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Evidence from Improved Cook Stoves in Burkina Faso

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#498

Imprint

Ruhr Economic Papers

Published by

Ruhr-Universität Bochum (RUB), Department of Economics
Universitätsstr. 150, 44801 Bochum, Germany

Technische Universität Dortmund, Department of Economic and Social Sciences
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Editors

Editorial Office

Ruhr Economic Papers #498

Responsible Editor: Manuel Frondel

ISSN 1864-4872 (online) – ISBN 978-3-86788-571-3

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Bibliografische Informationen der Deutschen Nationalbibliothek

Die Deutsche Bibliothek verzeichnet diese Publikation in der deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über: *http://dnb.d-nb.de* abrufbar.

http://dx.doi.org/10.4419/86788571
ISSN 1864-4872 (online)
ISBN 978-3-86788-571-3

Gunther Bensch, Michael Grimm, and Jörg Peters[1]

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Abstract

Around 3 billion people in developing countries rely on woodfuels for their daily cooking needs with profound negative implications for their workload, health, and budget as well as the environment. Improved cookstove (ICS) technologies in many cases appear to be an obvious solution. Despite continuous efforts of the international community to disseminate ICS, take up rates in most developing countries are strikingly low. In this paper, we examine the reasons for (non-)adoption of a very simple ICS in urban Burkina Faso. As a first result, we find that ICS users save between 20 and 30 percent of fuels compared to traditional stoves making the investment a very profitable one. Nonetheless, adoption rates are low at a mere 10 percent. It turns out that the major deterrent of adoption are the upfront investment costs – which are much more important than access to information, taste preferences, or the woman's role in the household. These findings suggest that more direct promotion strategies such as subsidies would help the household to overcome its liquidity constraints and hence improve adoption rates.

JEL Classification: D01, D12, D80, O33, Q56

Keywords: Household technology adoption; liquidity constraints; weak beliefs; norms and traditions; energy access; Sub-Saharan Africa

August 2014

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1 Gunther Bensch, RWI; Michael Grimm, University of Passau, Erasmus University of Rotterdam, and IZA; Jörg Peters, RWI, and AMERU, University of the Witwatersrand, Johannesburg, South Africa. *– The data underlying this research was collected for an impact evaluation commissioned by the Policy and Evaluation Department of the Ministry of Foreign Affairs of the Netherlands (IOB). We particularly thank Steffi Hamann for her keen support in the implementation of the field work. We would like to thank Willem Cornelissen, Katharina Peter, Luca Tasciotti, and Maximiliane Sievert for valuable input and comments as well as Ralf Kossmann for research assistance. Moreover we thank seminar participants at the University of Oxford, the University of Maastricht as well as participants of the Development Economics Conference 2013 of the German Economic Association (VfS-AEL) in Munich and the World Congress of Environmental and Resource Economics 2014 in Istanbul for their comments and suggestions.* *– All correspondence to: Michael Grimm, University of Passau, Innstr. 29, R. 158, 94032 Passau, Germany, e-mail: michael.grimm@uni-passau.de*

1. Introduction

Firewood and charcoal are the primary cooking fuels for poor people in developing countries. A common feature of biomass users is that the technology they have access to – often not more than three stones to support the cooking pot – is characterized by a low efficiency. Efficiency-enhancing improved cook stoves (ICS) have long been the evident instrument of policy makers to counter the wasteful and unhealthy use of biomass resources that goes along with traditional cooking. Furthermore, biomass usage for cooking is responsible for a considerable share of climate relevant emissions (Martin et al. 2011, Shindell et al. 2012). It is in this context that the United Nations set out the Sustainable Energy for All initiative with the ambitious goal of globally universal adoption of clean cooking stoves and electricity by 2030. A multitude of ICS promotion projects are implemented by various donor organisations and national governments. The currently favoured dissemination strategy is geared towards the establishment of sustainable markets by intervening on the demand side through awareness and marketing campaigns and on the supply side through trainings of small-scale producers (see Martin et al., 2011).

In spite of these efforts, ICS have not yet made inroads into households in developing countries. In particular in Africa, take-up rates are generally very low and even market based programs have difficulties in achieving sustainable usage in their target areas. One obvious reason might be that ICS simply do not always yield the benefits they promise. In fact, the academic literature shows an ambiguous picture with some promising evidence (Adrianzen, 2013, Bensch and Peters, 2013; Bensch and Peters, 2014; Smith-Sivertsen et al., 2009; Smith-Sivertsen et al., 2004; Smith et al., 2011), contrasted by very sobering examples that show that not all ICS can be expected to decrease woodfuel consumption and health burden (see Burwen and Levine, 2012, Hanna et al., 2012, Nepal et al. 2010). Little is known about other reasons that might discourage people from obtaining and using ICS. Mobarak et al. (2012) examine ICS adoption in Bangladesh and also observe low take-up rates. They find that monetary reasons and liquidity constraints are much more important in driving the decision on which stove to use as compared to health considerations. As a way forward for both future research and ICS promotion policy they call for designing cheaper cookstoves and disseminating ICS that are geared towards fuel savings in areas in which fuels are not easily or cheaply available.

The present paper steps into this research gap by examining the reasons for why people adopt or do not adopt a very simple ICS that is designed to achieve fuel savings and that is easy to use for the households. The ICS under research is disseminated by the Government of Burkina Faso together with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in the two major cities of the country, Ouagadougou and Bobo-Dioulasso. The analysis is based on a representative survey conducted in 2011 among 1,473 households in these two cities. The ICS is a low-cost and maintenance-free portable metal stove. It is produced in a fairly standardized way by local whitesmiths in their workshops and is marketed at a retail price of between 4 and 7 US$. This is also the price that has been paid by the ICS users in our sample. According to lab tests, so called controlled cooking tests

(CCT) that were conducted by the program at the beginning of the dissemination activities, the ICS is expected to save between 29 and 43 percent of firewood compared to the three-stone stove. As a first step of our analysis, we conduct a real-world usage evaluation of the woodfuel savings that ICS users actually achieve and compare this to the CCT results. The difference between savings rates obtained in CCTs and in our study reflects the behavioural component linked to technology adoption. Efficiency gains that are technically possible can rarely be expected to materialize in full in the field. In our specific case, stove users in the real world may do other things simultaneously while cooking, they may have incomplete knowledge on how to use the stove optimally, and they may not correctly maintain the stove or simply cook other meal types not tested in the CCT. In addition, not all ICS adopters switch from three stone stoves, the most inefficient traditional stove that was used as reference stove in the CCT, to an ICS but also from traditional metal stoves.

Using our survey data, we find actual saving rates between 20 and 27 percent, which is less than the rates observed in the CCT but still considerable. Even these actual saving rates make the investment into this ICS highly profitable. Nonetheless, the take-up rates in the two cities are surprisingly low at a mere 10 percent of all targeted households. In a second step, we therefore examine the drivers and barriers of adoption taking into account the findings of Mobarak et al. (2012), but as well factors that are usually put forward by development practitioners such as cultural traits and the role of women in the decision process on how to use the household budget.

Beyond the importance of the improved cooking sector, explaining low take-up rates in the presence of high returns is of general relevance in development economics, as they are plenty of examples where investments with high returns are not realized (De Mel et al., 2008; Duflo et al., 2011; Cohen and Dupas, 2010; Grimm and Treibich, 2014). Explanations for such behaviour include capital market imperfections and risk, as well as norms and traditions. We find that in fact financial constraints are the most important barrier to adoption, followed by information asymmetries, i.e. people are either unaware of the ICS' existence or not convinced by their returns. Unlike what is frequently spread as conventional wisdom, cultural traits do not seem to play an important role. Furthermore, low adoption has partly to do with imitations of ICS, which are not as efficient as the original ones, but perform also better than a traditional cook stove. Investment costs for these imitated ICS lie between traditional stoves and ICS. The emergence of the imitated ICS seems to be a spillover of the program under study.

The remainder of this paper is organized as follows. In Section 2 the stove intervention is presented along with the broader context in Burkina Faso. In Section 3 the evaluation methodology is described including a presentation of the data. In Section 4 we discuss our findings with respect to woodfuel savings and put them in perspective based on a relatively simple amortisation analysis. In Section 5 we explore the determinants of improved stove adoption, first theoretically and empirically. In Section 6 we conclude.

2. Context

The vast majority of primary energy supply in Burkina Faso is provided by woodfuels (83 percent), which is mostly used for cooking purposes. The most recent available census data for 2006 reports a national average of 88.2 percent of all households using firewood and 3.6 percent using charcoal as the main cooking energy. Even in the capital Ouagadougou, these shares amount to 56.5 percent and 10.8 percent respectively. LPG is the primary source for only 22.9 percent and electricity for a mere 0.8 percent of all households in the city (Ministère de l'Economie et des Finances, 2009). While in rural areas, firewood is mostly collected imposing a heavy workload on households, woodfuels are purchased in urban areas. As a consequence, cooking related expenditures make up a considerable share of households' expenditures.

Apart from LPG and electric stoves, three types of woodfuel stoves suitable for household use can be found in urban Burkina Faso. The most inefficient ones are self-constructed three-stone open fires used with firewood. In addition, simple metal stoves for both firewood and charcoal usage exist. The most common type is the *Malagasy* that is also available in several other West African countries.

The ICS disseminated by the Government of Burkina Faso and GIZ is called Roumdé, of which three versions exist, one that can be used only with firewood and two that can be used with both charcoal and firewood (see Table 1 for pictures and key attributes of the three Roumdé types). To put the Roumdé stove into perspective in the international movement to promote cleaner or more efficient cook stoves, it is clearly at the very lower end of the spectrum of improved biomass stoves. For example, they are uniquely made of metal and do not dispose of ceramic inlay components that better store the heat. Furthermore, they do not have a chimney or improve the combustion process in a way that would substantially bring down particulate matter or carbon monoxide emissions. While at the upper end of the spectrum, advanced biomass stoves exist that can reduce such emissions down to zero, the Roumdé is principally conceived only to save woodfuel. Efficiency gains have so far only been determined in CCTs, i.e. field laboratory tests in which local women cook typical meals under supposed day-to-day conditions and only for the firewood version of the Roumdé. The comparison in these CCT was the traditional three-stone stove. According to these tests, the Roumdé stoves are expected to economize between 29 and 43 percent of firewood, depending on the stove model (Sanogo, 2008). For imitated ICS and Malagasy stoves, no such tests have been conducted.

Spurred by donor support, the development of improved stove models in Burkina Faso dates back to the late 1970's and led to the establishment of a national improved stoves dissemination programme in 1984 as the main intervention in the sector including improved three-stone stoves and improved metal stoves (Simeni Tchuinte, 2007; ESMAP, 1991). Yet, no proper commercial market for ICS had evolved, because the public sector took over an intermediary role in the market that was not institutionalized sustainably. This dominant role of the public sector precluded the establishment of business relations between suppliers of raw material, producers, and retailers.

Table 1: Woodfuel cooking stoves for household use in Burkina Faso

1. Three-stones

fuel: firewood

classical model

improved version

	classical model	improved version
market share:	*81 %*	*19 %*

2. Malagasy, traditional metal stove *

charcoal model

firewood model

	charcoal model	firewood model
market share:	*65 %*	*35 %*
market price:	*600 – 2000 CFA F*	*500 – 1500 CFA F*

3. Improved metal stoves

Ouaga Métallique

Burkina Mixte

Multimarmite

	Ouaga Métallique	Burkina Mixte	Multimarmite
	fuel: firewood	*fuel: firewood and charcoal*	
market share:	*20 %*	*13 %*	*67 %*
market price:			
- ICS:	*1500 – 2500 CFA F (depending on model size)*		
- imitated:	*1000 – 2000 CFA F*		

Note: * Strictly speaking, only the charcoal model can count as what internationally is called a Malagasy. Nevertheless, we use the same name for the firewood model in accordance to the terminology used in the surveyed areas.

In addition, no market-based pricing was in place: ICS prices were fixed which implied low margins that generally discouraged ICS production. Instead, ICS sales were mainly triggered by temporary publicly funded rebate campaigns with 40 to 50 percent discounts. No durable subsidy scheme was established. As a consequence, ICS have largely disappeared after this government programme ended simultaneously with other ICS interventions in the early 1990's. Former ICS producers adapted to the phase out of ICS promotion by lowering quality and prices, because in many cases neither they nor users were aware of differences in quality and woodfuel consumption between different stove models (higher-quality materials are used and the stoves are generally better manufactured[2]) The differences are hard to detect for regular customers.

In mid-2005, the programme *"Foyers Améliorés du Burkina Faso"* (FAFASO) started to reintroduce the three ICS models in Ouagadougou and Bobo-Dioulasso. With 1.6 and 0.5 million inhabitants, respectively, the two cities account for about 15 percent of the country's total population. FAFASO supports the dissemination of ICS through the training of stove producing whitesmiths and potters complemented by promotion activities among potential customers since mid-2005. The ICS are not additionally subsidized so that households pay cost covering prices. The rationale behind the intervention is to relieve households from the financial burden associated with charcoal and firewood consumption. As part of the relaunch, FAFASO introduced an effective stove quality certification system for which a special label called 'Roumdé' has been designed. It is affixed to each stove as a sticker showing a red humanized smiling stove and the label is consistently used in all marketing channels including selling points and TV and radio spots. These activities respond to FAFASO's diagnosis on former unsuccessful stove dissemination programs in the country that were found to be unsustainable because the quality of improved stoves deteriorated after the programs had ended.

Next to the Roumdé, cheaper stoves coexist, which resemble the Roumdé stoves but do not carry the Roumdé label, because they do not exhibit all the mentioned quality features. In this paper, we refer to these stoves as 'imitated ICS', whereas we synonymously use the terms Roumdé and ICS for the certified ICS throughout the paper. The quality differences are also reflected in prices: While households usually pay between 1,000 and 2,000 CFA Francs (equivalent to 4.90 to 9.80 intl. $ PPP)[3] for an imitated ICS and thereby only marginally more than for a Malagasy, the average price of a Roumdé stove is almost twice as high, with prices typically ranging between 2,000 to 3,500 CFAF. For comparison, at the time of the survey, average fuel costs of an urban household cooking a main dish on a traditional stove are around 150 FCFA if charcoal is used and tend to be higher if firewood is used, though prices may vary drastically.[4]

FAFASO is implemented by GIZ as part of the Energising Development program (EnDev) that is globally active in 24 countries. According to FAFASO, by the end of 2011 about 104,000 Roumdé stoves were in use in the country, taking into account that also good parts of the ICS sold in the cities diffuse to rural areas and are therefore not exclusively used by urban households.

[2] Notably, genuine ICS are bigger, have better efficiency-enhancing aerodynamic features and spacers ensure an optimal match of stove and cooking pot. For ICS models with doors, the doors are typically precisely customized which they are not in the case of imitated ICS.

[3] If not Intl. $ PPP but market the exchange rate is used for conversion this corresponds to about 2 to 4 US$.

[4] The price of firewood ranged between 35 and 100 CFAF per kg in Bobo-Dioulasso and Ouagadougou. Charcoal is more expensive (50 and 200 CFA F per kg).

3. The measurement of fuel savings

3.1 Identification strategy

In the first step of our analysis, the outcome of interest is woodfuel savings per stove application in kg. A stove application is typically used to cook a typical dish, which are, for example, rice or a sauce. A meal usually consists of more than one dish and, hence, involves more than one stove application. The two main woodfuels, firewood and charcoal, are analysed separately. Given the absence of data before the roll-out of the programme, the present analysis relies on cross-sectional comparison of ICS users and non-users. As with most observational studies, self-selection poses the main methodological challenge: certain characteristics that make households more inclined to buy and use an ICS may at the same time influence the extent of woodfuel savings and thereby bias the estimated impacts. Examples for such confounding factors are the educational level of the household head and household income or the number of persons cooked for and the type of dish being prepared.

Considering these potential biases, special care has to be taken when defining identification strategies to derive a counterfactual situation and when selecting variables that control for household-specific characteristics as well as cooking patterns. As will be shown in the descriptive statistics below, self-selection is much stronger among ICS users than among imitated ICS users. In order to hence rigorously estimate *woodfuel savings per dish* induced by ICS usage, we apply a special variant of matching based on propensity score weighted regressions as proposed by Hirano, Imbens and Ridder (2003) and further discussed in Hirano and Imbens (2001). The basic idea here is to combine a propensity score approach with an Ordinary Least Squares (OLS) regression-based specification in order to benefit from their respective advantages. The 'matching estimation' delivers propensity scores that are used to create weights for OLS regressions to increase comparability between the two assessed groups. In other words, among the non-users those observations get more weight that are more similar to the users. The regression-based approach accounts for covariates that might be correlated with both ICS ownership and the outcome of interest, most notably the particularly important dish-level covariates such as cooking duration of the dish, type of dish (e.g. rice or sauce) and whether the dish is prepared for breakfast, lunch or dinner.

Given the detail of available information that has been collected about households and dishes (see next section), potential unobservable sources of selection bias are limited to only a few suspects and hence we believe that our approach can deal well with possible selection effects. For example, women that have an intrinsic tendency to safe woodfuels may be both more likely to buy an ICS and be more economical in using woodfuels at the same time. In order to further reduce the threat of a selection bias, much effort has been put into scrutinizing the existence of such unobservable confounding differences by complementary qualitative key informant interviews.

Technically, the propensity scores are determined by means of a standard binary response model (probit) with covariates that are deemed not to be affected by the treatment given our cross-sectional framework without baseline data (see Rosenbaum, 1984; Harding, 2003). These propensity scores then enter a weight that is applied to an OLS regression. To attain the average treatment effect on the treated (ATT), this weight can be computed as outlined in Brunell and DiNardo (2004) for both treatment and control observations, denominated $\mu^{i\,=\,1}$ and μ^{C} respectively:

$$\mu_i^{\,T\,=\,1} = 1 \;\text{ and }\; \mu^{C} = \frac{Pr(T=1\,|X)}{1 - Pr(T=1\,|X)} \times \frac{p^{C}}{p^{T}}, \tag{1}$$

where p^T and p^C refer to the fraction of treatment and control observations, respectively, *Pr* stands for probability and the vector *X* for the covariates explaining uptake (ICS treatment *T*=1). As a benchmark, we also apply standard OLS without propensity score weighting.

3.2 Data

The present research is based on a specific household survey that we conducted between February and March 2011 in Ouagadougou and Bobo-Dioulasso. In order to get a representative picture of the intervention zones, we applied a two-stage random sampling procedure. Sample sizes in each location were chosen proportional to the respective population size. Residential sectors as first stage sampling units were drawn randomly from each of six different wealth strata ranging from poor over mixed to wealthy, which represent the socio-economic status of the respective resident population. This classification was based on an ad hoc assessment by local project staff, as sufficiently disaggregated census information was not available. It was further decided to exclude the very rich neighbourhood called 'Ouaga 2000' where about 5 percent of Ouagadougou's population live, mainly international expatriates and high government officials, who usually cook with electricity or LPG.

We initially envisaged interviewing around 1,500 households to have enough statistical power to detect reductions in 'woodfuel consumption per dish' as small as 15 percent.[5] This was likely to be sufficient, as the lab tests conducted by FAFASO suggested that savings could be expected to be substantially higher. In total 1,473 households were finally surveyed applying systematic random sampling in each selected sector. We oversampled ICS owners, since according to the FAFASO program the ICS penetration rate was at around 10 percent only. Hence, a purely random sampling would have yielded a very small sample size for ICS owners with obvious implications for the precision of estimates, while the number of controls would have been unnecessarily high. More specifically, we sampled for every third household without an ICS an additional ICS-using household from the same sector, whereas the household without an ICS was only asked for basic information on stove ownership. This information served to compute weighing factors to ensure the ex-post representativeness of our findings. All other 1,166 respondents (all ICS owners and two-thirds of non-

[5] The envisaged power and the statistical significance were set to conventional levels (beta=0.8, alpha=0.05) for a two sided test. Further parameters that affect the required sample size to meet these statistical requirements (e.g. before and after level and standard deviation of the impact indicator) were determined based on a comparable study in urban Senegal (see Bensch and Peters, 2013).

owners) were interviewed using a structured questionnaire with a focus on cooking behaviour and energy usage. The questionnaire also covers socio-economic aspects of the households' lives encompassing housing conditions, education, revenues, activities, assets as well as gender issues. Actual and imitated ICS look very similar at the first glance and, hence, enumerators were meticulously trained on differences in the design of the two stove types to distinguish them in case the Roumdé label was missing.

Our impact variables on woodfuel usage for cooking and all other cooking-related information were elicited from the person responsible for cooking - typically a women. She was asked to enumerate all stoves used for each meal throughout a typical day as well as to provide information on the individual dishes cooked on the respective stoves (cooking duration, number of persons cooked for etc.). For the woodfuel stoves, she was further asked to specify and show the amount of fuel used with that particular dish, which the enumerators who were equipped with weigh scales weighed then.

Complementary expert interviews, for example with stove producers and representatives of the surveyed sectors served to provide contextual information such as local habits that influence the ownership and use of different stove types or local developments in the woodfuel markets.

4. Fuel savings and return to adoption

4.1 Description of the sample

Table 2 shows basic socio-demographic and economic information by type of stove user. Four groups are compared: Households that only use LPG, ICS owners, imitated ICS owners and other ICS non-owners. As substantiated by these descriptive statistics, LPG-only households are already on a higher step of the energy ladder. For this reason, they will be excluded from the further analysis. Across the whole sampling population, the ICS penetration rate is 9.6 percent with only minor differences between Ouagadougou and Bobo-Dioulasso. This share is the same even among households who regularly use woodfuels. This contrasts heavily with the ownership of imitated ICS, which are owned by 63 percent of households in Bobo-Dioulasso and (only) 14 percent in Ouagadougou (not shown in Table 2). The type of stove used is correlated with education and income and wealth proxies. Wealthier and better educated households are more likely to use LPG and poorer and households with low levels of education rather use traditional stoves. A more profound analysis will follow in Section 5. The users of ICS and imitated ICS are somewhere in-between and are not substantially different with respect to these two dimensions.

Table 2: Basic household characteristics

	LPG-only users mean (sd)	ICS owners mean (sd)	owners of imitated ICS mean (sd)	other ICS non-owners mean (sd)
Household size	4.4*** (2.2)	6.4 (3.4)	6.6 (3.3)	7.1*** (3.7)
Household is located in Ouagadougou (in %)	97.5***	73.7	39.7***	87.6***
Hh's ethnicity is Mossi (in %)	58.5	63.4	45.1***	78.3***
Hh head is public employee (in %)	27.2***	16.7	11.1*	9.2***
Education of male (in %)	***			***
No formal education	10.0	29.6	37.8	39.5
Primary education	18.9	18.6	18.4	21.3
Secondary education and more	57.0	34.4	30.0	24.3
(No male in household)	14.1	17.5	16.9	15.0
Education of female (in %)	***			*
No formal education	12.9	44.0	47.6	50.7
Primary education	21.0	29.1	29.6	24.0
Secondary education and more	53.4	25.1	20.4	21.4
(No female in household)	12.7	1.8	2.3	3.9
Electricity in the house (in %)	91.4***	77.4	71.4	58.9***
Household has bank account (in %)	58.3***	43.2	31.8**	30.9***
Any woman is involved in decisions on household expenditures (in %)	39.9	34.2	27.8	33.9
Per capita monthly expenditure (in CFA F)	40,690*** (43,650)	25,690 (25,340)	23,290 (26,700)	20,360*** (18,300)
Number of observations (unweighted)	157	377	180	414
Share of total woodfuel users (unweighted, in %)	-	38.8	18.6	42.6
Share of total woodfuel users (weighted, in %)	-	38.8	19.9	41.3

Notes: Households who own an ICS and only cook with LPG belong to the LPG-only group, households who own an ICS and an imitated ICS at the same time belong to the ICS owner group etc.; the total number of observations is 1,128 due to 38 households with missing information on any of the listed variables; sd – standard deviation; asterisks indicate the significance level of differences in means between ICS and the respective stove type as determined by *t*- and *chi-2*-tests: * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Fafaso household survey 2011.

90 percent of ICS-owning households own no more than one ICS. Yet, stove ownership not necessarily translates into regular usage: 15 percent of ICS-owning households in Ouagadougou and 1 percent in Bobo-Dioulasso usually do not use the improved stove. Most of these households use the woodfuel ICS as backup in case of an LPG shortage. The vast majority of households can be said to use their ICS regularly for cooking. These shares are very similar for imitated ICS, for which even slightly less owners can be found that do not regularly cook on the stove. 28 percent of ICS users have used their improved stoves for less than 15 months at the time of the survey, whereas more than half use their ICS for at least two years and more than a third for at least three years. Considering that these figures refer to stoves still in use, the average actual stove lifetime is likely to clearly exceed the two years lifespan expected by the project.

Table 3 shows further stove- and cooking-related characteristics. In most urban households that use woodfuels, food is actually prepared twice a day and during times of economic distress, a family might even cook only once a day and warm up the leftovers for the remaining meals. Owners of ICS and imitated ICS show very similar stove use patterns. In contrast, the two groups differ significantly in their stove usage compared to the other two groups. ICS owners and imitated ICS owners own significantly more stoves and, taking all stove applications together, use them significantly more often to prepare hot dishes (21.9 to 23.4 compared to 17.5 times per week). Table 3 suggests that this difference is due to differences in the number of stoves that households own and thus the number of meals that are cooked on multiple stoves simultaneously instead of only on one stove. Both the frequency of cooking full meals and cooking with multiple stoves will be accounted for in our subsequent empirical analysis. Another consequence of different stoves and stove types being used simultaneously is that exclusive ICS usage can only be observed among 15 percent of ICS users. Finally, electric stoves can be found in 1.4 percent of households; they do not play an important role in household cooking in Burkina Faso.

Table 3: Stove- and cooking-related characteristics

	LPG-only users mean (sd)	ICS owners mean (sd)	owners of imitated ICS mean (sd)	other ICS non-owners mean (sd)
Stove usage frequency per week	14.5***	21.9	23.4*	17.5***
	(7.5)	(8.7)	(9.1)	(7.5)
ICS usage frequency per week		10.4	-	-
Number of stoves in household	1.7***	2.6	2.5*	2.0***
	(0.8)	(1.0)	(1.0)	(0.9)
Number of full meals cooked per day	1.22***	1.39	1.48	1.29***
	(0.44)	(0.58)	(0.65)	(0.48)
Most often used stove in household (in %)				
Three-stone stove	-	7.1	9.8	36.4***
Malagasy	-	11.6	15.3	45.0***
ICS	-	50.3	-	-
Imitated ICS	-	3.7	57.2***	-
LPG	100***	26.3	16.7***	18.6***
Type of fuel used in household (in %)				***
Firewood	-	19.1	23.2	37.6
Charcoal	-	12.2	13.9	10.9
Firewood and charcoal	-	25.0	27.9	20.7
LPG	100***	-	-	-
LPG and Woodfuels		43.7	35.0	30.8
Number of observations (households)	157	377	180	414
Share of meals prepared with more than one stove (in %)	3.0***	31.3	35.8	25.9**
Number of people meals are cooked for	4.3***	6.2	6.4	6.8***
	(2.2)	(3.4)	(3.2)	(3.5)
Number of observations (meals, unweighted)	349	933	455	863

Notes: sd – standard deviation; asterisks indicate the significance level of differences in means between ICS and the respective stove type as determined by *t*- and *chi-2*-tests: * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Fafaso household survey 2011.

Against this background of multiple stove usage, it is important to know which stove is replaced in case the household buys an ICS. If, for example, mostly three-stone stoves were replaced, savings potentials would be much higher than if Malagasy stoves were replaced. In the extreme case of replacing LPG, the woodfuel savings obviously would even be negative. Yet, the data on the stove and fuel types used of ICS owners and other ICS non-owners suggest that mostly woodfuel stoves are replaced by an ICS and that there are no indications for a switch from LPG to ICS.

4.2 Computation of the weights based on propensity scores

As explained in Section 3.1 we analyse woodfuel consumption per dish prepared on a cooking stove within a matching framework. To construct the weights needed for the balancing of users and non-users we run a probit model regressing the binary variable 'using a Roumdé' on basic socio-demographic household characteristics and housing characteristics. We selected variables that can, at least in the short term, be considered as not being affected by our treatment, i.e. Roumdé ownership, but are correlated with uptake and usage. These are all variables listed in Table 2 except for household expenditures (which are excluded as they could potentially be affected if reduced energy expenditures lead to higher savings). Based on the estimated parameters, we compute the propensity scores and the corresponding weights as described in Section 3.1. Table A1 in the appendix shows average characteristics of users and non-users of an ICS with and without propensity-score-based reweighing. It can be seen that the reweighing procedure leads to a sample that is fully balanced along these characteristics; none of the differences between the group of owners and non-owners is statistically significant anymore.[6] Hence, the weights will be used in the following to estimate the woodfuel savings that can be attributed to the usage of a Roumdé.

4.3 Fuel savings

The results of the dish level woodfuel savings regressions are shown in Table 4a and b. We present various specifications, always separately for dishes cooked with firewood and dishes cooked with charcoal. In each case, the consumption per dish of firewood and charcoal (in kg) is regressed on the type of stove used and dish-specific characteristics. We also control for location-specific effects using sector (i.e. neighbourhood) dummies and for the main household characteristics listed in Table 2 – again except for household expenditures. The woodfuel consumption is transformed in log such that the estimated coefficients can be interpreted as semi-elasticities. The R^2 ranges depending on the specification between 19 percent and 33 percent and hence explains a fair part of the variation in the dependent variable.

[6] Hotelling's T-squared test, which scrutinizes the differences in means for the joint set of all included covariates between the compared groups, shows a significant difference before the weighing (*p*-value 0.000), which vanishes completely after weighing (*p*-value 1.000).

Table 4a: Estimated impacts of ICS usage on woodfuel consumption in kg per dish

	Firewood OLS PS weighted (1)	Charcoal OLS PS weighted (2)
Dish variables		
Three-stone stove	Ref.	
Malagasy stove	-0.079 (0.32)	Ref.
ICS	-0.272*** (0.00)	-0.061 (0.48)
Imitated ICS	-0.178 (0.11)	0.148 (0.18)
Breakfast	Ref.	Ref.
Lunch	0.238** (0.02)	0.047 (0.66)
Dinner	0.221*** (0.01)	0.009 (0.91)
Only one full meal per day	0.217*** (0.00)	0.049 (0.59)
Side dish	-0.147* (0.05)	0.118 (0.20)
Quick dish (<30 min)	-0.538*** (0.00)	-0.636*** (0.00)
Several stoves used for the meal	-0.120* (0.09)	-0.320*** (0.00)
Fuel used for several dishes	0.044 (0.55)	0.061 (0.56)
Outdoor cooking	-0.024 (0.75)	0.093 (0.32)
Cook has at least secondary education	0.145* (0.07)	0.001 (0.99)
Number of adult equivalents meal is cooked for	0.049 (0.16)	0.047 (0.34)
Squared number of adult equivalents meal is cooked for	-0.001 (0.70)	-0.002 (0.58)
Household characteristics	yes	yes
Neighbourhood effects	yes	yes
Constant	0.543** (0.03)	-0.547 (0.11)
Number of observations (unweighted)	984	780
Number of households (unweighted)	667	514
1 stove	424	312
2 stoves	182	152
3 stoves	49	41
4 and more stoves	12	9
Absolute consumption (at covariate means)		
Three-stone stove	3.83 kg	-
Malagasy	3.53 kg	1.54 kg
Imitated ICS	3.15 kg	1.74 kg
ICS	2.79 kg	1.45 kg

Table continues next page

Table 4a *(... continued)*		
Breusch-Pagan (Heteroscedasticity)	0	0.292
t-Test ICS vs. Malagasy (*p*-value)	0.024**	0.478
t-Test ICS vs. Imitated ICS (*p*-value)	0.372	0.104
t-Test Imitated ICS vs. Malagasy (*p*-value)	0.406	0.184
Adjusted R-squared	0.215	0.193

Notes: * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. *p*-values in parentheses. Instead of household size, these estimations rely on more specific adult equivalent values. Due to economies of scale in fuel use for meal preparation, adult equivalents (see McKay and Greenwell, 2007) can be expected to influence woodfuel consumption in a non-linear decreasing way and, hence, also enter the equations in squared terms. Cluster effects within households are accounted for, i.e. the fact that some households prepare different dishes with different stoves and thus enter the estimation with several – presumably correlated - observations. All standards errors are estimated in a way that they are robust to potential heteroscedasticity, i.e. an increasing variance of the errors with the level of predicted woodfuel consumption. The Breusch-Pagan Test in the lower part of the table indicates that heteroscedasticity might be a problem in columns (1).
Source: Fafaso household survey 2011.

Table 4b: Woodfuel savings coefficients in kg for ICS and imitated ICS estimated in alternative specifications

	Firewood per capita	Charcoal per capita	Firewood	Charcoal	Firewood	Charcoal
	OLS PS weighted	OLS PS weighted	Basic OLS	Basic OLS	OLS PS weighted	OLS PS weighted
	(3)	(4)	(5)	(6)	(7)	(8)
Three-stone stove	Ref.		Ref.			
Malagasy stove	-0.081	Ref.	0.033	Ref.		
	(0.31)		(0.68)			
ICS	-0.243***	-0.081	-0.249***	-0.091	-0.053	-0.218
	(0.00)	(0.35)	(0.00)	(0.32)	(0.59)	(0.13)
Imitated ICS	-0.171	0.157	-0.177*	0.162	Ref.	Ref.
	(0.11)	(0.18)	(0.09)	(0.13)		
Metal stove model	no	no	no	no	yes	yes
Other controls			as in Table 4a			
Number of observations (unweighted)	959	753	984	780	314	387
t-Test ICS vs. Imitated ICS (*p*-value)	0.483	0.072*	0.495	0.053*	0.592	0.131
Adjusted R-squared	0.305	0.334	0.237	0.247	0.270	0.196

Notes: * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. *p*-values in parentheses.
Source: Fafaso household survey 2011.

Column (1) in Table 4a shows the results for dishes that are cooked on stoves using firewood. The reference stove is the three-stone stove, which consumes 3.8 kg per dish (if all other covariates in this regression are set to their average values). The results suggest that dishes that are prepared on an ICS consume roughly 27 percent less than a three-stone stove. The coefficient is significant at the 1 percent level. Given that one might suspect self-reported firewood consumption to be a rather noisy variable, this is a striking result. Also, the magnitude of the effect in monetary terms is high given the low investment costs of the Roumdé stove. The savings rate corresponds to monetary savings of approximately 75 FCFA per dish (in Ouagadougou). We will probe more into this in the amortisation analysis in Section 4.4. The savings, though, are slightly lower than in the CCT. The regression results for firewood consumption also suggest that the ICS is significantly more efficient than the Malagasy stove model (*p*-value of 0.02, see bottom of table). With an estimated coefficient of -0.08 for the

Malagasy stove, the ICS can be said to save about 20 percent relative to the Malagasy stove (50 FCFA per dish). The imitated ICS seems to save around 18 percent compared to the three-stone stove, with this difference being statistically significant at the 10 percent level. Even though the corresponding savings rate of the 'real' ICS is 50 percent higher than that of the imitated stove, the difference is statistically not significant (the corresponding *p*-value is 0.37, see bottom of table), which might be due to the relatively small subsample size.

In column (2), the regression is repeated for charcoal dishes. Given that charcoal is not used in three-stone stoves, the charcoal version of the Malagasy stove is now the reference stove. For these stoves the average consumption of charcoal is 1.54 kg and the savings rate amounts to 6 percent (15 FCFA per dish). The difference is not statistically significant, though (*p*-value 0.48). For imitated ICS, no savings but rather a higher charcoal consumption than that of the Malagasy is indicated (although the significance levels are above 10 percent). In consequence, the Roumdé charcoal ICS consume significantly less fuel than the imitated versions (as indicated by *p*-values between 7 and 13 percent).

All other coefficient signs are as expected. Both the results for firewood and charcoal are robust to the inclusion of a large set of control variables that account for cooking- and household-related characteristics and if the regressions are estimated measuring the woodfuel consumption in per capita terms (see model (3) and (4) in Table 4b) or if – instead of the PS-weighted OLS – non-weighted OLS is applied (see model (5) and (6) in the same table). The results are confirmed if we further include control variables for the three metal stove models for which both ICS and imitated ICS exist (see model (7) and (8) in Table 4b).

It is worth mentioning that the estimated saving rates per dish do not necessarily reflect the total woodfuel savings for the household, most importantly because not all dishes in the households' weekly diet are cooked on an ICS. Furthermore, households might adjust their cooking behaviour after the acquisition of a more efficient stove as cooking in general and cooking with woodfuels as compared to LPG becomes less expensive, referred to as 'rebound effect' in the energy economics literature (Frondel et al., 2008).

At this stage, given these findings, it is safe to conclude that the potential woodfuel savings that can be achieved with an ICS should be a strong incentive for households to invest in this technology. If it comes to the choice between a Roumdé and an imitated version the Roumdé seems to be the more efficient solution, in particular if households have a preference for charcoal over wood.

4.4 Returns to adoption

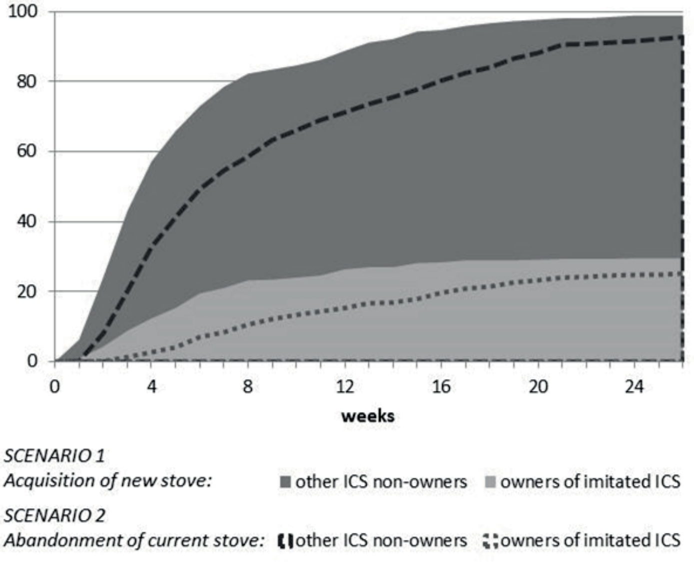
In a next step we relate the woodfuel savings to the investment costs for an ICS in a brief amortisation analysis. We conduct this analysis for the two woodfuel-using households without a Roumdé ICS, the *owners of imitated ICS* and the *other ICS non-owners*. It is important to emphasize that by focusing on woodfuel savings we only include private monetary returns in the short term, whereas potential returns in the long run (e.g. positive health effects related to less smoke exposure) or potential non-monetary returns (e.g. a relief in workload) are not taken into account. At least in the present case, firewood collection is virtually inexistent (less than 2 percent among woodfuel-using households) so that this factor does not need to be accounted for. Neither do we include potential public returns that might stem from a reduction in deforestation pressures. The idea behind our analysis is to examine the amortization calculation the household faces when confronted with the decision to invest into an ICS. It might constitute a conservative estimation in case households take further benefits like potential health effects into account. Moreover, we assume that fuel switching (e.g. from firewood to charcoal), rebound effects, or other dynamic adaptations do not occur.

In order to compute the returns to ICS adoption we distinguish two scenarios: a first scenario reflects the situation in which a household has to decide on acquiring a new stove, since a formerly used stove is broken or since the household needs an additional stove. The second scenario reflects the situation in which a household contemplates replacing an existing and still functioning stove by a new ICS. In this scenario the household has to weigh future savings induced by the ICS against the full price of the ICS and not just against the cost difference between an ICS and a non-ICS. This second scenario is of interest as many households explained the absence of ICS in their household by the fact that they already own other types of stoves and do not need an additional stove.

For both scenarios, we determine the amortization period accounting for household-specific stove and fuel usage patterns as well as stove and fuel-specific prices and savings rates as determined in the previous section. This information serves to identify for each household the pair of ICS model and traditional stove to be replaced that minimizes the amortization period of the investment. The resulting figure is the smallest number of weeks after which savings exceed costs. Since households differ in their usage patterns and wood prices are different at both locations, the time to amortization differs across households. Obviously, households that use their stove very often have shorter amortization periods than households that make less use of it. At the same time it leads to higher fuel savings when replacing a three-stones stove that is often used, but also implies a higher price difference to the ICS given the three-stones stove is for free.

Figure 1 shows the results for both scenarios where the shaded area represents all woodfuel-using households without a Roumdé in scenario 1 and the dotted lines refer to scenario 2. In both scenarios we distinguish owners of imitated ICS and owners of other non-ICS. It turns out that for more than half the households the ICS would already pay off after four weeks in the first scenario. In the second scenario, this share would still amount to 33 percent. This implies that for a third of the households it would pay off after one month to replace the most inefficient stove used by an ICS, even if the stove to be replaced was brand new. For a twelve week period, these shares are as high as 89 and 71 percent, respectively.

Figure 1: Amortization time of ICS acquisition as percentage of woodfuel users without Roumdé ICS



Source: Fafaso household survey 2011.

In conclusion, adopting a Roumdé is an investment with a very high return and in particular a rapid monetary pay-off. Even using the conservative estimate above, it implies roughly a yearly return of 300 percent. This is a huge return even compared to the interest rates of informal money lenders – typically around 60 percent per year. Provided that the ICS have been available in the surveyed cities since 2006 already, the penetration rate in our representative sample at around 10 percent is surprisingly low. Low investment rates in the presence of high returns are no exception in the developing country context. It is for example a well-known puzzle in the literature on investment in small firms (see e.g. McKenzie and Woodruff, 2008; De Mel et al., 2008; Kremer et al., 2010; Fafchamps et al., 2011; Grimm et al., 2011). Duflo et al. (2011) observed Kenyan farmers that forwent highly profitable investments in fertilizer. Low uptake has also been observed for highly effective insecticide treated bednets (Cohen and Dupas, 2010), inexpensive water disinfectants preventing dangerous waterborne diseases (Kremer and Holla, 2009) or motorbike helmets in India (Grimm and Treibich, 2014). Explanations vary from liquidity constraints in conjunction with capital market imperfections, risk and the need for precautionary savings, weak beliefs and other behavioural biases. Based on these experiences in the literature we use the current example to probe more into this conundrum of low uptake in spite of a high cost-effectiveness and try to find out why only very few households invest in an improved stove.

5. Why is uptake of improved cook stoves so low?

We start with a simple theoretical model of the decision process on stove uptake in a utility maximization framework in order to organize ideas and to derive alternative hypotheses about the possible drivers of uptake.[7] Subsequently we explore the data to see which of these hypotheses is supported by the data and which are not.

5.1. Theoretical considerations

Household utility is assumed to be a function of warm and tasty food F and a vector of other goods for consumption C_g including market-purchased commodities and leisure:

$$U = U(F, C_g) \tag{2}$$

Warm food, in turn, is a function of the amount of time spent on cooking, T, and the energy E_k provided by the different energy carriers k needed for warming the food ingredients, which – for simplicity – can be assumed to be part of C and to be available in sufficient quantities. Input both in terms of E_k and T are affected by energy and time efficiency parameter η_s and δ_s specific to each stove type s. The utility derived from warm and tasty food may further depend on taste preferences that are specific to the individual or shaped by community- or even society-wide norms and traditions, $\bar{N}$, i.e. F is larger if it is produced according to theses taste preferences. Hence, for F we have:

$$F = f(E_k(\eta_s), T(\delta_s), \bar{N}) \tag{3}$$

The household maximizes utility subject to the following budget constraint:

$$Y(Z) = p_g C_g + p_k E_k + (p_s + i_s) X_s, \tag{4}$$

where income Y is determined by household characteristics Z such as education. In line with actual conditions, we assume that there is no market for formal credits to purchase a stove. On the right-hand side, the budget constraint includes prices p_g for each of the g goods for consumption C_g, the prices p_k for each energy carrier k and stove-specific costs. These are composed of the retail price p_s of stove type s and transaction costs related to stove purchase, i_s, and enter the budget restriction if the household owns stoves X_S of stove type s. The transaction costs related to stove purchase i_s can be further specified. Among others, these include knowledge about and perception on the stove, K_s and P_s respectively, as well as the overall market development (awareness raising, supply chain management) and certification activities for the stove, $\bar{M}_s$, and $\bar{C}_s$. All these four parameters reduce transaction costs assuming that they stimulate the purchase of the respective stove. Household characteristics Z again play a role as well as the degree to which the stove meets the households' design requirements D_s, hence we have:

$$i_s = f(K_s, P_s, \bar{M}_s, \bar{C}_s, Z, D_s) \tag{5}$$

---

[7] The model is partly inspired by a framework proposed in Rehfuess et al. (2014), by the findings from a systematic review on stove uptake (Lewis and Pattanayak, 2012) and by Ruiz-Mercado et al. (2011).

The household's utility maximization problem is expressed with the Lagrangian in the following equation:

$$Max\ E\ (U(F(\eta_s, \delta_s, \bar{N}), C_g)\ +\ \lambda(Y(Z) - p_g C_g - p_k E_k - (p_s + i_s(K_s, P_s, \bar{M}_s, \bar{C}_s, Z, D_s)X_s) \quad (6)$$

As our data does not allow estimating such a model structurally, we refrain from solving the maximisation problem for the first order conditions. However, having structured the behavioural problem allows deriving four hypotheses addressing the question why households despite the substantial potential fuel savings (η_s) do not uptake a stove. These hypotheses address all parameters from Equation (6) as delineated in Table 5.[8] We examine them in the following empirical analysis. Part of our argumentation will be based on the results of a multinomial logit model estimation on stove ownership for the four household categories *LPG-only users*, *ICS owners*, *owners of imitated ICS* and *other ICS non-owners* using as explanatory variables the household characteristics from Table 2. ICS owners represent the base case. Accordingly, positive coefficients in the estimation imply that households with the respective attribute (e.g. female spouse is involved in expenditure decisions) are more likely to belong to the respective stove owner group (e.g. LPG-only) than to the ICS owner reference group. The results are shown in Table A2.

Table 5: Hypotheses about stove uptake

	Hypotheses	Affected parameters and variables
H1	The lack of information hypothesis: People are not aware of advantages and the existence of improved cook stoves	Z, K_s, $\bar{M}_s$, $\bar{C}_s$
H2	The beliefs hypothesis: People know about ICS, but are not convinced by their efficiency	P_s
H3	The norms and traditions hypothesis: The choice of the cooking technology is more related to prevailing norms and traditions than to individual preferences	D_s, $\bar{N}$
H4	The affordability hypothesis: Households face a liquidity and cash constraint, the stove is too expensive	Z, p_s, p_g

Source: Own representation.

5.2 Empirical analysis of adoption behaviour

Hypothesis 1 - The lack of information hypothesis: People are not aware of advantages and the existence of improved cook stoves

If that hypothesis was true, the parameter K_s would be key to understand uptake, i.e. we would expect non-users of ICS not to have heard of ICS. Moreover, since women should have more exposure to cooking-related messages and information than men, uptake should be higher in those households where women have some decision power over expenditures, in particular cooking expenditures. Uptake may also increase with education, because education may help to obtain the relevant

[8] We also rigorously assessed the second efficiency parameter, δ_s, by running a similar regression on cooking time as for woodfuel savings. Results are less pronounced than those for the fuel consumption analysis. At the same time, they are similar concerning the performance of firewood versus charcoal and ICS versus imitated ICS. ICS reduce the cooking time per dish on average by 10 minutes.

information and to process that information. The latter also includes the ability to make simple cost-benefit calculations.

According to our data the lack of information seems to be less a problem: four in five woodfuel-using households without ICS are in principle aware of them, among imitated ICS users even a bit more (85 percent). Only 19 percent of these households do not know where to buy an ICS. Households mainly know the ICS from broadcasting, selling points or heard about them through the family, friends, and neighbours (45, 33 and 25 percent, respectively). This has to do with concerted promotion activities in the starting phase of the project including TV and radio spots and sponsoring activities, e.g. of a fashion show. Furthermore, there are a number of easily recognisable kiosks and ambulant merchants selling the ICS – all this reflecting the parameters $\bar{M}_s$ and $\bar{C}_s$ from Table 5.

As can be seen in Table A2 we do not observe a significant correlation between uptake and male education as part of the parameter *Z*, whereas households with more educated females interestingly rather seem to be less inclined to buy an ICS (and particularly more inclined to buy LPG instead). This phenomenon is even more pronounced for households lacking a female, though it has to be acknowledged that only four percent of households fall into this category. We find also no evidence that a higher decision power of women increases the likelihood of ICS adoption as can be seen from the mostly insignificant and inconclusive coefficients of the variable 'female is involved in the decisions on household expenditures'. Hence, to conclude from the evidence it is unlikely that the major deterrent to uptake is a lack of knowledge or that uptake can be explained by differences in education and female decision making power.

Social networks such as women groups or similar female associations are generally another relevant information source. Including a dummy variable for spouses who are members of an association in the Multinomial logit model shows that the engagement in an association is positively correlated with ownership of any improved stove type (including imitated ICS and LPG). Yet, coefficients are insignificant and association membership is more frequent among imitated ICS owners than among ICS owners (results not shown in Table A2). These inconclusive results may also be due to the relatively low membership rate of less than 10 percent. It seems that informal social networks rather play a role in diffusing the idea of ICS.

Hypothesis 2 - The beliefs hypothesis: People know about ICS, but are not convinced by their efficiency

If that hypothesis was true, the uptake was mainly linked to the perceived benefits, P_s. Non-users of ICS would be expected to report to know ICS, but would associate a low quality and a low durability to it. Overall we find not much evidence for this hypothesis. Less than 5 percent of the ICS non-users mentioned not to be convinced of the efficiency and the durability of the improved stove.

In assessing the perceived benefits of using an ICS, we can additionally rely on two benchmarks: first, the perceived benefits of imitated ICS and second, the ex-ante motivation patterns for acquiring the imitated and the 'real' ICS. This is shown in Table 6. For both, fuel savings and a quicker cooking process are clearly the most valued perceived advantages. In all benefit categories listed in Table 6, ICS owners appreciate their improved stoves to a significantly higher degree than the users of imitated ICS their stoves. Particularly large differences in the perception of advantages can be observed when it comes to durability, money savings, appearance of the stove and comfort, which only a minority of ICS imitation owners declared as advantages.

Table 6: Perceived advantages and motivations (in *italics*) of ICS and imitated ICS owners as compared to traditional stoves, in percent

	ICS owners	Owners of imitated ICS		ICS owners	Owners of imitated ICS
fuel savings	94.2 *69.1*	81.0 *72.4*	beauty of stove	69.6 *39.3*	35.9 *22.5******
quick cooking	90.9 *70.6*	81.4 *78.3**	increased comfort	67.6 *36.8*	43.9 *33.8*
smoke reductions	86.2 *62.5*	60.1 *58.2*	durability of stove	65.9 *36.2*	38.7 *28.3**
mobility of stove	77.6 *43.0*	62.0 *48.4*	less respiratory diseases	62.3 *27.6*	49.3 *30.3*
cleanliness of kitchen	74.3 *44.9*	59.8 *49.7*	less eye diseases	62.2 *26.8*	54.2* *35.3***
money savings	71.9 *44.4*	47.5 *37.5*	less accidents/ burns	60.3 *26.2*	49.7** *31.0*

Notes: The upper values in each cell represent perceived advantages and the lower values the main motivations as stated by ICS owners and owners of imitated ICS. Asterisks indicate the significance level of differences in means between ICS and imitated ICS owners as determined by *t*- and *chi-2*-tests: * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. For perceived advantages, only significance levels different from the 1 percent level are indicated.
Source: Fafaso household survey 2011.

At the time when households have been confronted with the decision to buy their current stove, differences between the two groups have been far less pronounced (see values in italics in Table 6). The largest difference lies in the appreciation of the beauty of the stove. Along all assessed dimensions, actual satisfaction rates are even above initial motivations; households, hence, seem to somehow find their stoves even better than expected. Another notable difference to the ex-post assessment is that the primary motivation both for Roumdé ICS and imitated ICS owners has been a quicker cooking process.

Hypothesis 3 – The norms and traditions hypothesis: The choice of the cooking technology is more related to prevailing norms and traditions than to individual preferences

If this hypothesis was true, we should find that the Roumdé is in general quite incompatible with the preferences and requirements of the target populations, D_s. Moreover, households that belong to different ethnic and linguistic groups should show a clearly distinct uptake behaviour (related to the parameter $\overline{N}$). The reason for this is that indeed in the Mossi culture – to which two-thirds of the households in our sample belong – the mother-in-law is supposed to build a three-stone stove in the household as a welcome gift for the bride after marriage. The mother-in-law will remove the stove if, for some reason or another, she disapproves the marriage and wishes a divorce. As a consequence, these stoves are found in all Mossi households, even the wealthier ones. The data, however, reveals that Mossi and non-Mossi households neither differ in terms of three-stone stove usage nor in terms of ICS ownership (see Table A2).

There is also no evidence that the design of the stove is incompatible with the preferences of the target population. This has already been documented above (see Table 6). Moreover, the Roumdé is in a very similar form already available in the market since several decades as this type of stove has been developed in the 1980's by a local research centre in a way that they match local preferences in terms of cooking habits and production capacities. ICS are also available in different sizes (3, 5 and 7 litres) in order to meet the diverse cooking demands of the Burkinabè households. Design requirements are therefore very unlikely to represent an impediment for households to adopt these kinds of improved stoves. This is corroborated by the fact that only seven percent of ICS owners experience any difficulty in using the stove and merely one percent of ICS non-owners mentioned to not own an ICS because they consider the stove usage as too difficult.

Finally, another more specific comparison criterion not documented in Table 6 relates to the effect of the stove type used on the taste of the food that is prepared. 31 percent of all ICS users mention not to notice any difference as compared to the formerly used traditional stoves, contrasted to 46 percent who like the taste of food cooked on an ICS better and the remaining 23 percent see a difference in taste, which they, however, would neither classify as better or worse. In conclusion, it is also unlikely that norms and traditions are the main reason for low uptake.

Hypothesis 4 – The affordability hypothesis: Households face a liquidity and cash constraint and apply high discount rates

If that hypothesis was true we should find that households not owning a Roumdé state that the purchase price of the Roumdé, p_s, is too high compared to other stoves. Given the absence of formal credit for the purchase of a stove, uptake should increase with household expenditures and other indicators of income and wealth.

Income and wealth proxies among the vector Z (namely electricity access and expenditures) additionally explain differences in uptake behaviour, although as can be seen in Table 7 and Table A2 the correlations are not very strong. For an increase in expenditures by 1 percent, the probability of uptake for a woodfuel-using household increases by 3.1 percentage points. Running the same analyses, first, across quintiles of an asset index and, second, differentiated by the two surveyed cities delivers a consistent result.[9] This reflects well the transition from traditional woodfuel usage to an increased usage of improved forms of woodfuel usage and eventually towards cleaner fuels like LPG.

Table 7: Distribution of ownership of ICS and imitated ICS, in percent

	Expenditure Quintiles					Ouagadougou	Bobo-Dioulasso	Total (unweighted)
	1	2	3	4	5	(N=892)	(N=274)	(N=1,166)
ICS	6.9	8.4	8.8	11.6	12.3	9.5	9.9	9.6
Imitated ICS	21.2	25.8	34.5	22.2	24.4	14.2	63.5	25.7

Source: Fafaso household survey 2011.

Two-thirds of woodfuel-using households without an ICS indeed stated that ICS are simply too expensive compared to the existing alternatives. It is by far the most often cited disadvantage. While a reporting bias cannot be excluded given that households may be expecting to receive discounts on the ICS if they complain about the price, the congruence between these statements and the revealed adoption behaviour in the different expenditure groups is quite striking.

Conclusion on uptake

The exploration of the above hypotheses suggests that if any of these hypotheses really plays an important role, then we think it is the liquidity constraint hypothesis, i.e. for many households the stove is compared to the traditional stove or even the imitated versions simply too expensive. Households find it difficult to raise the cash necessary to buy a Roumdé and show a high preference for today's consumption (i.e. they apply rather high discount rates). As a matter of course, this still leaves room for other factors that might drive the decision to adopt an ICS. Our analysis may not capture the entire set of constraints and trade-offs people face or people may simply fail to take decisions that maximize their utility. However, a high discount rate which values current consumption largely over future returns from investment is in a low income context with high uncertainties not necessarily inconsistent and may partly underlie our *affordability hypothesis*.

6. Conclusion

Our assessment has shown that users of the Roumdé consume less woodfuel than users of traditional three-stone or metal stoves. In particular for firewood, the savings are statistically significant and substantial in magnitude (between 20 and 30 percent depending on the efficiency of the baseline stove). The findings strongly suggest, that these savings are related to the choice of the stove and not

[9] The asset index is a single index calculated not on per capita but on household level with principal component analysis (see, e.g., Filmer and Pritchett, 2001; Sahn and Stifel, 2003). In our case, the index is constructed based on information about the ownership of motorized vehicles, phones, TV sets, fridges, air conditioning, a PC, large animal livestock, housing property and the housing conditions (wall and floor material, glass windows).

to any other characteristics that may jointly determine the choice of a stove and fuel savings. For charcoal, savings are less pronounced and not statistically significant anymore, but economically still substantial if they are considered in monetary terms. The fuel savings are lower than has been found in laboratory tests conducted by FAFASO. The reason for this is the fact that the day-to-day cooking behaviour deviates from cooking in a controlled set-up in which the cook is observed and obviously not distracted by other household tasks.

The price of a Roumdé is depending on the model chosen between 4 and 7 US$. At least in Ouagadougou, virtually all households buy the woodfuels (and do not collect firewood). A simple amortisation calculation shows that the investment into a Roumdé already pays off after very few months implying a yearly return on investment of more than 300%. In spite of these obvious advantages, adoption rates are low at only 10 percent in the two cities, although the ICS are widely available.

We therefore investigated several hypotheses that may explain this low penetration rate. While there is certainly no single cause, the explorative evidence we gathered suggests that the upfront costs of the Roumdé compared to other stoves and, hence, the affordability are the main deterrent of adoption. This might be due to liquidity constraints, i.e. households cannot bring up the investment costs and have no access to consumption credits or due to time preferences, i.e. households value today's consumption much more than the future consumption. This may partly be an indication of the very tight budget constraint. This does of course not preclude other usual suspects of low technology adoption from playing a complementary role. It might, for example, be that households do not have the information at hand to correctly calculate the pay-off period. The vast majority of households, though, seems to be interested in the ICS and would also be eager to purchase one. We do not find evidence for cultural aspects like a clear preference for traditional cooking to be responsible for the underinvestment in ICS.

Obviously, these qualitative findings should be interpreted with some care; the consistency of patterns across a pretty large and representative sample is however striking. These findings provide a basis for future research on uptake and help to design randomized controlled trials that allow for strong causal statements. Not only in Burkina Faso, but in virtually all other Sub-Saharan African countries, woodfuels will remain to be the dominating energy source in the coming decades. Therefore, biomass usage for cooking and consequently the successful dissemination of improved cookstoves is of utmost importance for improving the livelihood of the poor, for climate change adaption and emission reduction as well as public health. In order to substantiate the dissemination strategies, more knowledge is required about why people obtain an ICS – and why they do not. Our findings suggest that the investment character this decision has for households needs to be more taken into account. If these results are corroborated in other studies, this calls for a more direct promotion of ICS which might include subsidies to bring down the price and help the poor overcoming its liquidity constraints.

Appendix

Table A1: Test of balancing property of matching procedure

	ICS owners	ICS non-owners: Not weighted	ICS non-owners: Weighted by propensity score based weights	Difference before weighting
Adult Equivalents meal is cooked for	5.883	6.316	5.845	**
Squared Adult Equivalents meal is cooked for	43.638	49.621	43.288	*
Household is located in Ouagadougou	0.737	0.731	0.730	
Household head's ethnicity is Mossi	0.634	0.682	0.623	
Household head is public employee	0.167	0.098	0.166	***
Male has…				***
at most primary education	0.494	0.604	0.483	
secondary education or more	0.335	0.245	0.341	
(no male in household)	0.171	0.151	0.176	
Female has…				
at most primary education	0.731	0.754	0.733	
secondary education and more	0.251	0.212	0.251	
(no female in household)	0.018	0.034	0.016	
Electricity in the house	0.774	0.627	0.779	***
Household has bank account	0.432	0.312	0.437	***
Any woman is involved in decisions on household expenditures	0.342	0.320	0.338	

Note: As indicated by the asterisks, there are a couple of covariates that are significantly different before weighting (four of them even at 1 percent level) whereas these differences disappear after weighting. Values for ICS owners are identical before and after weighting as a weight of 1 is assigned to these observations.
Source: Fafaso household survey 2011.

Table A2: Estimates of stove type ownership

	Multinomial logit		
	LPG only	imitated ICS	other non-ICS
Household size, in terms of adult equivalents	-0.468***	0.042	0.175*
	(0.00)	(0.76)	(0.05)
Squared household size, in terms of adult equivalents	0.017*	-0.002	-0.007
	(0.06)	(0.82)	(0.21)
Household is located in Ouagadougou	2.427***	-1.298***	0.856***
	(0.00)	(0.00)	(0.00)
Hh head's ethnicity is Mossi	-0.423*	-0.303	0.293
	(0.10)	(0.18)	(0.11)
Hh head is public employee	-0.04	-0.496	-0.343
	(0.90)	(0.17)	(0.21)
Male has at most primary education	Ref.	Ref.	Ref.
Male has secondary education	-0.023	0.008	-0.194
	(0.94)	(0.98)	(0.36)
No male in hh	-0.37	-0.125	-0.209
	(0.36)	(0.72)	(0.43)
Female has at most primary education	Ref.	Ref.	Ref.
Female has secondary education	1.075***	0.202	0.308
	(0.00)	(0.45)	(0.14)
No female in hh	2.162***	0.342	0.989**
	(0.00)	(0.61)	(0.04)
Electricity in the house	0.661*	-0.227	-0.756***
	(0.08)	(0.34)	(0.00)
Household has bank account	0.094	-0.274	-0.289
	(0.71)	(0.26)	(0.11)
Any woman is involved in expenditure decisions	0.546**	-0.186	0.017
	(0.04)	(0.49)	(0.93)
Constant	-0.976	2.102***	0.818**
	(0.18)	(0.00)	(0.04)
Wald F statistic		8.49***	
Number of observations (unweighted)		1128	

Notes: The group of ICS owners represent the reference category. All variables but household size are dummy variables. Following a standard approach (e.g., Morris, 2006, Augurzky et al., 2012), we deal with 27 missing values in the male education covariate by replacing them by the reference case and including an additional dummy variable indicating missing values. Further 36 observations are lost due to missing information for other explanatory variables. * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent. *p*-values in parentheses.
Source: Fafaso household survey 2011.

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