., J.B. Gelbach, and D.L. Miller. 2008. Bootstrap-Based Improvements for Inference with Clustered Errors. *Review of Economics and Statistics* 90 (3): 414–27.

Cillier, J., O. Dube, and B. Siddiqi. 2015. The White-Men Effect: How Foreigner Presence Affects Behavior in Experiments. *Journal of Economic Behavior & Organization* 118: 397–414.

Cohen, J., P. Dupas, and S. Schaner. 2015. Price Subsidies, Diagnostic Tests, and Targeting of Malaria Treatment: Evidence from a Randomized Controlled Trial. *American Economic Review* 105 (2): 609–45.

Cohen, J., and P. Dupas. 2010. Free Distribution or Cost-Sharing? Evidence from a Ran-Domized Malaria Prevention Experiment. *Quarterly Journal of Economics* 125 (1): 1–45.

Cole, S.A., D. Stein, and J. Tobacman. 2014. Dynamics of Demand for Index Insurance: Evidence from a Long-Run Field Experiment. *American Economic Review: Papers and Proceedings* 104 (5): 284–90.

Dherani, M., D. Pope, M. Mascarenhas, K.R. Smith, M. Weber, and N. Bruce. 2008. Indoor Air Pollution from Unprocessed Solid Fuel Use and Pneumonia Risk in Children Aged under Five Years: A Systematic Review and Meta-Analysis. *Bulletin of the World Health Organization* 86: 390–8.

Dupas, P. 2014. Short-Run Subsidies and Long-Run Adoption of New Health Products: Evidence from a Field Experiment. *Econometrica* 82 (1): 197–228.

Ezzati, M., and D.M. Kammen. 2002. Household Energy, Indoor Air Pollution, and Health in Developing Countries: Knowledge Base for Effective Interventions. *Annual Review of Environment and Resources* 27: 233–70.

Fischer, G., D. Karlan, M. McConnell, and P. Raffler. 2014. To Charge or Not to Charge: Evidence from a Health Products Experiment in Uganda. National Bureau of Economic Research (NBER) Discussion Paper, No. 20170.

Fitzgerald, J., P. Gottschalk, and R.A. Moffitt. 1998. An Analysis of Sample Attrition in Panel Data: The Michigan Panel Study of Income Dynamics. *Journal of Human Resources* 33 (2): 251–99.

Gebreegziabher, Z., A.D. Beyene, R. Bluffstone, P. Martinsson, A. Mekonnen, and M.A. Toman. 2018. Fuel Savings, Cooking Time and User Satisfaction with Improved Biomass Cookstoves: Evidence from Controlled Cooking Tests in Ethiopia. *Resource and Energy Economics* 52: 173–85.

Gill, P. 2013. *Working with Local People to Identify Tree Services, Deforestation Trends, and Strategies to Combat Deforestation: A Case Study from Senegal's Peanut Basin*. Thesis for Master's of Forest Resources, University of Washington.

Gregory, R., S. Lichtenstein, and P. Slovic. 1993. Valuing Environmental Resources: A Constructive Approach. *Journal of Risk and Uncertainty* 7 (2): 177–97.

Grieshop, A.P., J.D. Marshall, and M. Kandlikar. 2011. Health and Climate Benefits of Cookstove Replacement Options. *Energy Policy* 39 (12): 7530–42.

Grimm, M., A. Munyehirwe, J. Peters, and M. Sievert. 2017. A First Step Up the Energy Ladder? Low Cost Solar Kits and Household's Welfare in Rural Rwanda. *World Bank Economic Review* 31 (3): 631–49.

Grimm, M., L. Lenz, J. Peters, and M. Sievert. 2018. Demand for Off-Grid Solar Electricity—Experimental Evidence from Rwanda. Ruhr Economic Papers, No. 745.

Guiteras, R.P., D.I. Levine, S.P. Luby, T.H. Polley, K. Khatun-e-Jannat, and L. Unicomb. 2016. Disgust, Shame, and Soapy Water: Tests of Novel Interventions to Promote Safe Water and Hygiene. *Journal of the Association of Environmental and Resource Economists* 3 (2): 321–59.

Hanna, R., E. Duflo, and M. Greenstone. 2016. Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. *American Economic Journal: Economic Policy* 8 (1): 80–114.

Hoffmann, V. 2009. Intra-Household Allocation of Free and Purchased Mosquito Nets. *American Economic Review* 99 (2): 236–41.

Hosgood, H.D., P. Boffetta, S. Greenland, Y.-C.A. Lee, J. McLaughlin, A. Seow, E.J. Duell, et al. 2010. In-Home Coal and Wood Use and Lung Cancer Risk: A Pooled Analysis of the International Lung Cancer Consortium. *Environmental Health Perspective* 118 (12): 1743–7.

Jagger, P., and C. Jumbe. 2016. Stoves or Sugar? Willingness to Adopt Improved Cookstoves in Malawi. *Energy Policy* 92: 409–19.

Jamison, D.T., L.H. Summers, G. Alleyne, K.J. Arrow, S. Berkley, A. Binagwaho, F. Bustreo, et al. 2013. Global Health 2035: A World Converging within a Generation. *Lancet* 382 (9908): 1898–955.

Jetter, J., Y. Zhao, K.R. Smith, B. Khan, T. Yelverton, P. DeCarlo, and M.D. Hays. 2012. Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. *Environmental Science & Technology* 46 (19): 10827–34.

Jeuland, M.A., V. Bhojvaid, A. Kar, J.J. Lewis, O. Patange, S.K. Pattanayak, N. Ramanathan, I.H. Rehman, J.S. Tan Soo, and V. Ramanathan. 2015. Preferences for Improved Cook Stoves: Evidence from Rural Villages in North India. *Energy Economics* 52: 287–98.

Köszegi, B., and M. Rabin. 2006. A Model of Reference-Dependent Preferences. *Quarterly Journal of Economics* 121 (4): 1133–65.

Kremer, M., and E. Miguel. 2007. The Illusion of Sustainability. *Quarterly Journal of Economics* 122 (3): 1007–65.

Kumar, P., R.K. Rao, and N.H. Reddy. 2016. Sustained Uptake of LPG as Cleaner Cooking Fuel in Rural India: Role of Affordability, Accessibility, and Awareness. *World Development Perspectives* 4: 33–7.

Krishnan, P., and M. Patnam. 2013. Neighbors and Extension Agents in Ethiopia: Who Matters More for Technology Adoption? *American Journal of Agricultural Economics* 96 (1): 308–27.

Lacey, F.G., D.K. Henze, C.J. Lee, A. van Donkelaar, and R.V. Martin. 2017. Transient Climate and Ambient Health Impacts Due to National Solid Fuel Cookstove Emissions. *Proceedings of the National Academy of Sciences* 114 (6): 1269–74.

Langbein, J., J. Peters, and C. Vance. 2017. Outdoor Cooking Prevalence in Developing Countries and Its Implication for Clean Cooking Policies. *Environmental Research Letters* 12 (11): 115008.

Levine, D.I., T. Beltramo, G. Blalock, C. Cotterman, and A. Simons. 2018. What Impedes Efficient Adoption of Products? Evidence from Randomized Sales Offers for Fuel-Efficient Cookstoves in Uganda. *Journal of the European Economic Association* 16 (6): 1850–80.

Lewis, J.J., and S.K. Pattanayak. 2012. Who Adopts Improved Fuels and Cookstoves? A Systematic Review. *Environmental Health Perspectives* 120 (5): 637–45.

Lybbert, T.J., N. Magnan, D.J. Spielman, A.K. Bhargava, and K. Gulati. 2018. Targeting Technology to Increase Smallholder Profits and Conserve Resources: Experimental Provision of Laser Land-Leveling Services to Indian Farmers. *Economic Development and Cultural Change* 66 (2): 265–306.

Luoto, J., M. Mahmud, J. Albert, S. Luby, N. Najnin, L. Unicomb, and D.I. Levine. 2012. Learning to Dislike Safe Water Products: Results from a Randomized Controlled Trial of the Effects of Direct and Peer Experience on Willingness to Pay. *Environmental Science & Technology* 46 (11): 6244–51.

Lusk, J.L., J. Fox, T. Schroeder, J. Mintert, and M. Koohmaraie. 2001. In-Store Valuation of Steak Tenderness. *American Journal of Agricultural Economics* 83 (3): 539–50.

Maertens, A., and C.B. Barrett. 2012. Measuring Social Networks' Effects on Agricultural Technology Adoption. *American Journal of Agricultural Economics* 95 (2): 353–9.

Martin, II, W.J., R.I. Glass, J.M. Balbus, and F.S. Collins. 2011. A Major Environmental Cause of Death. *Science* 334 (6053): 180–1.

McCracken, J.P., G.A. Wellenius, G.S. Bloomfield, R.D. Brook, H.E. Tolunay, D.W. Dockery, C. Rabadan-Diehl, W. Checkley, and S. Rajagopalan. 2012. Household Air Pollution from Solid Fuel Use—Evidence for Links to CVD. *Global Heart* 3: 223–34.

Mobarak, A.M., P. Dwivedi, R. Bailis, L. Hildemann, and G. Miller. 2012. Low Demand for Nontraditional Cookstove Technologies. *Proceedings of the National Academy of Sciences of the United States of America* 109 (27): 10815–20.

Morey, M. 2016. Preferences and the Home Bias in Trade. *Journal of Development Economics* 121: 24–37.

Myers, S.S., L. Gaffikin, C.D. Golden, R.S. Ostfeld, K.H. Redford, T.H. Ricketts, W.R. Turner, and S.A. Osofsky. 2013. Human Health Impacts of Ecosystem Alteration. *Proceedings of the National Academy of Sciences* 110 (47): 18753–60.

Omotilewa, O.J., J. Ricker-Gilbert, and J.H. Ainembabazi. 2019. Subsidies for Agricultural Technology Adoption: Evidence from a Randomized Experiment with Improved Grain Storage Bags in Uganda. *American Journal of Agricultural Economics*.

Pattanayak, S.K., M.A. Jeuland, J. Lewis, F. Usmani, V. Bhojvaid, N. Brooks, A. Kar, et al. 2019. Experimental Evidence on Promotion of Electric and Improved Biomass Cookstoves. *Proceedings of the National Academy of Sciences (PNAS):* in press.

Peters, J., J. Langbein, and G. Roberts. 2018. Generalization in the Tropics–Development Policy, Randomized Controlled Trials, and External Validity. *World Bank Research Observer* 33 (1): 34–64.

Plott, C.R., and K. Zeiler. 2005. The Willingness to Pay–Willingness to Accept Gap, the "Endowment Effect", Subject Misconceptions, and Experimental Procedures for Eliciting Valuations. *American Economic Review* 95 (3): 530–45.

Po, J.Y.T., J.M. FitzGerald, and C. Carlsten. 2011. Respiratory Disease Associated with Solid Biomass Fuel Exposure in Rural Women and Children: Systematic Review and Meta-Analysis. *Thorax* 66 (3): 232–9.

Pope, C.A., R.T. Burnett, M.C. Turner, A. Cohen, D. Krewski, M. Jerrett, S.M. Gapstur, and M.J. Thun. 2011. Lung Cancer and Cardiovascular Disease Mortality Associated with Ambient Air Pollution and Cigarette Smoke: Shape of the Exposure-Response Function. *Environmental and Health Perspectives* 119 (11): 1616–21.

Putti, V.R., M. Tsan, S. Mehta, and S. Kammila. 2015. The State of the Global Clean and Improved Cooking Sector. ESMAP Technical Paper, No. 007/15.

Ramanathan, V., and G. Carmichael. 2008. Global and Regional Climate Changes Due to Black Carbon. *Nature Geoscience* 1 (4): 221–7.

Rosa, G., F. Majorin, S. Boisson, C. Barstow, M. Johnson, M. Kirby, F. Ngabo, E. Thomas, and T. Clasen. 2014. Assessing the Impact of Water Filters and Improved Cook Stoves on Drinking Water Quality and Household Air Pollution: A Randomised Controlled Trial in Rwanda. *PLoS One* 9 (3): e91011.

Rosenbaum, J., E. Derby, and K. Dutta. 2015. Understanding Consumer Preference and Willingness to Pay for Improved Cookstoves in Bangladesh. *Journal of Health Communication* 20 (sup1): 20–7.

Schlag, N., and F. Zuzarte. 2008. Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature. Stockholm Environment Institute Working Paper, No. 8.

Shindell, D., J.C.I. Kuylenstierna, E. Vignati, R. van Dingenen, M. Amann, Z. Klimont, S.C. Anenberg, et al. 2012. Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security. *Science* 335 (6065): 183–9.

Simon, G.L., R. Bailis, J. Baumgartner, J. Hyman, and A. Laurent. 2014. Current Debates and Future Research Needs in the Clean Cookstove Sector. *Energy for Sustainable Development* 20: 49–57.

Smith, K.R., N. Bruce, K. Balakrishnan, H. Adair-Rohani, J. Balmes, Z. Chafe, M. Dherani, H.D. Hosgood, et al. 2014. Millions Dead: How Do We Know and What Does It Mean? Methods Used in the Comparative Risk Assessment of Household Air Pollution. *Annual Review of Public Health* 35: 185–206.

Tarozzi, A., A. Mahajan, B. Blackburn, D. Kopf, L. Krishnan, and J. Yoong. 2014. Micro-Loans, Insecticide-Treated Bednets, and Malaria: Evidence from a Randomized Controlled Trial in Orissa, India. *American Economic Review* 104 (7): 1909–41.

Usmani, F., J. Steele, and M. Jeuland. 2017. Can Economic Incentives Enhance Adoption and Use of a Household Energy Technology? Evidence from a Pilot Study in Cambodia. *Environmental Research Letters* 12 (3): 035009.

van der Kroon, B., R. Brouwer, and P.J. van Beukering. 2014. The Impact of the Household Decision Environment on Fuel Choice Behavior. *Energy Economics* 44: 236–47.

van der Werf, G.R., D.C. Morton, R.S. DeFries, J.G.J. Olivier, P.S. Kasibhatla, R.B. Jackson, G.J. Collatz, and J.T. Randerson. 2009. CO_2 Emissions from Forest Loss. *Nature Geoscience* 2 (11): 737–8.

Vickrey, W. 1961. Counterspeculation, Auctions, and Competitive Sealed Tenders. *Journal of Finance* 16 (1): 8–37.

Yu, F. 2011. Indoor Air Pollution and Children's Health: Net Benefits from Stove and Behavioral Interventions in Rural China. *Environmental and Resource Economics* 50 (4): 495–514.

Wiedinmyer, C., K. Dickinson, R. Piedrahita, E. Kanyomse, E. Coffey, M. Hannigan, R. Alirigia, and A. Oduro. 2017. Rural–Urban Differences in Cooking Practices and Exposures in Northern Ghana. *Environmental Research Letters* 12 (6): 065009.

World Bank. 2017. *Global Tracking Framework 2017: Progress towards Sustainable Energy*. Washington DC: World Bank.