Clean Cookstoves and Health in Samlout, Cambodia

By

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Thesis submitted in partial fulfillment of

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ABSTRACT

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Abstract

This paper discusses results from a study of the use of cleaner cooking solutions and general health status of people in rural areas from the Battambang province of Cambodia. Data collection included 372 demographic, health and socio-economic surveys with households living in 6 villages in the Samlout district, general health examinations, and measurements of stove use and household concentrations of PM 2.5. The data reveal that health in this population is a major concern, with a very high prevalence of reported abdominal pain, nausea, chronic cough, chest pains, and fever during examinations. At the household level, we find that clean stove ownership is significantly correlated with the educational status of household head and socio-economic status of a household. Respondents from households with clean stoves appear less likely (though not statistically significantly so) to report household individuals having health problems such as occasional cough, high blood pressure and tuberculosis. Concentrations of PM2.5 are positively correlated with prevalence of occasional cough, high blood pressure and tuberculosis. Based on these results, we advise field testing and evaluation of targeted health interventions in these villages to address the numerous concerns of the local population, including exploring the potential role of clean stoves.

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Acknowledgement

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1. Background and rationale

Approximately 3 billion people worldwide rely on dirty solid fuels for cooking and heating, and most of these households use inefficient traditional cook stoves. Usage of such fuels and stoves generates high levels of Household Air Pollution (HAP). HAP is today the most serious environmental risk in developing world, and is estimated to cause 4 million deaths and 110 million disability-adjusted life years (DALYs) annually. Women and children are disproportionately affected by HAP, because they are more likely to stay at home, and because it is women who usually cook for the family.

In Cambodia, cooking with traditional cook stoves and solid fuels remains common and therefore results in high levels of HAP. The World Health Organization (WHO) estimates that 89% of the Cambodian population (or 13.2 million people) is exposed to dangerous levels of HAP, resulting in 11,876 deaths each year (1,674 of them in children). The Global Burden of Disease 2013 estimated that air pollution is the second risk factor for respiratory disease in Cambodia (GBD Cambodia, 2013).

In an effort to reduce HAP and other negative effects of traditional cookstoves such as household productivity loss and climate-forcing emissions, various government institutions and NGOs have been trying to ramp up distribution of cleaner technologies and fuels worldwide. For example, SNV Netherlands Development Organisationleads one such effort in Cambodia, the Advanced Clean Cooking Solutions (ACCS) project. In the low-income Samlout District, the site of this research, the Maddox-Jolie-Pitt Foundation (MJP) has been working to encourage use of clean stoves and fuels with key staff under its INSPiRE program, as part of its activities to promote health.

Despite these efforts, research on cooking practices and health status in Cambodia has been extremely limited. Existing research on cookstoves in Cambodia has covered issues of carbon finance (GL Simon et al, 2012), and emission factors of traditional fuels (SC Bhattacharya et al, 2002) without a particular focus on clean cooking solutions and health status. Since there have long been chronic diseases and multiple sources of smoke in places like Samlout (e.g., household cooking, forest clearing), it is not clear how closely difference in health status is related to differences in cooking practices and options. Given the mixed actual results from improved cookstove projects worldwide (Duflo, 2012), it would be beneficial to gain better knowledge of this issue in depth prior to planning interventions to reduce HAP. In addition, it is important to learn more about the determinants of ICS and clean fuel use, which include social, psychological, and financial factors (Lewis & Pattanayak, 2012). Such information can be useful for those planning interventions that seek to address the barriers to adoption of cleaner cooking solutions in rural Cambodia.

2. Specific objectives of the study

The study had two main objectives:

I. To understand and investigate price-related, socioeconomic, demographic and other drivers of ICS and clean fuel adoption in rural Samlout; and

II. To investigate the relationship between these clean cooking practices and health status among households in the same location.

3. Methodology

3.1 Study location and sampling

The study took place in one commune in the Samlout district (which itself is called Samlout Commune), located in the Battambang Province of Cambodia (Figure 1). Situated in northeast Cambodia adjacent to the Thai border, Samlout is home to a large natural protection zone. Samlout is also one of the least economically developed areas in Cambodia. Most households in the study commune still use traditional methods and technologies for cooking.

We conducted a total of 372 household surveys over a 5-week period of time in six villages located in the Samlout Commune (49 in Kantout, 107 in Beung Run, 81 in Chokroka, 58 in O Chrap, 32 in Sre Andoung and 45 in Samlout village). The six villages are where Maddox-Jolie-Pitt Foundation has been working for a decade, and where its presence and coordination is best developed. Roughly 20-25% of all the households living in these villages were interviewed. The study objectives required sampling households using different types of cooking stoves, so the protocol was developed to oversample households owning non-traditional technologies (to make sure at least 20% of the sample households own clean stoves, but ideally 50%). As such, to achieve target sample sizes for cleaner alternatives, the total number of households contacted using a field-based counting method for random selection was 765, or roughly twice the number of the households who were actually interviewed (372). Those among these 765 households who were not interviewed did not own clean stoves.

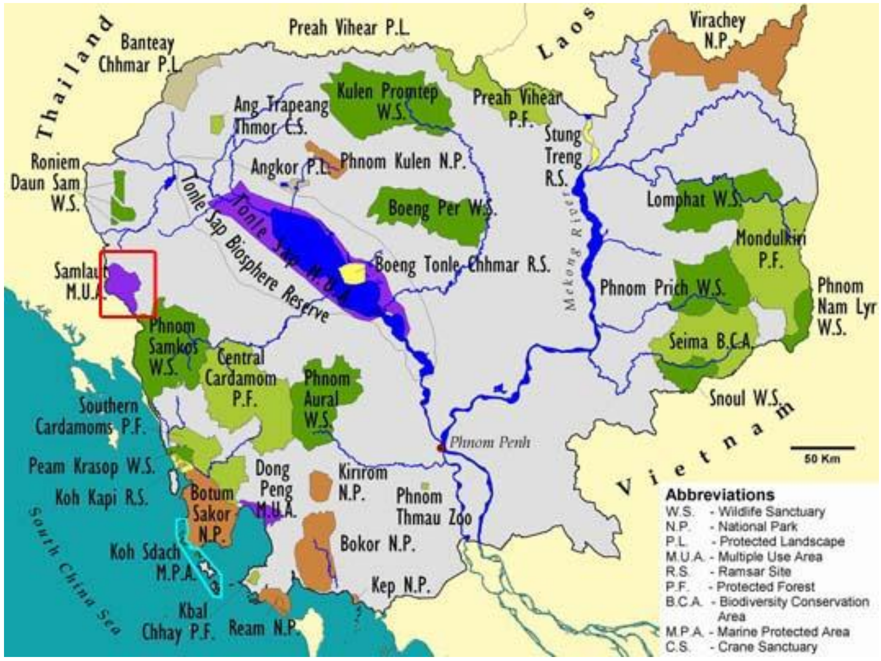

Figure 1. Map of the study location in Cambodia (Source: Maddox-Jolie-Pitt Foundation website)

3.2 Survey instrument

The survey comprised 8 sections in total, including a) location information; b) information and perceptions; c) a household roster; d) questions about general health status; e) cooking, heating and fuel (stove characteristics and use, fuel use); f) risk and time preferences; g) socioeconomic characteristics; and h) enumerator observations. Administration took on average between 1 and 1.5 hours in each household, and was conducted in Khmer language by trained enumerators.

The health examination portion of the survey contained questions about respiratory and other ailments, as well as household nutrition. In addition, we assessed the immunization status of young children under 5 years of age. Proof of immunization (an official card issued by the government) was requested from respondents if there was a young child living in the household (77 such cards were obtained, out of 113 children in the sample under the age of 5). In addition to the survey, we also conducted various measurements to monitor health status. These health measurements included pulse rate, blood oxygen level, blood pressure, middle upper arm circumference (MUAC), height, weight and lung function.

We used an Omron Blood Pressure Monitor to measure the systolic blood pressure, diastolic blood pressure and pulse rate. Blood oxygen level was measurement using pulse oximeters. These measurements were taken three times at an interval of 1 minute. For anthropometry, we measured MUAC and height using measuring tapes, and weight using scales. Finally, lung function was assessed using spirometers. The protocol for lung function is attached in Annex 1, and the spirometry consent form is attached in Annex 2. Medical staff from the health centers helped administer the health measurements. We referred any abnormal results to the local health center afterwards.

Note that the sample size varies across analyses described in this thesis. Even though the study covers a total number of 372 households with 1525 individuals, some measurements could not be conducted in all households or with all individuals. For instance, we measure height and weight for only cooks and young children under 5 years old in the household, so the total sample size for height and weight is 430. Likewise, we only measure the blood pressure and oxygen level for the cook in the household, so the total sample size is 372. For immunization, we only collected the record from young children, so the sample size is 77. These differences are reflected in the following sections.

3.3 PM2.5 and stove use

As an indicator of exposure to harmful HAP, we randomly measured PM2.5 concentrations over the course of a day in a sub-sample of 58 households covering 230 individuals (randomly selected about 4 households each day from Monday to Thursday in week 2 to 5 of sample collection, and 11 of which had clean stoves).[1] High concentration of PM2.5 is harmful to human health. The World Health Organization (WHO) estimates that "... fine particulate air pollution (PM2.5) causes about 3% of mortality from cardiopulmonary disease, about 5% of mortality from cancer of the trachea, bronchus, and lung, and about 1% of mortality from acute respiratory infections in children under 5 years, worldwide." (Aaron et al, 2005). Recognizing the negative health effects of PM2.5,

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[1] PM 2.5 (particulate matters 2.5) are defined as particles with a diameter of 2.5 micrometers or less.

many countries have established standards for average daily ambient concentrations. For example, the United States has a standard of 35ug/m^3, Australia's is 25ug/m^3, and China's standard is 75ug/m^3.

Finally, to measure stove use more precisely, we used stove use monitoring (SUMs) system devices, in 76 households (randomly selected among 372 households covering the households with PM monitors, and among the 76 households, 65 SUMs were placed on traditional stoves, and 11 were placed on clean stoves).

3.4 Study hypotheses and analytical approach

We use the survey and other data to test three main hypotheses, as described below.

Hypothesis 1: Socioeconomic status, risk preference and other factors are related to ownership of clean fuels and stoves in the households.

Analytical approach: We use a multivariate regression model to investigate the hypothesis, based on some of the priors established in Lewis and Pattanayak (2012). The dependent variable is the ownership of clean fuels/stoves, and the independent variables include indicators of socioeconomic status, risk preference, demographic characteristics, and health status. We thus estimate the following model:

$$\text{Ownership of clean stove} = A*\text{Demvars} + B*\text{Riskvars} + C*\text{SESvars} + D*\text{Vill} + E \qquad (1)$$

In equation 1, the demographic variables (Demvars) include factors such as the size of the household, age, gender and education of the household head, and education of the primary cook. The risk variables (Riskvars) include perceptions of health risks, knowledge of alternative stoves, time and risk perceptions, and other health risk avoidance behaviors such as water treatment and use of mosquito nets. The socio-economic variables (SESvars) include factors such as the number of rooms, total consumption, land ownership and tenure, and asset ownership. Finally, Vill are village fixed effects.

We run both an OLS and a probit regression for estimation of equation (1). The ordinary least squares (OLS) is a method to estimate the unknown parameters in a linear regression model, targeting at minimizing the differences between the observed responses in the dataset and the responses predicted by the linear model. It is the most commonly used model in regression. The probit model is a common specification for a binary response model, which adopts a probit link function to treat type of regression where the dependent variable can only take two values. It is similar to logistic regression in that they treat the same set of problems, but the probit model assumes normal distribution of errors instead of logistic distribution of errors. We assume normal distribution of errors in this case.

Hypothesis 2: PM concentration is negatively correlated with ownership of clean stoves in Samlout, Cambodia.

PM = A*Demvars + B*Stovevars + C*Fuelvars + D*Riskvars + E*SESvars + F*Vill+G (2)

In this (household-level) model, the outcome consists of different measures of exposure (PM2.5 concentration in the kitchen or a range of health measurements and self-reported results), and the independent variables are the same as above but also include stove (improved or no) and fuel characteristics (solid fuel, LPG or other).

We adopt the OLS regression model since PM concentration is a continuous variable.

Hypothesis 3: Usage of traditional fuels and stoves is negatively correlated with health status of people in Samlout.

Health = A*Demvars + B*Stovevars + C*Fuelvars + D*Riskvars + E*SESvars + F*PMconcentration+G*Vill+H (2)

In this (individual-level) model, the outcome consists of different measures of health status, and the independent variables are the same as above but also include stove (improved or no) and fuel characteristics (solid fuel, LPG or other). Standard errors are clustered at the household level. Alternatively, a household-level model can be used:

Health = A*Demvars + B*Stovevars + C*Fuelvars + D*Riskvars + E*SESvars + F*PMconcentration+G*Vill+H (3)

where standard errors are clustered at the village level, and village fixed effects are included.

Of course, there may be unobserved factors that are related to both use of a clean stove or fuel and the health outcomes of interest. To partially control for these issues, we utilize a Heckman two-stage model. This approach allows for correlation between the unexplained factors that explain treatment status (use of a clean stove/fuel) and health outcomes, and additionally structurally control for the individual-specific residuals from a model explaining treatment status when modeling health outcomes.

In the first stage, a probit regression is estimated for the probability of clean stove ownership:

$$\text{Prob}(D = 1|Z) = \Phi(Z\gamma), \quad (4)$$

where D indicates clean stove ownership (D=1 if the household owns clean stove and D = 0 otherwise), Z and γ are vectors of explanatory variables and unknown parameters respectively, and Φ is the CDF (cumulative distribution function) of the standard normal distribution. This estimation can further produce the results to predict the probability of clean stove ownership for each household.

In the second stage, we transform these predicted probabilities as an additional explanatory variable, and the health outcome is specified as

$$H^{*}=Y *a+b \quad (5)$$

where H^{*} indicated a health outcome. Y is the new vector of explanatory variables, and a is the new vector of unknown parameters, b is unobserved determinants of health status, then the health status can be estimated by replacing γ with Probit estimates from the first stage, and incorporate the two stages together. We can also get the estimate of significance of selection bias from the “hazard lamda” indicator when we run the model in STATA.

4. Results

4.1 Descriptive analysis

Demographics. A total number of 372 households were interviewed, and information for 1525 individuals living in these households was recorded (corresponding to an average household size of 4.1 members). Males make up around 50% of the population (792/1525), and are predominantly identified as head of household (265/370). The average age of household heads is 45.3 years, while the average age of the whole population is much younger (28.1) compared with that of household heads.

The average time of education for household members was 4.4 years, with the most educated people finishing 16 years of education, and the least no education at all. Nearly half of the population were married at the time of the survey (510/1264), followed by people never married (407/1264), and a small number of people divorced or separated. Almost half of the individuals are children of the head of household, and another half are household heads and their wives/husbands, leaving a small number of people with other relationships with the head of the household (e.g., grandchild, son/daughter in law).

Table 1. Demographic characteristics

	Total population	Head of household
Gender		
Male	792	265
Female	733	105
Missing	0	2
Total	1525	372
Age (mean)	28.1	45.1
Age (standard deviation)	19.1	14.4
Years of education (mean)	4.32	4.54
Years of education (standard deviation)	3.86	4.21

Information and perceptions. The top 5 environmental challenges identified by households (from a longer list of options), in order of importance, were: droughts (250/372); loss of forests and forest products including wood (53/372); flies, mosquitoes, cockroaches (49/372); loss of wildlife (35/372); and extreme hot or cold weather (19/372). When respondents were asked to list the three biggest environmental challenges that they face instead of only one, the top 5 mentioned were: droughts (295/372); loss of forests and forest products including wood (222/372); extreme hot or cold weather (211/372); flies, mosquitoes, cockroaches (113/372); loss of wildlife (71/372). Comparing the results, it can be seen that the top 5 environmental problems identified by the households as the biggest and among the biggest three are exactly same, but differ in order of importance.

Only 4 households reported household air pollution as the biggest environmental problem, and only 11 households ranked it among the top three environmental problems.

Water pollution, solid waste and outdoor air pollution received relatively few replies as well.

Approximately two thirds of the households reported that they have heard that traditional cooking practices can negatively impact human health, air quality and local forests. While around two thirds of the households had heard of the advantages of adopting clean stoves and fuels, most households said they believed that the use of improved stoves and clean fuels would only have a small impact on improving human health, local forests and air quality.

When asked about the attributes of traditional stoves and fuels, households reported "The cost of stove" (244/372), "The speed of cooking" (179/372) and "The taste of the foods" (118/372) as the best attributes of traditional stoves, and "The smoke produced by the stove" (256/372), "The amount of fuel required" (129/372) and "The work required to prepare fire before cooking" (64/372) as the worst attributes of traditional stoves.

As for non-traditional stoves (only answered by households with non-traditional stoves), "The speed of cooking" (96/372), "The ability to cook all foods" (33/372) and "The smoke produced by the stove" (30/372) were ranked among the top attributes people valued a lot. "Electrical shocks" (76/372), "Cost of fuel or electricity bill" (58/372), and "The cleaning requirement" (19/372) were among the worst.

General Health Status. Just over a quarter (26%) of the study population reported having cold occasionally, and 20% responded they had experienced a cough or cold in the previous 2 weeks (Table 2). Apart from that, in the past 2 weeks, 41% reported having had a sore throat, and 41% said they have problems with blocked nose, while only 5% reported fast breathing, and 2% wheezing. Around 64% of the respondents with these ailments had sought medical advice from a health professional or hospital, and they had paid an average of 34970 Riels(approximately 8.75 USD) for the treatment they received. Regarding other illnesses, 109 individuals reported having experienced loose stools(8.8%) in the past three months, 49 reported malaria in the past three months(3.9%), and 31 reported having TB (2.5%).

About 22% of the respondents reported smoking at some point in their life. For smokers, the average reported amount of smoking was 7.4 cigarettes per day, and on average, smokers had smoked for 8.9 years.

Anthropometry/other health measures. The average pulse rate measured over three consecutive times per individual was 73.5, with the highest single pulse rate recorded at 147 (Table 3). Average blood oxygen levels were 98%. For blood pressure, the average ranges for the three times were 73.4 (diastolic) and 122 (systolic). The MUAC average was 12.7 cm, with the maximum recorded value of 19.8 cm. On average, individuals (including both adults and children) weighed 50.1 kilograms, and the highest weight was 83 kilograms.

Finally, we attempted to measure lung function in adult subjects. However, around half of the respondent had contraindications for spirometry (57/122) [2], with the most important contraindications being reported heart problems or regular chest pain (14), a fever or new cough in last 6 weeks (12) and surgery to the chest, abdomen or other parts of the body (9).

Table 2. General health status

	No	Yes	Do not know
Cough & cold? (occasionally)	73.84%	26.10%	0.06%
Cough & cold? (last 2 weeks)	80.46%	19.54%	0
Last 2 weeks: sore throat?	35.23%	33.89%	30.87%
Last 2 weeks: Running/ blocked nose / sinusitus?	77.85%	22.15%	0
Last 2 weeks: Faster than normal breathing	83.56%	16.44%	0
Last 2 weeks: Wheezing sound in chest / nose	89.60%	10.40%	0
Loose stools?	90.36%	8.83%	0.81%
Malaria?	95.91%	3.93%	0.16%
TB?	97.48%	2.52%	0
Any other illness?	98.61%	1.39%	0

2 The total number of respondents of spirometry (122) is much smaller than 372, due to the fact that the equipment for spirometry were not ready until the last two weeks.

Table 3. Health measures

	Observations	Mean	St. Dev	Min	Max
Pulse rate	368	73.4	10.3	20	113
Blood oxygen level	370	98	1.98	74	99
Systolic blood pressure	365	122	19.1	83	210
Diastolic blood pressure	365	74.9	11.9	44	141
MUAC	35	12.7	5.61	0	19.8
Height	426	1.48	0.27	0.24	1.85
Weight	430	50.1	15.4	7	83

***** Here we measure pulse rate, blood oxygen level and blood pressure only for cooks, MUAC only for young children under age 5, and height as well as weight for both cooks and young children under age 5.

General symptoms and child immunization. We asked respondents whether they had symptoms such as nausea, shortness of breath, wheezing, chronic cough, sputum production and abdominal pain. 1106 out of 1525 reported occasional abdominal pain (73%), and 644/1525 reported occasional nausea (42%), followed by 420 reporting chronic cough (28%).

The 77 immunization records that were collected show that 77 children in households producing such cards had been immunized with the BCG, HepB Birth Dose, OPV (3 doses), DTP-HepB-Hib (3 doses), and JE vaccines, all of which are officially required for children in Cambodia. Recently the government of Cambodia also included PCV as a new compulsory immunization for young children, but only 2 of the sample children had received this vaccine at the time of the study, perhaps due to limited time from implementation of the new policy.

Cooking, heating and fuel. The most common stove used by households in the survey population is the New Lao stove in the survey population (321 interviewed households reported having at least one), followed by the LPG stove (54) and electric rice cooker (25) (Table 4). The total number of households with improved cooking devices was thus 78 out of 372 (or 21%; adjusting for the oversampling, the true proportion in the population is about 10%), and the total number of improved stoves they have is 96. Most families reported having one or two stoves in their house, while some households had 3 or 4 stoves. Most households use stoves for cooking rather than heating. Firewood is the most common fuel in the households with approximately 66% of households reporting using it (Table 5). Forty-seven percent of households use charcoal as a source of fuel. LPG, leaves and electricity represent minor sources of fuel for the study population.

With regards to households' cooking area, 28% had no ventilation at all, 13% had windows, 30% had openings in the wall or a raised roof, 0.7% were attached to a chimney, and 17% located their stoves next to open doors for ventilation.

Table 4. Households' ownership of traditional and improves stoves

Type of stoves		Clean stove		Total
		Do not own	Own	
Traditional stove	Do not own	0	17	17
	Own	294	61	355
Total		294	78	372

Table 5. Household usage of fuels

Fuel	No	Yes
Firewood	33.60%	66.40%
Charcoal	53.49%	46.51%
Agricultural crop residues	99.19%	0.81%
Leaves/twigs	93.01%	6.99%
Animal waste/dung	100%	0
Kerosene	100%	0
LPG	91.67%	8.33%
Electricity	95.70%	4.30%
Biogas	99.73%	0.27%
Trash	99.73%	0.27%
Other (specify)	100%	0

The SUMs recorded over 407250 minutes of time across the entire sample (approximately 283 days), and the total recorded cooking time was 14503 minutes. So the average cooking time per day is 51.28 minutes/day. Across the sample, the maximum recorded cooking time per day on any stove was 441 minutes (7 hours 21 minutes), while the minimum cooking time was 0 minutes. 32.1% of the monitored households used a stove for more than 1 hour per day.

PM2.5 concentrations. The mean of average daily (24-hour) PM2.5 concentration across the sub-sample for which such measurements were taken was 241.3 ug/m3. The maximum 24-hr average concentration was 758ug/m3, and the minimum was 2ug/m3. Overall, 73.4% of the sample households had higher 24-hr concentrations than the Chinese standard (75ug/m3), and 79.0% exceeded that in the US(35ug/m3).

Instantaneous concentrations peaked during cooking. In fact, average 24-hr measures are highly skewed by peak emissions during cooking events. The median concentration over all monitoring hours was 85.0 ug/m3 (with a minimum and maximum median in each household of 377ug/m3 and 2ug/m3, respectively). The daily median PM2.5 concentration exceeded the Chinese (US) standard in 35.5% (and 46.8%) of the sample households.

Risk and time preceptions. The majority of people perceive themselves as being patient (244/360, including "very patient", "mostly patient" and "more patient than impatient"), while 108 households reported themselves as "more impatient than patient". Meanwhile, 179 out of 360 households (roughly 50%) perceive themselves as "Not at all willing to take risks" or "Rarely willing to take risks". While the number of households "Moderately willing to take risks" and "Generally willing to take risks" are low (1/360, 4/360), 115 households (or 32%) reported being "very willing to take risks".

Socioeconomic characteristics. A large majority of households reported owning their houses (91%), and most did not have separate rooms for livestock or storage (73%). On average homes had 1.2 rooms. The average value of property is 17,000,000 Riels (4250 USD). Most households also own agricultural land (90%).

Regarding water and sanitation, 61% of respondents considered their water sources to be "Always safe" or "Usually safe", with 21% answering "Usually not safe" or "Never safe". For sanitation, 29% households perform open defecation, 60% have a private latrine, and 11% use a neighbor's toilet.

On average, households had 3.3 mosquito nets, 1.6 cellphones, 0.5 televisions, 0.6 bicycles, 0.3 pressure cookers, 1.7 cots, 0.5 cows, 0.8 pigs and 10.7 chickens. The average value of total household consumption is 9,366,116 Riels (2341.5 USD) per year (Table 6). In the more detailed breakdown of consumption, meat and eggs make up the majority of spending (6,522,659 Riels, 69.6% total consumption), followed by education (440,034

Riels, 4.7%). Health expenditure comprises only 0.9% of total household consumption, and cooking fuel costs 0.2% of total expenditure.

Table 6 Household consumption (all in thousands of Riel)

Consumption category	Obs	Mean	Min	Max
a. Food (Total estimated)	372	10.7	0	300
b. Beverages	311	29.9	0	600
c. Meat and eggs	287	6522.7	0	1800000
d. Milk and milk products	292	9.84	0	300
e. Cooking fuel	270	17.2	0	852
f. Electricity	295	16.6	0	200
g. Health expenses	313	87.1	0	3670
h. Education	297	440.0	0	110000
i. Mobile phone	318	46.6	0	8120
j. Liquor and tobacco	277	27.5	0	600
k. Other major expenses	281	244.2	0	4000
l. Total (estimated)	225	9366.1	0	1800000

**Note: 1USD=4,000 Riels*

Stove use

To test the first hypothesis for the determinants of stove use, we regress stove use on the covariates shown in equation 1 using both OLS model and probit specifications. The results show that years of education and household perception of economic status are positively associated with use of an improved stove (Table 7), which is generally consistent with the literature that finds higher SES households to be more likely to adopt cleaner technologies. Household expectation of higher economic status in 4 years however is negatively associated with improved stove use, perhaps reflecting the fact that households who are more optimistic about the future tend to have lower status today (and the size of this effect is negligible). No other variables have statistically significant relationships with improved stove use, but many nonetheless agree with our expectations. In particular, ICS users are more likely to have younger heads of household, to be more willing to take risks (of adopting a new technology). Results obtained from OLS and probit specifications are very similar.

As can be seen from the regression on PM concentration (Table 8), it is not statistically clear what factors are related to PM concentration. This may be due to the small sample size for the PM measurements.

4.2 Regression analysis

Apart from descriptive analysis, we also conducted regression analysis based on our hypothesis. The results are shown as below:

Stove Ownership

The regression on stove ownership is shown in Table 7.

Table 7 Regression: stove ownership (household level)

Stove ownership	OLS	Probit
Gender –head of household [0=female;1=male]	0.068 (1.51)	0.245 (1.34)
Age –head of household	-0.002 (1.58)	-0.006 (1.14)
Years of education –head of household	0.014 (2.76)***	0.056 (2.84)***
Self-perception of patience	-0.001 (0.38)	-0.005 (0.58)
Self-perception of risk behavior	0.001 (1.60)	0.006 (1.50)
Household perception of economic status	0.177 (6.41)***	0.724 (5.86)***
Household perception of economic behavior in 4 years	-0.002 (2.86)***	-0.006 (2.96)***
Total consumption	-0.000 (0.45)	-0.000 (0.40)
_cons	-0.235 (2.50)**	-2.833 (6.35)***
R2	0.16	0.16
N	336	336

** p<0.1;** p<0.05; *** p<0.01.*

Note: T-statistics[3] are shown in parentheses. Here stove ownership is a dichotomous variable for owning a clean stove: if a household owns a clean stove, then stove ownership=1; otherwise stove ownership=0 (there are a range of stoves that are categorized into clean stove or traditional stove under the instruction of our local partner).

As can be seen from the table, for both the OLS model and the probit model, years of education of household head, household perception of economic status for now and in 4 years are all significant factors associated with stove ownership. The more years of education the head of household receives, or alternatively the better economic status a household perceives itself to have now, the more possibility that they will own clean stove; on the other hand, the better economic status a household perceives itself to have in 4 years, the less likely they will own clean stove.

PM Concentration

To test the second hypothesis for the determinants of PM concentration, we conduct a regression on median level of PM concentration, as there may be some extreme values of PM concentration that distorts the mean of PM concentration. The results are shown below:

3 In statistics the *t*-statistic is a ratio of the departure of an estimated parameter from its notional value and its standard error.

Table 8 Regression: PM concentration (household level)

PM concentration (median)	OLS
Stove ownership	0.020 (0.41)
Gender –head of household [0=female;1=male]	-0.008 (0.16)
Age –head of household	0.002 (1.04)
Years of education –head of household	0.000 (0.10)
Self-perception of patience	0.007 (0.35)
Self-perception of risk behavior	0.001 (0.99)
Household perception of economic status	-0.045 (1.64)
Household perception of economic behavior in 4 years	-0.000 (0.44)
Total consumption	-0.000 (0.38)
_cons	0.135 (1.72)
R2	0.15
N	54

** p<0.1;** p<0.05; *** p<0.01*

Note: T-statistics are shown in parentheses.

As can be seen here, none of the factors are significantly associated with PM concentration. Besides, we have seen positive correlation between PM concentration and stove ownership, which may imply that clean stove ownership is a consequence of high PM concentration. The sample size for this regression is small however, since many households' PM concentrations could not be monitored.

Health Status

To test the third hypothesis for the determinants of health effects, we regress the health outcome of interest on the covariates shown in equation 3, again using an OLS model.

The results for occasional cough are shown in Table 9, followed by tuberculosis in Table 10 and Systolic blood pressure in Table 11.

Table 9 Regression: occasional cough (individual level, probit model)

Health status- *occasional cough*	(1)With PM concentration in the model	(2) Without PM concentration in the model
Stove type	-0.28 (0.84)	-0.28 (0.83)
Gender	-0.17 (0.76)	-0.15 (0.69)
Age	0.010 (1.77)*	0.011 (2.02)**
Self-perception of patience	-0.038 (0.24)	0.017 (0.11)
Self-perception of risk behavior	-0.006 (1.69)*	-0.005 (1.36)
Household perception of economic status	0.12 (0.69)	0.053 (0.32)
Household perception of economic behavior in 4 years	0.003 (1.09)	0.003 (0.90)
Total consumption	0.000 (1.11)	0.000 (1.37)
PM concentration (median)	1.81 (1.93)*	
_cons	-1.13 (1.96)*	-0.96 (1.71)*
R2	0.08	0.06
N	159	159

** p<0.1;** p<0.05; *** p<0.01.*

Note: T-statistics are shown in parentheses. Sample size is 1525. Clustering of standard errors at the household level. Here occasional cough is a dichotomous variable which equals to 1 if a person has occasional cough, 0 if otherwise. We conduct a probit model here due to the dichotomous nature of dependent variable.

As can be seen from Table 9, when PM concentration (median level concentration of 24-hour monitoring) is included in the model, incidence of occasional cough is significantly correlated to PM concentration. The higher PM concentration is, the more possibility that an individual will have occasional cough. In addition, age is another significant factor associated with occasional cough. The older a person is, the more chance he/she will have occasional cough.

Besides, there are also some other findings we can draw from the regression. If a household percepts itself as rich, then it is not likely that a person in the household will have occasional cough. Occasional cough is also negatively correlated to gender, which means women have more incidence of having occasional cough than men. However, the evidence is not statistically significant.

We next consider the results for chronic cough (Table 10), which may be different from occasional cough, because there can be more chronic factors that lead to chronic cough. We conduct the regression shown below:

Table 10 Regression: health status- chronic cough (individual level, probit model)

Health status- chronic cough	(1)With PM concentration in the model	(2) Without PM concentration in the model
Stove type	0.36(0.92)	0.29(0.75)
Gender	-0.065(0.21)	-0.05(0.17)
Age	0.014(1.80)*	0.015(1.96)*
Self-perception of patience	-0.62(2.52)**	-0.56(2.32)**
Self-perception of risk behavior	-0.002(0.45)	-0.001(0.26)
Household perception of economic status	0.58(2.20)**	0.49(2.00)**
Household perception of economic behavior in 4 years	-0.004(1.05)	-0.004(1.04)
Total consumption	-0.000(0.03)	0.000(0.33)
PM_median	1.48(1.12)	
_cons	-2.51(3.07)***	-2.31(2.93)***
R2	0.01	0.04
N	181	181

** p<0.1;** p<0.05; *** p<0.01*

Note: T-statistics are shown in parentheses. Sample size is 1525. Clustering of standard errors at the household level. Here chronic cough is a dichotomous variable which equals to 1 if a person has chronic cough, 0 if otherwise. We conduct a probit model here due to the dichotomous nature of dependent variable.

As can be seen from Table 10, age. Self-perception of patience and household perception of economic status are significant factors associated with chronic cough. Even though here the result shows that households with higher PM concentration tend to have more chronic cough problems, the significance of the result is limited. Compared with PM concentration, the result is more significant for self-perception of patience: the more patience a person thinks of himself/herself, the less likely he/she will have chronic cough.

Finally, we discuss the results for systolic blood pressure (Table 11).

Table 11: Regression: health status- Systolic blood pressure (individual level, OLS model)

Health status- Systolic blood pressure	(1) With PM concentration in the model	(2) Without PM concentration in the model
Clean stove ownership	-4.03(0.54)	-4.21(0.56)
Gender	13.2(2.21)**	14.1(2.40)**
Age	0.241(1.36)	0.26(1.50)
Self-perception of patience	1.04(0.30)	1.50(0.44)
Self-perception of risk behavior	0.209(2.01)*	0.23(2.22)**
Household perception of economic status	5.43(1.30)	4.97(1.20)
Household perception of economic behavior in 4 years	0.039(0.51)	0.04(0.51)
Total consumption	-0.000(0.45)	-0.00(0.50)
PM_median	18.4(0.84)	
_cons	76.7(4.15)	76,7(4.16)***
R2	0.23	0.22
N	52	52

** p<0.1;** p<0.05; *** p<0.01*

Note: T-statistics are shown in parentheses. Sample size is 365. Clustering of standard errors at the household level. As blood pressure is a continuous variable, here we use OLS model to conduct the regression.

As can be seen from the results, systolic blood pressure tends to be positively and significantly correlated to gender, meaning that men have more chances to have higher blood pressure. Self-perception of risk-taking is also positively associated with blood pressure. In addition, PM concentration has a positive correlation with systolic blood pressure, however, the correlation is not statistically significant.

4.3 Two-part model

Here we adopt a two-part model that aims to partially control for selection bias (the mechanism explained in early sections). The results shown below are based on individual level regression (clustered at household level).

Table 12 Two-part model: Occasional cough

Occasional cough	With PM concentration in the model	Without PM concentration in the model
Gender –head of household [0=female;1=male]	-0.027 (0.32)	-0.025 (0.29)
Age –head of household	0.002 (1.04)	0.003 (1.32)
Years of education –head of household	-0.012 (1.13)	-0.012 (1.12)
Self-perception of patience	-0.084 (0.81)	-0.068 (0.68)
Self-perception of risk behavior	-0.003 (1.62)	-0.003 (1.46)
Household perception of economic status	-0.023 (0.33)	-0.05 (0.70)
Household perception of economic behavior in 4 years	-0.000 (0.14)	-0.000 (0.22)
Total consumption	0.000 (0.77)	0.000 (0.88)
Stove ownership	0.14 (0.37)	0.17 (0.45)
PM concentration_ median	0.61 (1.72)*	
_cons	0.30 (1.21)	0.37 (1.46)
hazard lamda	-0.13 (0.57)	-0.15 (0.64)
N	135	135

** p<0.1;** p<0.05; *** p<0.01*

Note: T-statistics are shown in parentheses. Clustering of standard errors at the household level.

According to Table 12, in the clustered model with or without PM concentration, the selection bias is not significant, since the p-value is large in both cases. In the model with PM concentration, after controlling selection bias among the chosen variables in the regression, the median level of PM concentration is still positively correlated to occasional cough, and the correlation is still significant. The other variables become not significant after controlling for selection bias.

Note: when we are evaluating the significance of selection bias in this case, we look at the p-value of hazard lamda.

Table 13 Two-part model: Chronic cough

Chronic cough	With PM concentration in the model	Without PM concentration in the model
Gender –head of household [0=female;1=male]	0.005 (0.11)	0.004 (0.09)
Age –head of household	0.001 (1.00)	0.001 (1.15)
Years of education –head of household	-0.001 (0.10)	-0.000 (0.08)
Self-perception of patience	-0.07 (1.33)	-0.059 (1.15)
Self-perception of risk behavior	-0.002 (1.47)	-0.002 (1.40)
Household perception of economic status	-0.042 (1.44)	-0.049 (1.52)
Household perception of economic behavior in 4 years	-0.001 (1.65)	-0.001 (1.66)
Total consumption	0.000 (0.77)	0.000 (0.86)
Stove ownership	0.13 (0.54)	0.120 (0.56)
PM concentration_ median	0.20 (0.92)	
_cons	0.097 (0.96)	0.11 (1.09)
hazard lamda	-0.14 (0.75)	-0.129 (0.82)
N	134	134

** p<0.1;** p<0.05; *** p<0.01*

Note: T-statistics are shown in parentheses. Clustering of standard errors at the household level.

According to Table 13, in the clustered model with or without PM concentration, the selection bias is not significant, since the p-value is large in both cases. In the model with PM concentration, after controlling selection bias among the chosen variables in the regression, the median level of PM concentration is still positively correlated to chronic cough, but the correlation is not significant any more. The other variables become not significant after controlling for selection bias.

Table 14 Two-part model: Systolic blood pressure

Systolic blood pressure	With PM concentration in the model	Without PM concentration in the model
Gender –head of household [0=female;1=male]	8.91 (1.26)	8.52 (1.30)
Age –head of household	0.35 (1.83)	0.35 (2.08)**
Years of education –head of household	-0.57 (0.64)*	-0.68 (0.83)
Self-perception of patience	5.75 (0.49)	4.72 (0.41)
Self-perception of risk behavior	0.22 (2.77)	0.22 (3.25)***
Household perception of economic status	6.43 (1.01)***	5.26 (1.11)
Household perception of economic behavior in 4 years	0.05 (0.47)	0.04 (0.50)
Total consumption	0.00 (0.39)	0.000 (0.41)
Stove ownership	-19.7 (0.57)	-13.2 (0.43)
PM concentration _ median	11.3 (0.42)	
_cons	73.1 (2.39)**	78.9 (3.04)***
hazard lamda	16.1 (0.00)	9.81 (0.54)
N	42	42

** p<0.1;** p<0.05; *** p<0.01*
Note: T-statistics are shown in parentheses. Clustering of standard errors at the household level.

According to Table 14, in the clustered model with or without PM concentration, the selection bias is not significant, since the p-value is large in both cases. In the model with PM concentration, after controlling selection bias among the chosen variables in the regression, the median level of PM concentration is still positively correlated to systolic blood pressure, but the correlation is not significant as well. Besides, in the model with PM concentration, years of education for head of household, household perception of economic status are significant factors associated with systolic blood pressure; in the model without PM, self-perception of risk behavior and age of household head are significant factors of systolic blood pressure.

5. Discussion:

There are a number of interesting findings in these results. It is noteworthy that PM concentration is a significant factor associated with incidence of occasional cough, this implies that occasional cough may arise from exposure to household air pollution. However, PM concentration is not significantly associated with chronic cough and blood pressure according to the regression. Neither is it significantly correlated to stove ownership. Of course, limitations exist regarding this result, as the PM concentration we are using here only comes from a sub-sample of households from the whole. It would have been better to have collected data from a more complete set of households.

Another interesting finding on the factors of stove ownership is that both household perception of economic status for now and in 4 years are significant factors of stove ownership, their correlations with stove ownership are in different directions. The better economic status they perceive now, the more likely they will have improved stoves; however, the better economic status they perceive in 4 years, the less likely they will have improved stoves. This could be explained that when households have higher expectation of their future wealth, they tend to purchase improved stoves in the future when they become richer, instead of purchasing improved stoves now. It can also be explained that poor households that do not have improved stoves are optimistic about their future. This phenomenon can be an explanation for the low rate of clean stove ownership in the sample villages.

There are also some limitations of this study. One limitation may lie in the measurement of stove use and household air pollution. We use SUMs to measure stove usage and PM monitors to measure household air pollution. Unfortunately, we were only able to measure a randomly selected subset of the total sample, given that we have limited devices. We do not put SUMs data into regression because we were not able to link them all to the household data.

Another limitation lies in the error in some health measurements. For instance, we measured height of children under the age of 5. Due to the special protocol of measuring young children's height, specific measurement boards are required and the children have to lie down in order to get an accurate measurement. However, due to limited resources available, we were only able to obtain 2 of these boards with our 4 teams, and the rest 2 teams have to use the conventional way of height measurements. This could create some inaccuracy in measurements of children's height. In addition, in order to control the total time for household survey, for blood pressure measurements, we allow the possibility of having only 1 minute (instead of 3) as the time interval among the three measurements. This could be a source of inaccuracy as well.

Besides, we have got some different sample sizes for different variables, such as PM concentration, blood pressure measurement, height and weight and other variables. On reason is because of the design of the research, so that we target different group of people in the sample households, so the sample size would be different. However, we also faced challenges in some measurements, so we chose to conduct survey in a sub sample of it. The other challenge is missing data in the record, so it does affect the statistical power as well.

In terms of selection bias, we did not find significant evidence in the sub sample with PM concentration measurement. Given the limited statistical power of the regression, this lack of evidence for selection bias in the regression on outcomes should not be taken as definitive evidence for a lack of it. In addition, there may still be omitted variables in the regression for health outcomes that bias the coefficient on clean stove use or PM concentration.

6. Recommendations

Based on our results and discussions, the following recommendations can be considered by MJP or other organizations working in Samlout:

1) Increase awareness-raising related to the benefits of clean cook stoves and fuels in the villages. As shown from our results, education status of households is closely related to clean stove ownership. While educational status is difficult to change in the short term, raising awareness of the harmful effects of traditional cook stoves and long-term education on environmental health may be an effective strategy for reaching less educated households.
2) HAP is significantly related to respiratory diseases as shown from our results. As a result, increased monitoring of HAP may be effective for identifying households most at risk of illness, and may help to inform better targeting of interventions that promote clean cooking solutions, including possible incentives for adoption of clean cooking solutions.
3) Many households who have clean stoves at home still tend to use traditional stoves, so regular visits and training on maintenance and repair of clean stoves may help to improve the sustainability and impacts of ICS projects.
4) The results of this study are correlational and highly suggestive, so additional research on the impacts of clean cook stoves (LPG, ACE1, etc.) on health status would be beneficial. Interventions should be accompanied by rigorous evaluation of impacts and outcomes.

7. Appendices

<u>1. Performing spirometry</u>

It is very important that you follow all of the infection control instructions here to prevent infections. It is your responsibility to ensure you practice good infection control.

In order to get reliable and accurate results you must ensure the patient understands how to perform the test and give them lots of encouragement to complete the test properly.

1. Ensure the consent process has been completed. Ensure there are no contraindications.
2. Wash your hands and ask the patient to wash their hands. Put on your gloves. Clean the machine with medical alcohol – ensure you clean all surfaces and the tube thoroughly.
3. Make sure patient is comfortable and **sitting down.** Loosen tight clothing. They should be sitting up straight, not leaning forward.
4. Record how long ago they had their last meal, cigarette, drank alcohol or did strenuous exercise (can remove if too complex)
5. Explain to the patient what you will ask them to do

'Take you biggest breath in and completely fill your lungs with air. Put lips tightly around the mouthpiece. Blast the air out as hard and fast as possible into the tube. Keep breathing out into the tube until all the air has emptied out of your lungs. You should keep going till you cannot breathe out anymore. Then take the tube away from you mouth and breathe normally.'

6. Demonstrate the above steps using a mouthpiece (either use a mouthpiece only or clean the machine after you demonstrate).
7. Give the patient a new clean mouth piece to fix onto the machine.
8. Ask the respondent to perform the procedure, check that:
   - They maintain an upright position and do not lean forward
   - They breathe in quickly and completely fill the lungs with air at start of test

- They do not pause or hesitate before they breath out or during the test
- They do not obstruct the mouth piece with their teeth or tongue. Tongue should be down and teeth around the mouthpiece. Do not purse lips.
- They have a good seal around the mouth piece and there are no air leaks
- They do not cough during the test
- They do not take an extra breath in during the test
- They do not close their glottis during test.
- They do not stop the test early but carry on breathing out into the machine until their lungs are empty and they cannot breathe out anymore. They may need lots of encouragement to do this.

9. You must give strong verbal encourage throughout the test e.g.

'And blow down the tube…and keep blowing…and keep blowing…and keep blowing!'

10. Repeat the test until you have 3 attempts which fit the criteria listed above (an **acceptable** result) – observe for mistakes each time and correct and encourage patient. Allow the patient to pause for around 30 seconds after each test and take some normal breathes. Do not allow more than 8 attempts.
11. When you have **3 acceptable results** review the 2 largest measurements

- are the two largest values of FVC within 0.150 L of each other?
- are the two largest values of FEV1 within 0.150 L of each other?

12. If the answer is yes to these 2 questions then you can stop testing and record the 2 highest results for FVC and FEV1 and PEFR.
13. If the answer is no to both or either of these 2 questions then continue testing. Observe for mistakes each time and correct and encourage patient. Allow the patient to pause for around 30 seconds after each test and take some normal breathes. Stop when the two largest values of FVC within 0.150 L of each other and are the two largest values of FEV1 are within 0.150 L of each other. (Only include **acceptable** results). Record the 2 highest results for FEV1 and FVC and PEFR.

14. Do not perform more than 8 attempts. If you do not get values within 0.150L then simply record the **largest 3 acceptable** measurements you made. If you are unable to record any acceptable measurements make a record of the **3 best results** and why they were unacceptable e.g. coughing during procedure, not full expiration etc.
15. Stop at any time if the respondent feels discomfort, dizziness or unwell.
16. When the test is completed ask the respondent to dispose of the mouth piece themselves into your clinical waste bag. Clean the machine with medical alcohol – ensure you clean all surfaces and the tube thoroughly.
17. Remove gloves and put into clinical waste bag
18. Clean hands thoroughly with soap and water or alcohol gel and thank the respondent.
19. Take clinical waste back to the health centre for disposal. This waste should be handled with gloves and wash hands after handling it.

Talk to your supervisor if any concerns.

Notes:

1. Only the medical personnel should perform spirometry
2. Key thing: maximal inspiration; a "blast" of exhalation; continued complete exhalation to the end of the test
3. demonstration and practice
4. common mistakes
5. examples of different results
6. start and stop button
7. clinical waste
8. hand wash and medical alcohol supply
9. record the temperature?
10. how to record the data

2. Spirometry Consent

We would like to measure your lung function by undertaking spirometry testing. This test will not be used for diagnosis or to give you any treatment but it will help us learn about the effects of cooking smoke on lung function in the Samlout population. Spirometry is a simple and very low risk test. We will ask you some questions first to ensure it is the test will be safe for you to complete.

If the answer to any of the following questions is **yes** then **do not** perform spirometery in the participant.

Do you ever cough up blood? Yes/No

Have you ever had a pneumothorax (a hole in the lung wall)? Yes/No

Do you have any heart problems or regular chest pain? Yes/No

Have you ever had a stroke? Yes/No

Have you ever had any surgery to your chest, abdomen, brain, ears or eyes? Yes/No

Have you ever had a pulmonary embolism (blood clot on your lung)? Yes/No

Have you ever been told you have an aneurysm (ballooning of a blood vessel)? Yes/No

Have you had a chest infection in the last 6 weeks? Yes/No

Have you had a fever, **new** cough, **new** chest pain or **new** sputum **new** breathlessness production within the last 6 weeks? (do not include **chronic** cough, sputum, breathessness) Yes/No

Have you had any recent ear infections or other ear problems? Yes/No

Are you pregnant? Yes/No

Do you feel unwell in anyway today e.g nausea, diarrhoea, fever? Yes/No

Have you or anyone else in your family or household ever been diagnosed with:

- TB Yes/No

- HIV Yes/No
- Hepatitis Yes/No

Was the blood pressure reading systolic >200 mm Hg, diastolic >120 mm Hg? Yes/No

Does the participant have any obvious open sores or bleeding around lips, mouth or teeth? Yes/No

<u>If the answer to all of the above questions is no then move on to explain the test and ask for consent. If the answer to any of the above questions is yes then do not gain consent and do not perform spirometry, move on to the next section of the survey.</u>

<u>Explain the procedure to the participant</u>

Spirometry tests how your lungs work by measuring how much and how fast air moves out of your lungs

You will be asked to take a deep breath in and blow the air out as hard and fast as you can into this small machine (show machine). This machine measures the amount of air you have in your lungs and how well you can blow the air out. You will need to do this between 3 and 8 times to get an accurate measurement.

To get accurate results it is very important that you blow out as fast and as long as you can so you empty all the air from your lungs. This can feel uncomfortable but it is not harmful or dangerous for you to do this. It is very important to follow the instructions to get reliable results.

You can stop the test at any time.

<u>Explain the risks to the participant</u>

Spirometry may make you cough, feel breathless or feel lightheaded. This will go away shortly after the test is finished.

Spirometry is a very low-risk test. However, blowing out hard can increase the pressure in your chest, tummy (abdomen) and eyes. We have already asked you about any conditions which may be affected by this so the risk of any problems is extremely small.

There is a potential risk of transmission of infections so we advise you not to do the test if you have or have had an infection recently and we clean the equipment and use a new mouth piece for every patient which is then thrown away. The mouth pieces only let you breathe air out so you cannot breathe in any air from a previous person. These all make the chance of infection extremely small.

Ask the participant if they have any questions about the test? And answer any questions they have.

Please read this statement aloud to the participant and ask them participant to sign or thumb print.

I confirm that I have answered the questions regarding my health honestly and that the test and it's risks have been explained to me. I confirm I have had the opportunity to ask any questions. I consent to undertake spirometry lung function testing.

Signature of participant.………………………..Date…………………………….

Surveyor please read and sign the statement below

I have verbally explained all information on this sheet and allowed the participant time to ask questions before gaining consent.

Signature of surveyor……………………………..Date……………………

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