BARGAINING POWER, SOCIAL CAPITAL AND ENVIRONMENTAL HEALTH

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ABSTRACT

Ipsita Das: Bargaining Power, Social Capital and Environmental Health
(Under the direction of Pamela Jagger)

Environmental health is a huge contributor to the global burden of disease, particularly in low- and middle-income countries in Asia and sub-Saharan Africa. However, there is a dearth of empirical evidence on the determinants of behaviors that can potentially reduce the burden on human health, time, and education and livelihood opportunities. This dissertation comprises three empirical chapters examining understudied determinants of environmental health behavior adoption and health outcomes, as the necessary first step, prior to generalizing a one-size-fits-all program based on anticipated benefits. In the first chapter, in a panel of nationally representative Indian households, I estimate the effect of women's bargaining power on households' adoption of environmental health behaviors. The results show that objective measures of women's household-level bargaining have positive effects on environmental health behaviors among rural households. However, subjective measures of women's autonomy have negative effects on the same suite of outcomes. In the second chapter,

using the same data set as the previous chapter, I examine the effects of structural and cognitive social capital on Indian households' choice of clean cooking and safe sanitation. The analysis demonstrates variation in results across rural and urban samples, based on different social capital dimensions. In the third chapter, using baseline data from an ongoing randomized controlled trial in Rwanda, I analyze the microenvironment factors that affect under-five children's health. Results show that important housing and cooking area infrastructure reduce the prevalence of household air pollution-related health symptoms in this age group.

To my parents, Sagarika and Prasanta Das

&

My maternal grandfather, Banamali Patnaik

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LIST OF ABBREVIATIONS

AQG	Air quality guidelines
ARI	Acute respiratory infection
CO	Carbon monoxide
CLTS	Community-led total sanitation
DW	Drinking water
EH	Environmental health
FE	Fixed effects
GACC	Global Alliance for Clean Cookstoves
GBD	Global burden of disease
GPS	Global positioning system
GoI	Government of India
HAP	Household air pollution
HW	Handwashing
ICS	Improved cookstoves
IHDS	India Human Development Survey
INR	Indian Rupee
LPG	Liquefied petroleum gas
LPM	Linear probability model
OLS	Ordinary least squares
OBC	Other Backward Class
OSM	OpenStreetMap
NREGS	National Rural Employment Guarantee Scheme
PM	Particulate matter
PPM	Parts per million

PAHAL	Pratyaksha Hastaantarit Labh
PSU	Primary sampling unit
RCT	Randomized Controlled Trial
RWF	Rwandan Franc
SC	Scheduled Caste
SHG	Self-help group
SSA	Sub-Saharan Africa
SDG	Sustainable Development Goal
ST	Scheduled Tribe
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
WaSH	Water, sanitation and hygiene
WTP	Willingness to pay
WHO	World Health Organization
YLL	Years of life lost

CHAPTER 1: INTRODUCTION

Environmental factors are responsible for nearly 23% of global deaths, and low and middle-income countries in Asia and sub-Saharan Africa disproportionately bear the greatest share of disease burden (WHO 2016). The three leading causes of years of life lost (YLL), globally, (ischemic heart disease, stroke and lower respiratory infections) are linked to household air pollution (HAP), caused from burning solid fuels (wood, crop residue, dung, charcoal and coal) in inefficient stoves for meeting daily energy needs of cooking, heating and lighting (GBD 2016 Causes of Death Collaborators 2017). Black carbon emitted during incomplete combustion of burning solid fuels is the second largest contributor to global warming (Ramanathan and Carmichael 2008). The third and fourth leading causes of YLL (lower respiratory infections and diarrheal diseases, respectively) are associated with inadequate and unsafe water and sanitation (GBD 2016 Causes of Death Collaborators 2017). The use of polluting energy and unsafe water and sanitation also imposes time burden on families, particularly women and children. Owing to time spent collecting fuel and water, children lose out on educational opportunities, and women on possibly engaging in income-generation.

There are environmental health (EH) technologies that households in the developing world can adopt, and behaviors that they can engage in that not only improve human health but also protect the environment. However, their levels of adoption are abysmally low. In the face of multiple challenges of HAP and poor water and sanitation, it is critical that we understand not just what EH interventions and programs work, but also what facilitates them to work. While many socio-demographic drivers of EH adoption, such as income, education, household assets, location, socially marginalized status, family size, and costs of technologies have been rigorously studied, there still remain many unknowns (Lewis and Pattanayak 2012; Rehfuess *et al* 2014). The role of consumer preferences (Jeuland *et al* 2015; Orgill *et al* 2013), women (Miller and Mobarak 2013; Pachauri and Rao 2013; Puzzolo *et al* 2013), peer influence (Beltramo *et al* 2014; Bonan *et al* 2017; Miller and Mobarak 2015), and non-governmental organizations in EH adoption is relatively understudied.

While the Global Alliance for Clean Cookstoves (GACC) has set a goal of encouraging adoption of clean cookstoves and fuels in 100 million households by 2020 (GACC 2017) to address the HAP problem, catalyzing the shift from traditional cooking to clean cooking solutions is challenging. This is particularly true in settings where markets for improved energy are thin or non-existent. Therefore, additive solutions may be necessary while countries make the clean energy transition. Though there is recent literature of the role of ventilation improvements and housing structure on minimizing HAP pollutant exposure (Ruth *et al* 2014; Yadama *et al* 2012), evidence of the role of infrastructure in reducing health symptoms linked to HAP is limited.

This dissertation comprises three empirical papers attempting to study previously understudied determinants of EH behavior adoption, and HAP-related health outcomes. Each paper focuses on advancing understanding of the household and community processes that could assist or hinder EH: from understand decision-making of women and community involvement and how they relate to household take-up of environment and health-improving behaviors, to infrastructural factors that reduce under-five children's HAP-related health symptom prevalence. In totality, these papers examine ways in which EH programs can be used to encourage uptake of interventions, and potentially drive sustained and exclusive use in the long-run.

With the sustainable development agenda reinforcing the central role of women in achieving goals for clean water and sanitation (SDG 6), and clean energy for all (SDG 7), there is a need for establishing ways in which women can catalyze change. In my first chapter, using nationally representative household-level panel data from the 2005 and 2012 rounds of the India Human Development Survey, I examine whether women's bargaining power explains household adoption of EH behaviors. Using household fixed effects models, I find significant positive effects of women's co-ownership of bank account on likelihood of household adoption of clean cooking, toilets and drinking water treatment in rural areas. Women's co-ownership of house or rental agreement also has significant positive impacts on rural households' likelihood of clean cooking and handwashing with soap. However, there are no significant results in the urban sample. With the Indian Government's recent programs on expanding financial inclusion, accelerating liquefied petroleum gas (LPG) provision, and strengthening previous sanitation schemes, this paper provides guidance on policy levers that can enhance women's agency, and increase EH behaviors that improve human well-being.

Community cohesion is a collective asset that can have positive externalities, as evidenced in the impact of social networks on various development, health and agricultural outcomes. Their role in facilitating adoption of EH interventions is, however, not well-understood. In Chapter Two, using the same data set as my first chapter, I examine whether structural and cognitive social capital enable or limit household adoption of EH technologies in India. I find strong positive effects of linking and bridging social capital on household choice of clean cooking, but strong negative effects of political participation and bonding social capital on clean cooking. Consistent with the broader development literature, bonding social capital and social cohesion have strong positive effects on household adoption of toilets. These results vary by geographic location, underscoring the need for governments to leverage different social structures in EH programs.

Exposure to HAP from cooking and heating with solid fuels is a major risk factor for morbidity and mortality in sub-Saharan Africa. Children under five are particularly at risk for acute lower respiratory infection. In Chapter Three, along with my coauthors, Joseph Pedit, Sudhanshu Handa and Pamela Jagger, I use baseline data from a randomized controlled trial evaluating a household energy intervention in Gisenyi, Rwanda to investigate the role of the microenvironment as a determinant of children's HAP-related health symptoms. We examine the association between likelihood of HAP-related health symptom prevalence and characteristics of the microenvironment, including: dwelling and cooking area structure; distance to nearest road; and tree cover. We find that children residing in groups of enclosed dwellings, in households that cook indoors, and in households proximate to tree cover, are significantly more likely to experience symptoms of respiratory infection, illness with cough and difficulty breathing. On the other hand, children in households with cemented floors and ventilation holes in the cooking area, are significantly less likely to experience the same symptoms. Our findings suggest that in addition to promoting increased access to clean cooking technologies, there are important infrastructure and microenvironment-related interventions that mitigate HAP exposure.

In summary, my thesis has important policy implications. Our understanding of intra-household decision-making on EH adoption is limited; I demonstrate that objective measures of women's bargaining, such as co-ownership of a bank account and house or rental agreements, have a positive role to play in EH behavior adoption. These results coincide with the wider global policy landscape, and specific policies in India aimed at increasing financial access to the previously unbanked, increasing LPG provision and promoting safe sanitation. In examining different dimensions of social capital, I show that existing social groups and institutions at the community level can initiate positive EH behavior change. This information finds resonance in existing group-based programs in India on child nutrition and rural health. Finally, in presenting evidence that key housing and cooking area structural factors are related with child health symptoms, there is scope for infrastructure-related policy interventions. In each of these study settings, these research insights can enhance EH behavior change and contingent on exclusive and sustained use, improve human health, environmental quality and regional climate.

REFERENCES

Beltramo, T., Blalock, G., Levine, D. I., & Simons, A. M. (2015). Does peer use influence adoption of efficient cookstoves? Evidence from a randomized controlled trial in Uganda. *Journal of Health Communication*, 20(sup1), 55-66.

Bonan, J., Battiston, P., Bleck, J., LeMay-Boucher, P., Pareglio, S., Sarr, B. A., & Tavoni, M. (2017). Social interaction and technology adoption: experimental evidence from improved cookstoves in Mali. *Working Paper.*

Global Alliance for Clean Cookstoves (2018). 2017 Progress Report.

GBD 2016 Causes of Death Collaborators (2017). Global, regional and national age-sex specific mortality for 264 causes of death 1980-2016: systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, 390(10100), 1151-1210.

Jeuland, M. A., Bhojvaid, V., Kar, A., Lewis, J. J., Patange, O., Pattanayak, S. K., ... & Ramanathan, V. (2015). Preferences for improved cook stoves: Evidence from rural villages in north India. *Energy Economics*, 52, 287-298.

Lewis, J. J., & Pattanayak, S. K. (2012). Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives*, 120(5), 637.

Miller, G., & Mobarak, A. M. (2013). Gender differences in preferences, intra-household externalities, and low demand for improved cookstoves (No. w18964). *National Bureau of Economic Research*.

Miller, G., & Mobarak, A. M. (2015). Learning about new technologies through social networks: Experimental evidence on nontraditional stoves in Bangladesh. *Marketing Science*, 34(4), 480-499.

Orgill, J., Shaheed, A., Brown, J., & Jeuland, M. (2013). Water quality perceptions and willingness to pay for clean water in peri-urban Cambodian communities. *Journal of Water and Health*, 11(3), 489-506.

Pachauri, S., & Rao, N. D. (2013). Gender impacts and determinants of energy poverty: are we asking the right questions? *Current Opinion in Environmental Sustainability*, 5(2), 205-215

Prüss-Üstün, A., & Neira, M. (2016). *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks*. World Health Organization.

Puzzolo, E., Stanistreet, D., Pope, D., Bruce, N., & Rehfuess, E. (2013). Factors influencing the large-scale uptake by households of cleaner and more efficient household energy technologies. *London: EPPI Centre*.

Ramanathan, V., & Carmichael, G. (2008). Global and regional climate changes due to black carbon. *Nature Geoscience*, 1(4), 221.

Rehfuess, E. A., Puzzolo, E., Stanistreet, D., Pope, D., & Bruce, N. G. (2014). Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environmental Health Perspectives*, 122(2), 120.

Ruth, M., Maggio, J., Whelan, K., DeYoung, M., May, J., Peterson, A., & Paterson, K. (2014). Kitchen 2.0: Design guidance for healthier cooking environments. *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, 151 169.

Yadama, G. N., Peipert, J., Sahu, M., Biswas, P., & Dyda, V. (2012). Social, economic, and resource predictors of variability in household air pollution from cookstove emissions. *PloS One*, 7(10), e46381.

CHAPTER 2: WOMEN'S BARGAINING POWER AND HOUSEHOLD ADOPTION OF ENVIRONMENTAL HEALTH BEHAVIORS: EVIDENCE FROM INDIA

Introduction

The United Nations Development Programme's (UNDP's) fifth Sustainable Development Goal (SDG 5), aims to promote gender equality not just as a human right but as being central to sustainable development. There is recognition that female empowerment[1] has multiplier effects at the household and societal levels, across various domains. The realization of SDG 6 (clean water and sanitation) and SDG 7 (affordable and clean energy) is closely tied to SDG 5. Gender relations and the transformation of the energy system, especially for the 1.1 billion without electricity access and approximately 3 billion people without access to clean cooking, are interrelated (Clancy 2016). While renewable energy and energy efficiency projects have a major role to play in increasing energy access, they are likely to be more effective when accounting for equality of gender (Rojas *et al* 2011). In addition to facilitating the clean energy transition, women can also benefit in many ways from investments in the

[1]Kabeer (1999) defines empowerment as a dynamic process comprising three phases: (1) status quo referring to initial endowments, rights over resources and household decision-making; this also includes voting rights or traditional norms (2) increase in agency resulting from reforms and changing social norms (e.g. land titling, land inheritance rights) (3) achievements in the form of responding to new agency for the welfare of the woman and others.

energy sector, through inclusion in formal sector employment, and livelihood opportunities in micro- and small-scale enterprises, including those in renewable energy supply chains (Shankar *et al* 2015). As approximately 2.3 billion people lack a basic sanitation service, and 844 million people lack a basic drinking water service (WHO and UNICEF 2017), women and their families stand to gain from water, sanitation and hygiene (WaSH) improvements through reduced time burden, opportunities for education and paid work, and reduction in adverse health consequences and nutritional deficiencies (Global Burden of Disease 2016 Causes of Death Collaborators 2017; Montgomery and Elimelech 2007; Nelson and Kuriakose 2017; Rehfuess 2006; WHO and UNICEF 2017).

Despite recognition of the critical role of women in achieving development outcomes (e.g. children's educational investments, survival rates, nutrition, anthropometrics; food budget shares; agricultural production), there is a dearth of empirical evidence examining women's bargaining power in relation to household choice of clean energy and WaSH. Much of the empirical literature assumes that the only bargaining is between spouses, and other members are assumed to have a passive role within households (Doss 2013; Pachauri and Rao 2013). As the latest sustainable development agenda emphasizes universal access to clean energy, clean water and sanitation, and the role of women in accelerating this transition, it is particularly important to understand bargaining within households in a country where 64% of the population uses solid fuels for cooking (GACC 2016) and 524 million people still practice open defecation (UNICEF 2017). As per the latest India-specific Global Burden of Disease (GBD) estimates, air pollution and unsafe WaSH were the leading environmental risk factors for disability-adjusted life years in 2016 (Dandona *et al* 2017).

Using a nationally representative panel (between 2005 and 2012) of rural and urban Indian households, this paper examines the relationship between women's bargaining power and adoption of environmental health (EH) behaviors. Decision-making within households, especially in a joint family system as is common in India, is a "culmination of negotiation between different household members" (Richards *et al* 2012). In considering women's decision-making in the household vis-à-vis their husbands, and senior male and female household members, this paper is a departure from previous studies on the binary assessment of gender roles in a single dimension of power relations. Specifically, I include women's control over resources (sole or joint ownership with a household member of a bank account or house) and perceived autonomy in the household (survey-based score). Using both objective indicators about control in household resources and a subjective measure of perceived decision-making power, allows for a more complete characterization of women's bargaining power within households by illuminating potential channels. As for the outcomes, this paper acknowledges the synergies between energy and related fields of WaSH (Ferroukhi *et al* 2015), and thus considers EH technologies (clean cooking i.e. non-biomass stove and liquefied petroleum gas or LPG cooking fuel, toilets and piped drinking water) as well as WaSH behaviors (drinking water treatment and handwashing with soap after defecation). Women's influence over EH behaviors is likely to vary depending on their access to these services. There are stark differences between rural and urban India in the provision of water and sanitation[2] services, and access to energy[3]. Recognizing this heterogeneity and that over 69% of India's population resides in rural areas, this paper separates analyses for rural and urban households.

To preview results, models with household fixed effects show that women's co-ownership of a bank account positively affects households' likelihood of adopting clean cooking, toilets and drinking water treatment in the rural sample. Likewise, female co-ownership of house/rental agreement positively affects likelihood of adoption of clean cooking and handwashing with soap among rural households. Autonomy score, surprisingly, has negative effects on most EH behaviors, suggesting feelings of

[2]According to the 2011 Census Survey of India, 47% of Indian households have a water source within their house premises (35% in rural and 71% in urban areas) and, 36% rural households collect drinking water from a source within 500 meters of the house compound, while the same percentage of urban households collect drinking water from a source within 100 meters of their premises. While over 81% urban households have a latrine facility, only 31% rural households have a latrine; the national average is 47%.

[3]Over 93% urban households are electrified, while only 55% rural households have electricity, with a national average of 67% household electrification. A meagre 12% rural Indian households use clean cooking energy (LPG, electricity, biogas), while over 66% urban households use the same; national average is 29% (Census of India 2011).

autonomy might not be a good proxy for decision-making power, while effective control of resources is.

Over the last three years, there have been some policy changes at the national level in India, intended to address these EH and related social challenges. The *Jan Dhan Yojana* (People Money Scheme), launched in August 2014, aims to extend financial services (banking, savings and deposit accounts, remittance, credit, insurance, pension) to the previously unbanked across rural and urban India. This financial inclusion scheme has the potential to benefit women with previously no bank accounts. Restructuring India's previous clean sanitation program, the *Swachh Bharat Abhiyan* (Clean India Mission), launched in October 2014, aims to eliminate open defecation through construction of toilets; demand creation through increased information, education and communication; strengthening of delivery mechanisms, and monitoring outputs (toilet construction) and outcomes (toilet use). Subsequently, in November 2014, the Government of India (GoI) modified and relaunched the previous national government's *Pratyaksha Hastaantarit Labh* (PAHAL) scheme (also known as the Direct Benefit Transfer of LPG), wherein LPG subsidy is transferred directly to consumers' bank accounts, restricting the role of middlemen in LPG subsidy distribution.

The GoI has envisioned creation of a secure and seamless digital payments infrastructure that links the *Jan Dhan Yojana*, universal biometric identification (*Aadhaar* card) and mobile phone numbers to provide direct subsidy transfers. Programs like

PAHAL have shifted fuel subsidy payments directly to people's accounts, allowing LPG sale at market rates. The 'Give It Up' campaign started in March 2015 aimed to motivate better-off consumers to voluntarily give up their subsidy and introduce direct transfer of the LPG subsidy to households that previously could not afford LPG. In May 2015, under the *Pradhan Mantri Ujjwala Yojana*, the GoI committed to providing 50 million LPG connections in three years. Around the same time (January 2015), the government also launched the '*Beti Bachao, Beti Padhao*' (Save Daughter, Educate Daughter) scheme that is targeted at the declining child sex ratio and connected issues of women's empowerment over a life cycle continuum. Components of this scheme include awareness campaigns and interventions comprising first trimester registration of pregnancies, institutional deliveries, and prohibition of sex-determination.

In light of these six major policy reforms, this paper aims to provide guidance on effective policy levers that can improve women's positions in society, enhance clean cooking and related EH behavior adoption, and achieve human capital-improving outcomes in the long-run. This paper is particularly relevant given recent research that argues for the inability to leverage gender differences in preferences regarding improved cookstoves (ICS) adoption if there is no wider social change that allows women to exert their choices in household resource use (Miller and Mobarak 2015; Mohapatra and Simon 2015).

Literature Review

The unitary model of the household assumes it to be a single consumption unit, where the distribution of income or other bargaining power indicators do not impact outcomes (Becker 1991). In the alternative collective model, husbands and wives are individual decision-makers, and following the "sharing rule"-a function of prices, household income, sex ratios etc.-, resources are distributed among spouses (Chiappori 1992, Chiappori *et al* 2002). However, multimember households have varying dynamics and differing resource allocation affects outcomes (Doss 2013). Unequal social norms and practices shape men's and women's behavior differently and asymmetrically (Goetz 1997; Van Staveren and Odebode 2007). Three dimensions of bargaining discussed in the literature include (a) bargaining over objects, e.g. unpaid labor division regarding cooking and child care; (b) endogenous preferences of men and women formed by beliefs and expectations; and (c) ways of communication and negotiation that demonstrate bargaining agency (Agarwal 1997; Kabeer 1999; Sen 1990).

Studies have argued for female ownership of land, property and assets, and access to cable television as a source of female autonomy and bargaining power (Agarwal 1994, 1997; Allendorf 2007; Anderson and Eswaran 2009; Jensen and Oster

2009; Kabeer 1999; Mishra and Sam 2016)[4]. Increasing women's access to financial resources (e.g. commitment savings products, microloans and household expenditures) increases their self-reported decision-making, ownership of female-specific durables (Ashraf, Karlan and Win 2010)[5], household assets and incomes (Garikipati 2008; Prennushi and Gupta 2014)[6], household food budget shares (Porter 2016), and their children's education and nutrition outcomes (Attanasio and Lechene 2002; Doss 2006; Hoddinott and Haddad 1995; Menon, Van Der Meulen Rodgers and Nguyen 2014; Quisumbing and de la Briere 2000; Quisumbing and Maluccio 2000; Rubalcava, Teruel and Thomas 2009).

Through improvements in bargaining power, women's ownership of land and other immovable assets could encourage their economic development and enable their households to recover from economic shocks (Agarwal 1994, Deere and Doss 2006, Peterman 2011). Land allocation and inheritance reforms significantly increase girls'

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[4]Jensen and Oster (2009) create a single autonomy measure, ranging from 0 to 1, by averaging the values of six variables (household decision-making about obtaining healthcare for oneself, purchasing major household items, whether or not to visit/stay with family members/friends; permission from husband to visit the market, visit friends/relatives; whether women were allowed to keep money aside to spend as they desire), where higher values indicate more autonomy.

[5]Ashraf, Karlan and Yin (2010) create an index of women's sole or joint decision-making power by taking an equally weighted mean of women's responses to 9 decision-making questions.

[6]Garikipati (2008) defines women as 'empowered' if they have a positive score on three or more of the following indicators: ownership of household assets or incomes, control over minor finances, control over major finances, say in household decisions, work time allocation and division of domestic chores.

education attainment (Deininger *et al* 2013) and weight-for-age (Wang 2014), women's autonomy[7] (Mookerjee 2017), upkeep of soil conservation activities, particularly for female-headed households (Ali, Deininger and Goldstein 2014), and security of tenure, agricultural investments and women's engagement in agriculture decisions (Santos *et al* 2014). Increase in women's household bargaining power, owing to other exogenous changes has been empirically found to positively impact numerous development outcomes. Pensions received by women in South Africa had a higher impact on girls' anthropometrics (height for age, weight for height) but no significant impact on boys' health status (Duflo 2003). Increase in hours worked by adult women and educational investments in children, resulted from changes in marriage law in Brazil that provided alimony rights and duties to cohabiting couples (Rangel 2006). There is also evidence from China that increasing female agricultural income increases survival rate for girls and children's education attainment (Qian 2008). More recently, Kalsi (2017) demonstrates the positive impact of female political seat reservation on higher birth order girls' survival, after implementation of state-level female political seat reservations in India.

In the agriculture sector, there are differences by gender in crop choices and labor divisions that vary by geography (FAO and IFPRI 2014). There is evidence of

[7]Mookerjee (2017) measures autonomy using binary variables for two questions on women's mobility and seven questions on women's joint or sole decision-making in the household.

increase in agricultural production owing to individual's political hierarchy position (Goldstein and Udry 2008), and gender differences in access to agricultural inputs affecting adoption of improved crop technology (Doss and Morris 2000). Differences in agricultural input adoption result from households' awareness of land rights (Deininger, Ali and Yamano 2008) and access to credit and cash (Gladwin 2002). There is also evidence to the contrary: women's participation at multiple levels of decision-making may not necessarily have positive environmental and development outcomes (Mwangi *et al* 2011).

Proxies for women's status (e.g. secondary school enrollment, contraceptive prevalence rate, fertility rates, female labor participation, male first child, intra-household influence) have been used to predict use of solid fuels (Austin and Mejia 2017), household biomass energy per capita (Burke and Dundas 2015), clean fuels (Kishore and Spears 2014), and non-biomass chimney stoves (Mohapatra and Simon 2015)[8]. Among the few randomized controlled trials (RCTs) conducted on clean cooking, there is evidence of women's higher preferences for ICS but low decision-making authority over purchases (Miller and Mobarak 2013). While rural Ethiopian

[8]Mohapatra and Simon (2015) use an ordered variable for women's intra-household role, wherein women decide alone, in consultation with men, men decide but consult women and men decide alone on what household appliances to purchase.

women's intra-household bargaining power[9] increases households' willingness to pay (WTP) for ICS (Hassen *et al* 2015), female-headed rural Indian households and female respondents have lower WTP for ICS (Jeuland *et al* 2015). There is need for aiming ICS promotional campaigns at both women and men to increase overall household WTP, since men usually have higher control over expenditures and control decisions relating to purchase of a new technology (Puzzolo *et al* 2013). The reverse is also possible: in households where women's status is higher, women may still choose to sacrifice investing in products or technologies that improve their well-being in favor of spending on resources that improve the well-being of the household (World Bank 2015). Existing literature ignores women's bargaining power with respect to access to energy resources, possibly because most improved energy interventions provided to households have either been heavily subsidized or are free (Pachauri and Rao 2013).

Studies in the WaSH sector argue for women's involvement in the development and sustenance of WaSH interventions (Hoque *et al* 1994; Pardeshi 2009; Smith *et al* 2004; Wilson and Chandler 1993). RCT studies find that participatory women's groups lead to significant decreases in under-five morbidities from fever and acute respiratory infections (Younes *et al* 2014), and social marketing sanitation campaigns targeted to households with marriageable-age boys, significantly increase toilet coverage,

[9]Hassen *et al* (2014) use nine survey measures of decision-making asked both to husbands and wives. Autonomy index created from these nine measures is instrumented with number of surviving adult male siblings and spouses' birth order.

particularly in marriage markets where women were scarce (Stopnitzky 2016). Latrine ownership in India is associated with married women in the household (Coffey, Spears and Vyas 2017), and women's access to radio and television ownership (Lee 2017); qualitative evidence finds women's non-involvement in sanitation-related decision-making owing to their low socio-economic position and incapacity to affect household's financial decisions (Routray *et al* 2017). However, not many sanitation intervention studies consider cultural factors (Garn *et al* 2016).

As discussed above, the quantitative evidence of the effect of women's empowerment on household choice of EH behaviors is limited and inconclusive, and does not reflect a representative sample of populations. The data and setting used in this paper provide an opportunity to rigorously test this hypothesis.

Data

This paper uses data from the Indian Human Development Survey (IHDS), conducted by the University of Maryland, College Park and the National Council for Applied Economic Research, New Delhi, India (Desai and Vanneman 2005, 2011-12). IHDS-I (collected in 2004-05) is a nationally representative survey of 41,554 households in 1,503 villages and 971 urban neighborhoods across India. IHDS-II (collected in 2011-12) re-interviewed a majority of these households (42,152). A three-stage clustered sampling design was used to select the IHDS sample. Both rounds of data contain detailed information on household and individual socioeconomic and demographic factors, education, household farm, livestock, wage and salary work, non-farm business, income, and household consumption. The women's questionnaire, administered privately to ever-married women in the age group of 15-49 years, collected data on water, sanitation, fuel and energy use in the household, short term and major morbidity, gender relations, marital and fertility history, natal care and anthropometry. IHDS-I interviewed only one eligible woman in each household for detailed questions in the women's questionnaire. For IHDS-II, the same eligible woman from IHDS-I was interviewed, if she was still part of the household, or another eligible woman if not, and a second eligible female if available. I restrict the panel to households and women that were present in both rounds. This paper uses balanced panel data of 49,892 observations (24,946 households from each IHDS round) and Table 2.1 shows the rural-urban and zone-wise analytic sample split.

Measures

The five outcomes of interest at the household-level fall under two broad categories: (A) EH technologies and (B) WaSH behaviors. Three EH technologies I consider are: (1) clean cooking energy (use of non-biomass stove and LPG cooking fuel); (2) toilets; and (3) piped drinking water inside the dwelling. Eligible women were asked which type of stove the household used. For each type of fuel (fuelwood, animal dung, crop residue, kerosene, LPG and coal/charcoal), eligible women were asked (a) whether the household used it for cooking, heating, lighting or a combination of energy services,

(b) where they were procured from, and (c) how much did they pay for what was used in the 30 days prior to the survey. Using these two questions on household choice of stove and fuel, I create a clean cooking energy variable for households that did not use a biomass stove and used LPG fuel for cooking. Women were asked whether the household has a toilet facility of its own and what type (traditional pit latrine, ventilated improved pit latrine or flush toilet). I combine the three toilet types to a single category for whether the household has any type of toilet (coded 1, 0 if household practices open defecation) to create a binary variable. Women were also asked about the household's main source of drinking water. I create a binary variable for whether the household has piped drinking water access (coded 1) or other sources i.e. tube well, hand pump, dug open well or covered well (coded 0).

Two WaSH behaviors analyzed in this paper are: (1) drinking water treatment and (2) handwashing with soap after defecation. Households were asked if during a regular week, they ever treated or purified drinking water by boiling, filtering with a purchased filter, using Aquaguard (branded advanced water purifier) or by adding chemicals (straining with cloth or strainer were excluded). I create a binary variable for drinking water treatment, where 1 was coded if households responded 'always treated' and 0 for other responses. Eligible women were also asked about their handwashing practices; here again I create a binary variable that is coded 1 if women respond 'wash hands with soap after defecation' and 0 if responses are 'no handwashing, or handwashing with water alone or mud/ash.

The three main explanatory variables are proxies for women's bargaining power: (1) sole/joint bank account ownership; (2) sole/joint house ownership/rental paper agreement; and (3) autonomy score[10]. Women were first asked if anyone in their family has a bank account, and if so if they have their name on any of these bank accounts. Using these two questions, I create a binary variable coded 1 if women respond 'Yes' to having their name on a bank account and 0 if either the woman does not have her name on a bank account or if the household does not have a bank account. Women were then asked if they have their name on the ownership or rental papers for their house. I create a binary variable coded 1 if women respond 'Yes' and coded 0 if women respond 'No' or if the household does not own a house or have rental papers.

Women's autonomy in the household is a composite score measured by averaging the score of women's responses to 9 questions indicative of their autonomy in the household [similar to Jensen and Oster (2009) and Ashraf, Karlan and Win (2010)]. A higher score on each of the questions indicates higher autonomy. Eligible women were asked who in the family decides (a) what to cook on a daily basis, (b) whether to buy an expensive item such as a TV or fridge, (c) how many children to have, (d) what

[10]There are strong ($p<0.01$) positive correlations between all three measures of women's bargaining power.

to do if a child falls sick, (e) whom their children should marry; and who has most say in making these decisions. For each of these variables, I assign a score of 3 if women are the sole decision maker, 2 if women make a joint decision with other household members, 1 if women have a say in decision-making but are not the main decision makers, and 0 if women have no say and other household members decide. The women's questionnaire captures information on whether eligible women have to ask permission of their husband or senior family member to go to (a) the local health center, (b) the home of relatives or friends in the village or neighborhood, and (c) the local grocery store. For each of these questions, I assign a score of 3 if women do not have to seek permission and can go alone, 2 if women do not have to seek permission but cannot go alone, 1 if women have to seek permission but can go alone, and 0 if women have to seek permission and cannot go alone. The other binary variable included in creating this score is whether women have cash-in-hand for household expenditures. Women's autonomy score ranges from 0 to 2.8.

Empirical Strategy

Three specifications were used to estimate the effect of women's bargaining power on household adoption of EH behaviors: pooled ordinary least squares (OLS) regression, household fixed effects (FE) and cluster FE[11]. Women's socio-demographics

[11]Linear probability models were used for binary outcomes.

(age, education, has at least one child, hours worked/year) were included in the models to explain their bargaining power. Intra-household externality could inhibit women from adopting behaviors that benefit them and the entire household. Though they prefer health-improving EH behaviors, owing to their liquidity constraints they are unable to act on their preferences, when products are not offered free (Miller and Mobarak 2011). Similar to Miller and Mobarak (2011), I create power differential variables for age and education gap between women and the household head. Following Kishore and Spears' (2014) finding that urban Indian women with a first born male child have higher status in the household, my models include gender of women's first born child. Women's relationship to the household head, and gender of household head are also important determinants of their bargaining power. Consistent with the empirical literature, characteristics of the household controlled for include total number of members, dependency ratio[12], log of per capita total monthly expenditure, and hours of electricity access.

My first estimation uses a pooled OLS model to examine the association between women's bargaining power and household EH behaviors as follows:

$$(1)\ Y_{jt} = \beta_0 + \beta_1 Women's\ bargaining\ power\ indicators_{jt} + \theta Time_t + \alpha_{jt} + \varepsilon_{jt}$$

[12]Dependency ratio was calculated by adding the number of children (15 years and under) and the older population (aged 65+), and dividing that sum by the working-age population (aged 15-64 years).

Where Y_{jt} denotes EH behavior in household 'j' in time 't'; Women's bargaining power indicators=name on bank account, name on house ownership/rental agreement and autonomy score (three separate indicators in the same specification); θ_t=1 if IHDS-II, 0 otherwise; α_{jt} represents household-level characteristics (time-varying and time-invariant), ε_{jt}=error term.

The measures of women's bargaining power may be subject to omitted variable bias owing to measurement error and/or due to unobserved women- and household-specific factors such as their adaptive preferences and ability to convince their husbands or senior family members. Women with higher persuasion-ability are more likely to have higher bargaining power, and subsequently more likely is the household to adopt EH behaviors. While FE models do not address the measurement error problem, they can be used to control for time-invariant characteristics that bias estimates. Since household factors affect women-specific characteristics, next, I use the household FE model to estimate the effect of women's bargaining power on household choice of EH behavior:

(2) $Y_{jt} = \beta_0 + \beta_1 Women's\ bargaining\ power\ indicators_{jt} + \delta_j + \theta_t + \Omega_{jt} + \varepsilon_{jt}$

Where δ_j is the household fixed effects and Ω_{jt} represents household-level time-varying characteristics.

Community-level factors can also determine household dynamics (Agarwal 1997) and as women's bargaining power is largely influenced by social norms and practices, women's empowerment should be analyzed using an institutional approach rather than an individual one only (Mabsout and Van Staveren 2010). Since the combined influence of unmeasured neighborhood-level omitted variables is correlated with the different women's bargaining power measures used in this analysis, omitting them will lead to biased estimates. To correct for this bias, I also use cluster-level or primary sampling unit[13] (PSU) FE estimation:

(3) $Y_{jct} = \beta_0 + \beta_1 Women's\ bargaining\ power\ indicators_{jct} + \rho_c + \theta_t + \Omega_{jct} + \varepsilon_{jct}$

Where Y_{jct} is an EH behavior in household 'j', cluster 'c' in time 't'; ρ_c is cluster fixed effects, Ω_{jct} represents household-level time-varying characteristics in cluster 'c', and ε_{jct} is the error term.

In all the three models, standard errors are clustered by PSU to reflect the IHDS three-stage survey design.

[13]In the IHDS data, primary sampling unit (PSU) is defined as village in the rural sample and neighborhood in the urban sample. In the rural sample (using the IHDS-II rural/urban classification, wherein some PSUs that were classified as rural in IHDS-I are classified urban in IHDS-II), in IHDS-I there were 1,483 PSUs and in IHDS-II, 1,469 PSUs. In the urban sample (also using the IHDS-II rural/urban classification), in IHDS-I there were 986 PSUs and in IHDS-II 1,038 PSUs.

Results

Environmental health behaviors and household characteristics

Similar to the 2011 Census Survey of India that reported 68% rural households (i.e. 16.8 million rural households out of a total of 24.7 million households), nearly 65% of the analytic sample is located in rural areas. An increase[14] in non-biomass stove users is observed in 2011-2012, with rural non-biomass stove users nearly doubling from 9% to 17% (Table 2.2). Compared to non-biomass stove users, a lower percentage of urban households use LPG for cooking. Use of clean cooking i.e. combination of non-biomass stove and LPG cooking fuel increased among rural (5% to 14%) and urban sampled households (37% to 54%). Toilet ownership also increased in rural (by almost 1.5 times), and urban households (from 71% to 82%). Piped drinking water access increased only by 4% for rural households but decreased for urban households by less than 1%. Though there were increases in drinking water treatment, the percentages were low for both rural (9%) and urban households (19%) in 2011-2012. Handwashing with soap increased among rural women by 1.5 times and among urban women by 1.2 times.

The percentage of rural women with names on bank account (Table 2.3) nearly tripled in 2011-2012 (from 13% to 39%), while it almost doubled for urban women (from 26% to 48%). While women's sole or joint house ownership or rental agreement

[14]Results in this paper report statistically significant changes only, unless stated otherwise.

remained below 22% across both survey rounds, there were increases over time for both rural and urban women. The mean autonomy score increased for rural women but decreased for their urban counterparts over time. At baseline, rural and urban women's highest decision-making score was regarding cooking (2.1 and 2.2, respectively), followed by child sickness-related action (1.2 and 1.3, respectively), and number of children (Table 2.4B). For all three indicators of permission-seeking, women scored lower in 2011-2012 i.e. higher percentage of rural and urban women sought permission from a household member. Over 90% rural and urban women had money to spend on household expenditures in 2011-2012.

There are observed changes in household size and dependency ratio (Table 2.4A). While there was increase in daily hours of electricity access among rural households (from 10 to 12), there was a marginal but significant decrease in the same among urban households. Both rural and urban (not statistically significant) households reported increase in land ownership, while only urban households reported increase in at least one non-farm business between survey rounds. Adjusting for inflation, there were increases in households' monthly per capita consumption (614 INR[15] for rural households and 2,829 INR for urban households). Female-headed households almost doubled in 2011-2012, and there is an increase in the education level of the household

[15] 1 USD=64.33 INR (as of February 5, 2018)

head. Rural eligible women, on average, at baseline were 33 years, had completed 3 years of education and had 3 children (Table 2.4B). Urban eligible women at baseline, were similar to their rural counterparts in age (34 years), but had fewer children (2) and higher years of education (6 years).

Factors associated with bargaining power of women

Prior to examining the effects of women's bargaining power on household adoption of EH behaviors, I first examine the determinants of women's household-level bargaining. There are differences in measures of women's bargaining power for both rural and urban households[16]. Women co-owning bank accounts and house or rental agreements are older, work longer hours per year, belong to female-headed households, and are in households with lower dependency ratio. These results are stronger for rural women. Women with higher autonomy score are younger (only urban sample), less educated (rural sample only), and have lesser age gap with the household head, have at least one child, and work longer hours per year. Compared to the daughter-in-law, wife of the household head has higher perceived autonomy. I also find that higher autonomy score women belong to female-headed households, households with fewer members, higher dependency ratio (only rural households), lower per capita monthly consumption (only rural sample) and longer hours of electricity (Table 2.5).

[16]Only household FE results are presented here, to be consistent with intra-household bargaining theory. Results from pooled OLS and cluster FE regressions are not substantively different.

Adoption of EH behaviors: Results from fixed effects models

In the naïve regression models (Table 2.6), there is a positive relationship between household adoption of all EH behaviors and women's co-ownership of bank account. Likewise, for the correlation between most EH behaviors (except drinking water treatment in both samples, and piped drinking water in the urban sample) and women's co-ownership of house or rental agreement. In the urban sample, while households with high autonomy score among women, are more likely to have piped drinking water, there is an opposite relationship with clean cooking, toilets and handwashing with soap.

On controlling for time-invariant household characteristics, in the household FE models (Table 2.7)[17], I find that rural women's sole or joint bank account ownership linearly increases the likelihood of household adoption of clean cooking by 2.6 percentage points, toilets by 2.7 percentage points, and drinking water treatment by 2.2 percentage points[18]. Similar to the coefficient on bank account co-ownership, women's co-ownership of a house or rental agreement is linearly associated with a 2.7 percentage-point increase in rural households' clean cooking take-up, but unlike co-

[17]Note that each column in the table refers to a different regression. Controls used in the household FE and cluster FE models are all the covariates included in the models in Table 2.5.

[18]Results from the pooled OLS models are in Appendix A-1. In addition to all the covariates included in Table 2.5, the pooled OLS models also include a dummy for region (North, Central, North-East, East, West and South). Fixed effects model is preferred to the pooled OLS and random effects models following results from the Hausman and Breusch-Pagan tests.

owning bank accounts, having a woman co-own a house/rental agreement, increases handwashing with soap by 4 percentage points. There is no effect of either women's bank or house co-ownership on any of the five EH behaviors in the urban sample. Contrary to hypothesis, women's autonomy score has a strong negative effect on clean cooking and drinking water treatment in the rural sample, and weak negative effect on toilet adoption in the urban sample. In other words, an increase in women's autonomy score by 1-unit linearly decreases households' likelihood of clean cooking take-up by 2.1 percentage points, and drinking water treatment by 1.6 percentage points among rural households, and linearly decreases likelihood of toilet uptake in urban households by 2.6 percentage points.

Turning to the cluster FE models (Table 2.8), I find that rural women's sole or joint bank account ownership linearly increases likelihood of household clean cooking adoption by 2.7 percentage points, which is similar to estimates from the household FE model; latrine adoption by 1.8 percentage points and drinking water treatment by 1.4 percentage points, which are lower estimates but higher statistical significance (especially for clean cooking and drinking water treatment) than those in the household FE model. For urban households, having a woman sole or joint bank account owner linearly increases likelihood of household adoption of drinking water treatment by 3.5 percentage points. Women's co-ownership of a house or rental agreement has strong positive effects on all EH behaviors, except toilet take-up and drinking water treatment in the rural sample, and only toilet take-up in the urban sample. Similar to the household FE model, women's autonomy score has a strong negative effect on rural households' adoption of clean cooking and drinking water treatment, and urban households' toilet take-up.

In exploring the relationship between bargaining power of women and household choice of EH behaviors, though I find more statistically significant coefficient estimates on my main explanatory variables in the cluster FE model, I prefer the household FE model despite its inefficiency and lower precision for the following reasons. First, the similar magnitude of coefficient estimates across models emphasizes the robustness of results. I would prefer using the household FE model as the comparison group for the household is itself in a different time period, which is the best counterfactual provided all other time-varying factors are controlled for. Second, choice of household FE model is supported in intra-household decision-making theory, but the same cannot be argued for cluster-level FE. In subsequent heterogeneity analysis and falsification tests, I use the household FE models only.

Adoption of EH behaviors: Results by caste and region

In the Indian social stratification system, there have historically been differences among caste groups. There is also variation across geographic regions within the country owing to cultural differences and varying levels of socio-economic development. In the study sample, over the 7 year time period, there are differences in outcomes and measures of women's bargaining power, across caste groups and government-assigned regional zones[19]. The pooled OLS models also show differences in results by caste category and region. To explore this further, I conduct disaggregated analysis by caste category and regions using the household FE model (equation 2).

Caste

Except for Other Backward Classes (OBCs), there are no significant effects of women's bargaining power on household EH adoption in other caste categories (Table A-2). I find a strong positive effect of women's bank account co-ownership on OBCs' household adoption of drinking water treatment. Women's co-ownership of house or rental agreement also has a strong positive effect on household take-up of handwashing with soap, but weak positive effect on clean cooking, among OBCs.

Region

There is regional variation in effects of women's bargaining power on household EH adoption (Table A-3). In the North, I find a strong positive effect of women's bank account co-ownership on household adoption of toilets and handwashing with soap. Consistent with the results for all rural households, I find a weak negative effect of autonomy score on clean cooking and drinking water treatment, among the Northern states. In the North-East, I find strong positive effects of women's bank-account and

[19]See Table 2.1 for regional categories.

house co-ownership on clean drinking water-related outcomes (drinking water treatment and piped drinking water, respectively). In the Eastern states, the only significant positive effect (though weak) is that of women's autonomy score on household take-up of handwashing with soap. There are strong results for many outcomes in the Western region. There is a strong positive effect of women's bank account co-ownership on household adoption of drinking water treatment, but stronger positive effects of women's house ownership on household choice of clean cooking, toilets, drinking water treatment and handwashing with soap. Women's autonomy score has a strong negative effect on household choice of toilet, but a strong positive effect on women's handwashing with soap.

Falsification tests: Placebo assets

To test whether the relationship between women's bargaining power and EH behaviors is unique and is not due to omitted heterogeneity in household preferences or status which are unaccounted for, I estimate the relationship between women's bargaining power and household goods preferred by men. Using the household FE model and restricting the sample to households with agricultural land, I use five alternate dependent variables: tube well, electric pump, tractor, diesel pump, and bullock cart. Except for weak positive effects of women's bank account co-ownership on rural households' choice of tube well and electric pump, I find no significant effect of women's bargaining power measures on other agricultural equipment (Table 2.9).

These null results for placebo assets preferred by men rule out an alternate mechanism: that households invest in all types of assets as a result of women's increased bargaining power.

Discussion

The locational heterogeneity in women's bargaining power and EH behaviors presented in my analysis highlights important institutional constraints to be considered in explaining behavioral responses to environmental health programs. This paper contributes to the sparse literature on this topic as follows. First, I include both specific and perceived measures of women's bargaining power to center attention on the differences in EH outcomes based on choice of power measures. Second, in using nationally-representative data from rural and urban settings that are generalizable, I demonstrate geographic variation in adoption of multiple EH behaviors. Then I use household and cluster FE models, separately, to test difference in size and significance of estimates depending on estimation strategy. Prior studies consider women's bargaining relative to their spouses only, and in some analyses in relation to other household members. However, besides individual beliefs and preferences, women's bargaining power in the household is also determined and shaped by societal changes external to the household. Fourth, I show that effects vary by caste and region.

In my analysis of the range of household and individual characteristics that determine each of the three indicators of women's bargaining power, I find women's bargaining power to be positively correlated with age, having at least one child, hours of work, and female-headed household, and negatively correlated with dependency ratio. Women's autonomy score has other determinants as well: lesser age gap between women and household head, relationship to household head (higher if wife or other household member, compared to daughter-in-law), smaller household size, lower monthly per capita expenditure and longer hours of daily electricity. These findings are similar to previous studies that consider these variables.

Focusing on the household FE model to explain differences in results between EH technologies and WaSH behaviors, I find rural women's bank account co-ownership to have strong positive effects on household choice of clean cooking, toilets and drinking water treatment, but no significant effect on private piped water or handwashing with soap. A plausible reason for insignificant results for private piped drinking water could be its reliance not just on household desirability for improvements in environmental quality and purchase, but also on infrastructural support from local governments and community management of water resources, unlike clean cooking options and toilets. Drinking water treatment, however, is a household-level intervention that could be more effective in preventing health-debilitating diseases (Clasen *et al* 2007), and since water treatment options are fairly low-cost, rural women with bank accounts could be making these decisions. Separate analyses by region also show variation. I find strong positive effects of female bank account co-ownership on take-up of toilets in the North and North-East, drinking water treatment in the North-Eastern and Western regions and handwashing with soap only in the North.

House co-ownership has strong positive effects only on clean cooking and handwashing with soap take-up in the rural sample. However, it has strong positive regional effects on adoption of toilets (West), piped drinking water (North-East) and drinking water treatment (West). On this bargaining power measure, strong positive effects are also observed in the Western states for clean cooking adoption and handwashing with soap. It is likely that in the North-East (i.e. Assam), housing infrastructure includes piped water inside the dwelling, or that having a rental agreement allows tenants to either request housing improvements from owners or make changes themselves. Though one would expect to see a positive effect of house/rental paper co-ownership on drinking water treatment as well, one of the reasons for not seeing this result in the current analysis could be either due to households viewing the two behaviors as substitutes, or that households are treating their drinking water at longer intervals (i.e. fortnightly or monthly basis) than is asked in the survey.

There is a negative effect of women's autonomy score on three EH behaviors, across rural and urban samples. These counter-intuitive results could either be owing to women's low preferences for EH behaviors, although studies show women's high preferences for clean cooking (Miller and Mobarak 2013; Hassen *et al* 2015) and toilets

(Stopnitzky 2017); or that the variable incorrectly measures women's bargaining power. As this indicator mirrors women's perceived and stated autonomy, it may not truly suggest their control over resources to exercise their autonomy. In running alternate analyses of the effect of autonomy score without the permission variables (since their scores decrease over time, and could be driving the decrease in autonomy score for the urban sample), I find the same negative results. Regional analyses, however, demonstrate weak positive effects of women's perceived autonomy on handwashing with soap (East and West regions), and negative effects on clean cooking (North) and toilet adoption (West). However, including all three measures of women's bargaining power in each estimation helps explain whether and which subjective and objective indicators affect EH behaviors. Future analysis could consider assigning different weights to the decision-making variables and include other questions relating to gender relations. In surveys with detailed questions on women's empowerment across agricultural domains of production, resources, income, leadership and time, an index similar to the women's empowerment in agriculture index could be created (Alkire *et al* 2013). The creation of a similar index in non-agricultural contexts could be a useful tool to track progress towards gender equality and measure its impact on household well-being.

While it is puzzling that these results do not hold for the urban sample, it is likely that the low changes in outcomes and key explanatory variables for urban households, relative to those in rural areas, could be a possible reason for not seeing significant results.

In terms of limitations, I note first that my results come from a non-experimental setting that does not involve a specific or bundle of development interventions targeted to increase women's bargaining power. Second, though FE estimations have been used to address the omitted variable bias and control for unmeasured characteristics that could affect the endogenous bargaining power measures, they do not control for measurement errors of these key explanatory variables. Third, my analysis neither covers all potentially measurable variables of women's bargaining power, nor includes the diversity of outputs in EH interventions (e.g. improved energy studies: types and number of clean stoves and fuels used, stove stacking, objective stove use; water interventions: water quantity and quality; and sanitation programs: objective measures of toilet use). Future experimental designs in single or multiple EH intervention studies should collect data on women's objective control over resources, and consider including household-level bargaining games among all household members.

Conclusion

The scale of the environmental health burden and the critical role of women in development, necessitates understanding female empowerment to address the global household air pollution problem (Austin and Mejia 2017; Burke and Dundas 2015), and increase adoption and consistent use of WaSH interventions. Policy on sustainable development should not only seek to bridge gender disparities but also work towards changing the broader social landscape within which these gender inequalities are perpetuated. At the global level, results from this paper are timely, given the SDGs' emphasis on women's role in safe water and sanitation and clean energy access. These results also coincide with the current policy landscape in India with recently introduced programs to ensure financial access to all and increase LPG market penetration, reinvigorated prior sanitation policies to encompass a gamut of cleanliness initiatives, and a scheme aimed at preventing female infanticide and educating the girl child. Evidence suggests reduction in leakages in government-run welfare programs (National Rural Employment Guarantee Scheme-NREGS and Social Security Pension Program) in Andhra Pradesh India, from introduction of smart card intervention (Muralidharan *et al* 2016), reduction in women's time spent collecting payment from transfer via mobile money versus cash in Niger (Aker *et al* 2016) and increase in women's work from deposit of NREGS payments into female-owned bank accounts, relative to male-owned bank accounts, in Madhya Pradesh, India (Field *et al* 2016). Results from this paper show positive effects of women co-owned bank accounts on adoption of clean cooking, toilets and drinking water treatment among rural households-the population with least provision of these services. However, future research must examine whether and how government programs on women's financial inclusion not only reduce leakages in subsidy provision (e.g. LPG) but also translate into household adoption, and sustained and exclusive use of related EH behaviors.

Tables

Table 2.1. Analytic sample distribution per survey round

	Rural	Urban	Total
# Primary sampling units (PSU)	1,422	937	2,359
# PSU by region			
North	300	204	504
Central	327	145	472
North-East	29	19	48
East	231	172	403
West	189	138	327
South	346	259	605
# Households	17,280	7,666	24,946

NOTE: Region categories are based on the national government's classification of zones. Each region comprises the following States & Union Territories: North (Delhi, Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Rajasthan); Central (Chhattisgarh, Madhya Pradesh, Uttarakhand, Uttar Pradesh); North-East (Assam); East (Bihar, Jharkhand, Odisha, West Bengal); West (Goa, Gujarat, Maharashtra) and South (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu). The following States or Union Territories are excluded from this analysis, owing to this paper's inclusion criteria: Chandigarh (North); Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura (North-East); Dadra & Nagar Haveli, Daman & Diu (West); Pondicherry (South).

Table 2.2. Outcome variables: IHDS-I (2004-2005) and II (2011-2012)

	Rural (N=34,560)		Urban (N=15,332)	
	IHDS-I	IHDS-II	IHDS-I	IHDS-II
Environmental health technologies (%)[Ɨ]				
Non-biomass stove	8.8	17.4	57.8	73.3
LPG mainly used as cooking fuel	18.1	28.4	49.3	62.0
Clean cooking energy (use of LPG fuel & non-biomass stove)	4.9	13.9	36.6	54.2
Toilet ownership	26.8	41.9	71.2	82.4
Piped drinking water	30.7	35.1	69.8	69.1
WaSH behaviors (%)[Ɨ]				
Weekly drinking water treatment	4.6	8.8	14.1	19.4
Women practice handwashing with soap after defecating	38.8	59.4	72.3	84.5
	Rural (N=22,242)		Urban (N=1,592)	
	IHDS-I	IHDS-II	IHDS-I	IHDS-II
Agricultural equipment (%)				
Tube well[ƗƗ]	19.0	20.2	7.5	15.8
Electric pump[ƗƗ]	17.0	18.1	11.1	13.0
Tractor[Ɨ]	5.2	6.5	1.5	3.7
Diesel pump[ƗƗ]	10.7	9.9	5.5	4.9
Bullock cart[Ɨ]	15.5	13.0	6.2	4.0

NOTE: [Ɨ] Variables are significantly different across survey rounds (1% significance level).
[ƗƗ] Variables are significantly different across survey rounds at the 10% significance level.

Table 2.3. Women's bargaining power variables: IHDS-I (2004-2005) and II (2011-2012)

	Rural (N=34,560)		Urban (N=15,332)	
	IHDS-I	IHDS-II	IHDS-I	IHDS-II
Specific control over resources				
Name on any bank account-joint/sole (%)	12.6	38.9	26.2	48.4
Name on house ownership or rental papers- joint/sole (%)	14.3	17.2	16.1	20.7
Perceived control over resources				
Autonomy score	1.11 (0.50)	1.16 (0.44)	1.28 (0.53)	1.19 (0.44)

NOTE: ᵻ All variables are significantly different across survey rounds (1% significance level). Standard deviation in parentheses for continuous variables.

Table 2.4. Summary statistics: IHDS-I (2004-2005) and II (2011-2012) [Ɨ]

	Rural (N=34,560)		Urban (N=15,332)	
A. Household characteristics				
	IHDS-I	IHDS-II	IHDS-I	IHDS-II
Household size	5.8 (2.6)	5.3 (2.4)	5.3 (2.2)	5.1 (2.2)
Dependency ratio	0.8 (0.7)	0.6 (0.7)	0.7 (0.6)	0.5 (0.6)
Caste category (%)				
General	26.8		40.4	
Other backward class	40.9		39	
Scheduled caste	23		17.9	
Scheduled tribe	9.2		2.8	
Hours of electricity access per day	9.9 (8.7)	11.5 (8.0)	17.3 (7.4)	17.1 (6.8)
Household has any owned or cultivated land (%)	63	65.7	**10.1**	**10.6**
Household has at least one non-farm business (%)	**17.3**	**17.2**	31.6	33.7
Monthly per capita consumption (in INR)	1322.0 (1278.4)	1936.3 (2074.8)	2001.8 (1697.0)	2829.5 (3236.3)
Age of household head (in years)	45.2 (12.7)	50.4 (11.7)	44.5 (11.9)	50.1 (10.9)
Years of education of household head	4.4 (4.4)	5.1 (4.6)	7.4 (4.9)	7.9 (4.9)
Female household head (%)	7.5	14.4	8.3	14.1
B. Woman characteristics				
Age (in years)	32.9 (8.0)	39.9 (8.0)	33.9 (7.7)	40.8 (7.7)
Age gap between eligible woman and household head (in years)	12.3 (13.7)	10.6 (12.6)	10.6 (12.1)	9.2 (11.1)
Years of education	3.2 (4.1)	3.3 (4.1)	6.4 (5.0)	6.6 (5.0)
Educational difference between eligible woman and household head (in years)	1.2 (4.5)	1.8 (4.5)	1.0 (4.6)	1.3 (4.4)
Age of marriage (in years)	16.9 (3.3)	17.0 (3.3)	**18.4 (3.6)**	**18.5 (3.6)**
Marital status (%)				
Married	96.4	92.5	95.7	91.2
Widowed	3.1	6.8	3.4	7.8
Separated	0.3	0.5	**0.5**	**0.6**
Divorced	**0.2**	**0.2**	**0.3**	**0.4**

Total number of children	2.8 (1.6)	3.1 (1.5)	2.5 (1.5)	2.7 (1.4)
First born is a boy (%)	48.3	43.9	48.6	48.6
Number of hours worked in the past year	335.2 (638.4)	395.5 (680.4)	245.5 (675.6)	342.9 (800.1)
Household member has bank account (%)	30.2	68.5	50.8	75.6
Decision-making score for:				
Cooking	2.1 (1.0)	2.1 (0.9)	2.2 (0.9)	2.1 (0.9)
Purchase of expensive item (e.g. television or fridge)	0.8 (0.7)	0.9 (0.7)	0.9 (0.7)	1.0 (0.7)
Number of children	1.0 (0.7)	1.2 (0.7)	1.1 (0.8)	1.2 (0.7)
Child sickness-related action	1.2 (0.9)	1.3 (0.8)	1.3 (0.9)	1.3 (0.8)
Children's spouse	0.6 (0.7)	0.9 (0.8)	0.7 (0.8)	0.9 (0.8)
Permission-seeking score:				
Health center	1.1 (1.0)	0.9 (0.7)	1.5 (1.1)	1.0 (0.8)
Home of relatives or friends	1.1 (1.0)	1.1 (0.9)	1.3 (1.1)	1.1 (0.8)
Local grocery store	1.3 (1.2)	1.3 (1.0)	1.6 (1.2)	1.2 (1.0)
Cash-in-hand to spend on household expenditures (%)	79.7	92.2	86.9	95.2

NOTE: [ł] All variables are significantly different across survey rounds (1% significance level), except results marked in bold. Standard deviation in parentheses for continuous variables.

Table 2.5. Determinants of women's bargaining power by location: Household FE models

	Rural (N=34,560)			Urban (N=15,332)		
	Name on bank account	Name on house ownership/rental papers	Autonomy score	Name on bank account	Name on house ownership/rental papers	Autonomy score
Individual characteristics						
Age (in years)	0.011***	0.003*	-0.002	0.012***	0.004**	-0.020***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Number of years of education completed	0.004	0.000	-0.007*	0.003	-0.002	-0.002
	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.005)
Age gap between woman and household head (in years)	-0.001	-0.000	-0.002***	-0.002	-0.002	-0.003*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Education gap between woman and household head (in years)	0.000	0.002	-0.002	-0.003	0.001	-0.005
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Has at least one child	-0.017	0.023	0.221***	0.021	0.029	0.315***
	(0.023)	(0.020)	(0.027)	(0.044)	(0.034)	(0.045)
First born child is a boy	0.015	0.018	0.004	-0.007	-0.036	-0.020
	(0.013)	(0.014)	(0.015)	(0.025)	(0.024)	(0.029)
Number of hours worked/year	0.000***	0.000*	0.000**	0.000***	0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Relationship to household head						
Wife	-0.020	-0.023	0.123***	0.004	0.008	0.131**
	(0.021)	(0.019)	(0.026)	(0.042)	(0.038)	(0.053)
Other family member	0.035	0.002	0.329***	0.038	0.101**	0.313***
	(0.030)	(0.027)	(0.035)	(0.054)	(0.049)	(0.071)
Household characteristics						

Household size	-0.004	0.000	-0.023***	-0.000	-0.000	-0.023***
	(0.003)	(0.003)	(0.003)	(0.005)	(0.005)	(0.006)
Dependency ratio	-0.002	-0.011*	0.035***	-0.009	0.013	0.009
	(0.006)	(0.006)	(0.009)	(0.012)	(0.013)	(0.015)
Log of per capita total monthly expenditure/consumption adjusted for inflation (in INR)	0.013	-0.002	-0.020*	0.020	0.027*	-0.005
	(0.009)	(0.011)	(0.012)	(0.015)	(0.016)	(0.018)
Hours of electricity access/day	-0.001	-0.001	0.005***	-0.002*	-0.001	0.010***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Female-headed household	0.041*	0.058**	0.234***	0.044	0.010	0.276***
	(0.023)	(0.023)	(0.028)	(0.038)	(0.037)	(0.044)
Family member has bank account	0.463***			0.488***		
	(0.012)			(0.018)		
Constant	-0.407***	0.038	1.100***	-0.514***	-0.164	1.536***
	(0.073)	(0.084)	(0.104)	(0.140)	(0.134)	(0.171)
Observations	34,560	34,560	34,560	15,332	15,332	15,332
Adjusted R-squared	0.709	0.546	0.658	0.712	0.562	0.647

NOTE: Clustered standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. ‘Daughter-in-law’ is the base category for 'relationship to household head'.

Table 2.6. Women's bargaining power and household EH behavior adoption (Naïve regression estimates): Summary of coefficients

	Rural (N=34,560)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.094***	0.178***	0.019*	0.042***	0.167***
	(0.006)	(0.009)	(0.01)	(0.005)	(0.009)
House co-ownership/rental agreement	0.036***	0.028**	0.079***	0.001	0.050***
	(0.006)	(0.011)	(0.013)	(0.006)	(0.012)
Autonomy score	0.003	0.012	0.065***	0.014***	-0.01
	(0.004)	(0.009)	(0.010)	(0.004)	(0.009)
Adjusted R-squared	0.024	0.029	0.010	0.006	0.024
	Urban (N=15,332)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.199***	0.162***	0.038***	0.125***	0.157***
	(0.012)	(0.01)	(0.011)	(0.01)	(0.01)
House co-ownership/rental agreement	0.039***	0.053***	0.004	0.009	0.028**
	(0.013)	(0.011)	(0.015)	(0.01)	(0.011)
Autonomy score	-0.026**	-0.062***	0.055***	0.008	-0.044***
	(0.011)	(0.01)	(0.012)	(0.008)	(0.011)
Adjusted R-squared	0.041	0.043	0.005	0.028	0.038

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses.

Table 2.7. Women's bargaining power and household EH behavior adoption (Household FE estimates): Summary of coefficients

	Rural (N=34,560)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.026**	0.027**	0.010	0.022**	0.003
	(0.010)	(0.013)	(0.012)	(0.010)	(0.015)
House co-ownership/rental agreement	0.027***	-0.007	0.012	-0.002	0.040**
	(0.010)	(0.012)	(0.016)	(0.009)	(0.018)
Autonomy score	-0.021**	-0.000	-0.016	-0.016**	-0.003
	(0.009)	(0.012)	(0.012)	(0.008)	(0.015)
Adjusted R-squared	0.638	0.766	0.766	0.604	0.675
	Urban (N=15,332)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	-0.017	-0.008	-0.006	0.028	0.001
	(0.022)	(0.015)	(0.016)	(0.018)	(0.016)
House co-ownership/rental agreement	-0.010	0.021	0.013	0.010	-0.004
	(0.024)	(0.016)	(0.018)	(0.017)	(0.017)
Autonomy score	0.013	-0.026*	0.010	0.018	0.014
	(0.020)	(0.014)	(0.015)	(0.015)	(0.017)
Adjusted R-squared	0.636	0.747	0.745	0.606	0.657

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses. Household-level (household size, dependency ratio, log of per capita monthly expenditure, hours of daily electricity access, female-headed household, family member has bank account) and individual-level (age, years of completed education, age gap between woman and household head, education gap between woman and household head, has at least one child, first born is a boy, number of hours worked in the past year, relationship to household head) factors have been included in all the models.

Table 2.8. Women's bargaining power and household EH behavior adoption (Cluster FE estimates): Summary of coefficients

	Rural (N=34,560)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.027***	0.018**	0.002	0.014***	-0.001
	(0.006)	(0.007)	(0.006)	(0.005)	(0.008)
House co-ownership/rental agreement	0.024***	0.011	0.013*	-0.001	0.039***
	(0.005)	(0.007)	(0.008)	(0.005)	(0.010)
Autonomy score	-0.013***	-0.011*	-0.011*	-0.009**	-0.005
	(0.005)	(0.006)	(0.006)	(0.004)	(0.007)
Adjusted R-squared	0.287	0.483	0.578	0.301	0.423
	Urban (N=15,332)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	-0.013	-0.001	0.000	0.035***	-0.008
	(0.012)	(0.008)	(0.008)	(0.010)	(0.008)
House co-ownership/rental agreement	0.011	0.023***	0.005	0.012	0.013
	(0.012)	(0.009)	(0.010)	(0.009)	(0.009)
Autonomy score	-0.002	-0.029***	0.013*	0.008	0.006
	(0.010)	(0.008)	(0.008)	(0.008)	(0.008)
Adjusted R-squared	0.369	0.452	0.522	0.322	0.404

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses. Household-level (household size, dependency ratio, log of per capita monthly expenditure, hours of daily electricity access, female-headed household, family member has bank account) and individual-level (age, years of completed education, age gap between woman and household head, education gap between woman and household head, has at least one child, first born is a boy, number of hours worked in the past year, relationship to household head) factors have been included in all the models.

Table 2.9. Women's bargaining power and household adoption of agricultural equipment (Household FE estimates): Summary of coefficients

	Rural (N=22,242)				
	Tube well	Electric pump	Tractor	Diesel pump	Bullock cart
Bank account co-ownership	0.036* (0.018)	0.032* (0.017)	-0.002 (0.008)	-0.005 (0.013)	-0.013 (0.013)
House co-ownership/rental agreement	-0.010 (0.019)	0.004 (0.019)	-0.004 (0.009)	-0.016 (0.012)	0.007 (0.015)
Autonomy score	-0.009 (0.018)	-0.022 (0.017)	-0.004 (0.007)	-0.001 (0.013)	-0.007 (0.013)
Adjusted R-squared	0.690	0.718	0.758	0.687	0.711
	Urban (N=1,592)				
	Tube well	Electric pump	Tractor	Diesel pump	Bullock cart
Bank account co-ownership	-0.025 (0.079)	0.047 (0.050)	0.002 (0.042)	0.004 (0.067)	0.041 (0.040)
House co-ownership/rental agreement	0.021 (0.078)	-0.104 (0.099)	0.022 (0.061)	0.048 (0.065)	-0.016 (0.045)
Autonomy score	-0.004 (0.104)	0.023 (0.071)	0.028 (0.028)	-0.034 (0.043)	0.023 (0.038)
Adjusted R-squared	0.722	0.818	0.714	0.724	0.783

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses. Household-level (household size, dependency ratio, log of per capita monthly expenditure, hours of daily electricity access, female-headed household, family member has bank account) and individual-level (age, years of completed education, age gap between woman and household head, education gap between woman and household head, has at least one child, first born is a boy, number of hours worked in the past year, relationship to household head) factors have been included in all the models.

REFERENCES

Agarwal, B. (1994). Gender and command over property: A critical gap in economic analysis and policy in South Asia. *World Development*, 22(10), 1455-1478.

Agarwal, B. (1997). ''Bargaining'' and gender relations: Within and beyond the household. *Feminist Economics*, 3(1), 1-51.

Aker, J. C., Boumnijel, R., McClelland, A., & Tierney, N. (2016). Payment mechanisms and antipoverty programs: Evidence from a mobile money cash transfer experiment in Niger. *Economic Development and Cultural Change*, 65(1), 1-37.

Allendorf, K. (2007). Do women's land rights promote empowerment and child health in Nepal? *World Development*, 35(11), 1975-1988.

Ali, D. A., Deininger, K., & Goldstein, M. (2014). Environmental and gender impacts of land tenure regularization in Africa: Pilot evidence from Rwanda. *Journal of Development Economics*, 110, 262-275.

Alkire, S., Meinzen-Dick, R., Peterman, A., Quisumbing, A., Seymour, G., & Vaz, A. (2013). The women's empowerment in agriculture index. *World Development*, 52, 71-91.

Anderson, S., & Eswaran, M. (2009). What determines female autonomy? Evidence from Bangladesh. *Journal of Development Economics*, 90(2), 179-191.

Ashraf, N., Karlan, D., & Yin, W. (2010). Female empowerment: Impact of a commitment savings product in the Philippines. *World Development*, 38(3), 333-344.

Attanasio, O., & Lechene, V. (2002). Tests of income pooling in household decisions. *Review of Economic Dynamics*, 5(4), 720-748.

Austin, K. F., & Mejia, M. T. (2017). Household air pollution as a silent killer: women's status and solid fuel use in developing nations. *Population and Environment*, 1-25.

Becker, G. S. (1991). A Treatise on the Family, enl. ed. *Cambridge, Mass: Harvard*.

Burke, P. J., & Dundas, G. (2015). Female labor force participation and household dependence on biomass energy: Evidence from national longitudinal data. *World Development*, 67, 424-437.

Census of India. 2011. Houses, household amenities and assets data 2001-2011: Visualizing through maps. Available at: http://censusindia.gov.in/2011-Common/NSDI/Houses_Household.pdf [Accessed on January 29, 2018]

Chiappori, P. A. (1992). Collective labor supply and welfare. *Journal of Political Economy*, 100(3), 437-467.

Chiappori, P. A., Fortin, B., & Lacroix, G. (2002). Marriage market, divorce legislation, and household labor supply. *Journal of Political Economy*, 110(1), 37-72.

Clancy, J. (2016). In the light of what we know: gender and energy transformations.

Clasen, T., Schmidt, W. P., Rabie, T., Roberts, I., & Cairncross, S. (2007). Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *BMJ*, 334(7597), 782.

Coffey, D., Spears, D., & Vyas, S. (2017). Switching to sanitation: understanding latrine adoption in a representative panel of rural Indian households. *Social Science & Medicine*, 188, 41-50.

Dandona, L., Dandona, R., Kumar, G. A., Shukla, D. K., Paul, V. K., Balakrishnan, K., ... & Nandakumar, A. (2017). Nations within a nation: variations in epidemiological transition across the states of India, 1990–2016 in the Global Burden of Disease Study. *The Lancet*, *390*(10111), 2437-2460.

Deere, C. D., & Doss, C. R. (2006). The gender asset gap: What do we know and why does it matter? *Feminist Economics*, 12(1-2), 1-50.

Deininger, K., Ali, D. A., & Yamano, T. (2008). Legal knowledge and economic development: The case of land rights in Uganda. *Land Economics*, 84(4), 593-619.

Deininger, K., Goyal, A., & Nagarajan, H. (2013). Women's inheritance rights and intergenerational transmission of resources in India. *Journal of Human Resources*, 48(1), 114-141.

Desai, Sonalde, Reeve Vanneman, and National Council of Applied Economic Research, New Delhi. India Human Development Survey (IHDS), 2005. ICPSR22626-v11. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2016-02-16. https://doi.org/10.3886/ICPSR22626.v11

Desai, Sonalde, and Reeve Vanneman. India Human Development Survey-II (IHDS-II), 2011-12. ICPSR36151-v5. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2016-08-01. https://doi.org/10.3886/ICPSR36151.v5

Doss, C.R., and M. Morris. (2000). How does gender affect the adoption of agricultural innovations? *Agricultural Economics* 2 5(1): 27–39.

Doss, C. (2006). The effects of intrahousehold property ownership on expenditure patterns in Ghana. *Journal of African Economies*, 15(1), 149-180.

Doss, C. (2013). Intrahousehold bargaining and resource allocation in developing countries. *The World Bank Research Observer*, 28(1), 52-78.

Duflo, E. (2003). Grandmothers and granddaughters: old-age pensions and intrahousehold allocation in South Africa. *The World Bank Economic Review*, 17(1), 1-25.

FAO and IFPRI (2014). Gender in agriculture: closing the knowledge gap.

Ferroukhi, R., Nagpal, D., Lopez-Peña, A., Hodges, T., Mohtar, R. H., Daher, B., ... & Keulertz, M. (2015). Renewable energy in the water, energy & food nexus. IRENA, January.

Field, E., Pande, R., Rigol, N., Schaner, S., & Moore, C. T. (2016). *On Her Account: Can Strengthening Women's Financial Control Boost Female Labor Supply?*. Technical report.

Forouzanfar, M. H., Alexander, L., Anderson, H. R., Bachman, V. F., Biryukov, S., Brauer, M., ... & Delwiche, K. (2015). Global, regional, and national comparative risk assessment of 79 behavioral, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*, 386(10010), 2287-2323.

Garikipati, S. (2008). The impact of lending to women on household vulnerability and women's empowerment: evidence from India. *World Development*, 36(12), 2620-2642.

Garn, J. V., Sclar, G. D., Freeman, M. C., Penakalapati, G., Alexander, K. T., Brooks, P., ... & Clasen, T. F. (2016). The impact of sanitation interventions on latrine coverage and latrine use: A systematic review and meta-analysis. *International Journal of Hygiene and Environmental Health.*

Gladwin, C. (2002). Gender and soil fertility in Africa: Introduction. *African Studies Quarterly*, 6(1/2).

Global Alliance for Clean Cookstoves. (2016). Country Profiles-India. Available at: http://cleancookstoves.org/country-profiles/focus-countries/5-india.html [Accessed on March 8, 2017]

Global Burden of Disease 2016 Causes of Death Collaborators. (2017). Global, regional, and national age-sex specific mortality for 264 causes of death, 1980-2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, 390.10100 (2017): 1151-1210.

Goetz, A. M. (1997). *Getting institutions right for women in development*. London: Zed Books.

Goldstein, M., & Udry, C. (2008). The profits of power: Land rights and agricultural investment in Ghana. *Journal of Political Economy*, 116(6), 981-1022.

Hassen, S., Alem, Y., & Kohlin, G. (2015). Bargaining power and demand for energy efficient technologies: experimental evidence from rural Ethiopia. University of Gothenburg, Sweden. *Unpublished manuscript.*

Hoddinott, J., & Haddad, L. (1995). Does female income share influence household expenditures? Evidence from Côte d'Ivoire. *Oxford Bulletin of Economics and Statistics*, *57*(1), 77-96.

Hoque, B. A., Aziz, K. M., Hasan, K. Z., & Sack, R. B. (1994). Women's involvement in a rural Bangladesh water and sanitation project. *The Southeast Asian journal of tropical medicine and public health*, 25(1), 67-73.

Jensen, R., & Oster, E. (2009). The power of TV: Cable television and women's status in India. *The Quarterly Journal of Economics*, 124(3), 1057-1094.

Jeuland, M. A., Bhojvaid, V., Kar, A., Lewis, J. J., Patange, O., Pattanayak, S. K., ... & Ramanathan, V. (2015). Preferences for improved cook stoves: Evidence from rural villages in north India. *Energy Economics*, 52, 287-298.

Kabeer, N. (1999). Resources, agency, achievements: Reflections on the measurement of women's empowerment. *Development and Change*, 30(3), 435-464.

Kalsi, P. (2017). Seeing is believing-can increasing the number of female leaders reduce sex selection in rural India? *Journal of Development Economics*, 126, 1-18.

Kishore, A., & Spears, D. (2014). Having a son promotes clean cooking fuel use in urban India: Women's status and son preference. *Economic Development and Cultural Change*, 62(4), 673-699.

Lee, Y. J. (2017). Informing women and improving sanitation: Evidence from rural India. *Journal of Rural Studies*, 55, 203-215.

Menon, N., Van Der Meulen Rodgers, Y., & Nguyen, H. (2014). Women's land rights and children's human capital in Vietnam. *World Development*, 54, 18-31.

Miller, G., & Mobarak, A. M. (2013). Gender differences in preferences, intra-household externalities, and low demand for improved cookstoves (No. w18964). *National Bureau of Economic Research*.

Miller, G., & Mobarak, A. M. (2015). Learning about new technologies through social networks: Experimental evidence on nontraditional stoves in Bangladesh. *Marketing Science*, 34(4), 480-499.

Mishra, K., & Sam, A. G. (2016). Does women's land ownership promote their empowerment? Empirical evidence from Nepal. *World Development*, 78, 360-371.

Mohapatra, S., & Simon, L. (2015). Intra-household bargaining over household technology adoption. *Review of Economics of the Household*, 1-28.

Montgomery, M. A., & Elimelech, M. (2007). Water and sanitation in developing countries: including health in the equation.

Mookerjee, S. (2017). Gender-Neutral Inheritance Laws, Family Structure, and Women's Status in India. *The World Bank Economic Review*, lhx004.

Muralidharan, K., Niehaus, P., & Sukhtankar, S. (2016). Building state capacity: Evidence from biometric smartcards in India. *The American Economic Review*, *106*(10), 2895-2929.

Mwangi, E., Meinzen-Dick, R., & Sun, Y. (2011). Gender and sustainable forest management in East Africa and Latin America. *Ecology and Society*, *16*(1).

Nelson, S. and Kuriakose, A.T. (2017). Gender and renewable energy: entry points for women's livelihood and employment. Climate Investment Funds.

Pachauri, S., & Rao, N. D. (2013). Gender impacts and determinants of energy poverty: are we asking the right questions? *Current Opinion in Environmental Sustainability*, 5(2), 205-215

Pardeshi, G. (2009). Women in total sanitation campaign: a case study from Yavatmal district, Maharashtra, India. *J Hum Ecol*, 25(2), 79-85.

Peterman, A. (2011). Women's property rights and gendered policies: implications for women's long-term welfare in rural Tanzania. *The Journal of Development Studies*, 47(1), 1-30.

Porter, M. (2016). Effects of microcredit and other loans on female empowerment in Bangladesh: the borrower's gender influences intra-household resource allocation. *Agricultural Economics*, 47(2), 235-245.

Prennushi, G. & Gupta, A. (2014). Women's empowerment and socio-economic outcomes: Impacts of Andhra Pradesh Rural Poverty Reduction Program. *World Bank Policy Research Working Paper 6841.*

Puzzolo, E., Stanistreet, D., Pope, D., Bruce, N., & Rehfuess, E. (2013). Factors influencing the large-scale uptake by households of cleaner and more efficient household energy technologies. *London: EPPI Centre*.

Qian, N. (2008). Missing women and the price of tea in China: The effect of sex-specific earnings on sex imbalance. *The Quarterly Journal of Economics*, 123(3), 1251-1285.

Quisumbing, A. R., & De La Brière, B. (2000). *Women's assets and intrahousehold allocation in rural Bangladesh: Testing measures of bargaining power*. Washington, DC: International Food Policy Research Institute.

Ramanathan V, Carmichael G. (2008). Global and regional climate changes due to black carbon. *Nature Geoscience*, 1(4):221-227.

Rangel, M. A. (2006). Alimony rights and intrahousehold allocation of resources: evidence from Brazil. *The Economic Journal*, 116(513), 627-658.

Rehfuess, E., & World Health Organization. (2006). Fuel for life: household energy and health.

Richards, E., Theobald, S., George, A., Kim, J. C., Rudert, C., Jehan, K., & Tolhurst, R. (2013). Going beyond the surface: gendered intra-household bargaining as a social determinant of child health and nutrition in low and middle-income countries. *Social Science & Medicine*, 95, 24-33.

Rojas, A., Schmitt, F., Aguilar, L. 2011. *Guidelines on renewable energy technologies for women in rural and informal urban areas*. IUCN and ENERGIA.

Routray, P., Torondel, B., Clasen, T., & Schmidt, W. P. (2017). Women's role in sanitation decision making in rural coastal Odisha, India. *PloS One*, 12(5), e0178042.

Rubalcava, L., Teruel, G., & Thomas, D. (2009). Investments, time preferences, and public transfers paid to women. *Economic Development and Cultural Change*, 57(3), 507-538.

Santos, F., Fletschner, D., Savath, V., & Peterman, A. (2014). Can government-allocated land contribute to food security? Intrahousehold analysis of West Bengal's Microplot Allocation Program. *World Development*, *64*, 860-872.

Sen, A. (1990). Gender and cooperative conflicts. In I. Tinker (Ed.), *Persistent inequalities. Women and world development* (pp. 123–149). Oxford: Oxford University Press.

Shankar, A. V., Onyura, M., & Alderman, J. (2015). Agency-based empowerment training enhances sales capacity of female energy entrepreneurs in Kenya. *Journal of Health Communication*, *20*(sup1), 67-75.

Smith, M. A., Garbharran, H., Edwards, M. J., & O'Hara-Murdock, P. (2004). Health promotion and disease prevention through sanitation education in South African Zulu and Xhosa women. *Journal of Transcultural Nursing*, 15(1), 62-68.

Staveren, I. V., & Ode bode, O. (2007). Gender norms as asymmetric institutions: A case study of Yoruba women in Nigeria. *Journal of Economic Issues*, 41(4), 903-925.

Stopnitzky, Y. (2017). No toilet no bride? Intrahousehold bargaining in male-skewed marriage markets in India. *Journal of Development Economics*, 127, 269-282.

UNICEF (2017). Eliminate open defecation: Introduction Available at: http://unicef.in/Whatwedo/11/Eliminate-Open-Defecation [Accessed on January 29, 2018]

Wang, S. Y. (2014). Property rights and intra-household bargaining. *Journal of Development Economics*, 107, 192-201.

Wilson, J. M., & Chandler, G. N. (1993). Sustained improvements in hygiene behavior amongst village women in Lombok, Indonesia. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 87(6), 615-616.

World Bank (2015). Toward gender-informed energy subsidy reforms: Findings from qualitative studies in Europe and Central Asia.

World Health Organization and UNICEF. (2017). "Progress on Drinking Water, Sanitation and Hygiene–2017 Update and SDG Baselines". Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF).

Younes, L., Houweling, T. A., Azad, K., Kuddus, A., Shaha, S., Haq, B., ... & Prost, A. (2014). The effect of participatory women's groups on infant feeding and child health knowledge, behaviour and outcomes in rural Bangladesh: a controlled before-and-after study. *J Epidemiology Community Health*, jech-2014.

CHAPTER 3: SOCIAL CAPITAL AND CHOICE OF CLEAN COOKING AND SAFE SANITATION IN INDIA

Introduction

Household air pollution (HAP), from burning solid fuels in inefficient cookstoves, and poor water and sanitation are the leading environmental risk factors for disease burden (6th and 7th highest, respectively) in developing countries (Fourouzanfar *et al* 2015). India, home to over 1.34 billion people, with 10 of its 29 states and union territories exceeding a population of 60 million (equivalent to large countries), has four of its highest disease burden risk factors linked to HAP and inadequate water and sanitation (Dandona *et al* 2017; GBD 2017). These leading causes, in order, are ischemic heart disease, chronic obstructive pulmonary disease, diarrheal diseases and lower respiratory infections[20].

Although clean household energy alternatives, such as improved cookstoves (ICS), liquefied petroleum gas (LPG) and electricity are possible solutions to the HAP problem, their uptake has been dismally low (Lewis and Pattanayak 2012; Puzzolo *et al*

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[20]Among these risk factors, HAP-related illnesses include ischemic heart disease (WHO 2018), chronic obstructive pulmonary disease (Kurmi *et al* 2010; Smith *et al* 2004; van Gemert *et al* 2015), lower respiratory infections (Gurley *et al* 2014; Smith *et al* 2000; van Gemert *et al* 2015), and stroke (WHO 2018). Poor water and sanitation conditions lead to diarrhea (Fewtrell *et al* 2005; Prüss *et al* 2002) and lower respiratory infections (Rabie and Curtis 2006; Walker *et al* 2013).

2013; Rehfuess *et al* 2014). In the absence of behavior change programs, interventions to increase access to safe water and sanitation have also met with limited success (Mosler 2012). Various components of the complex concept of social capital have been examined in the development literature. Community cohesion, for example, is a collective asset that can have positive externalities (Kawachi *et al* 2008), and there is empirical evidence from the developing world of the positive impact of social networks on microfinance participation (Banerjee *et al* 2013), adoption of fertilizer (Isham 2002), agricultural weather insurance (Cai, de Janvry and Sadoulet 2014) and healthcare utilization (Oster and Thornton 2012; Story 2014). Social learning is a crucial channel through which people could adopt environmental health (EH) technologies in the long-run after short-run subsidies (Dupas, 2014). However, the role of social capital, including social relations, norms and formal institutions, in clean energy adoption is understudied (Lewis and Pattanayak 2012; Pachauri and Rao 2012; Rehfuess *et al* 2014). Examining the role of community social capital in the broader context of EH technologies will provide an important perspective into existing societal factors that enable or inhibit their adoption.

Using a nationally representative panel dataset of Indian households, this paper examines whether community-level structural and cognitive social capital explain household adoption of EH technologies, including LPG for cooking, individual household latrines or toilets, and piped drinking water. Across rural and urban areas, I find linking ties and social cohesion to significantly positively influence household adoption of LPG and toilets, respectively. The significant effect of bridging groups on clean cooking energy, particularly in rural settings, depends on their nature (positive for female-centric groups and negative for activity-based organizations). Bonding groups have strong positive effects on toilet adoption. There also exist complementary effects of EH interventions, with effects being stronger between clean energy and toilet uptake.

While the Indian government's policy push towards LPG provision is recent (Government of India 2018), programs since the mid-1980s (National Program on Improved *Chulhas* in 1985, National Biomass Cookstove Initiative in 2009) have attempted to extend use of 'clean energy' (Venkataraman *et al* 2010). Since the late 1980s, clean sanitation programs in various forms have been implemented but with limited success: Central Rural Sanitation Program in 1986, 'demand-driven' and 'community-led' Total Sanitation Campaign in 2001, *Nirmal Bharat Abhiyan* in rural India and Basic Services for Urban Poor in 2007, and *Swachh Bharat Abhiyan* (Clean India Mission) in 2014 (WSSCC 2016). Though there has been an increase in the percentage of households with latrines between 2001 (36.4%) and 2011 (46.9%) (Census of India 2011), India is still home to the highest number of open defecators, globally (WHO and UNICEF 2017). Among many revisions to its predecessor program, the *Swachh Bharat Abhiyan* aims to focus on (a) behavior change towards toilet construction and use among populations and communities, and (b) use of technology and media to communicate the advantages of safe sanitation and hygiene (Government of India 2014). A better understanding of existing social resources, that can be leveraged, is central to realizing the intended benefits of these national programs for clean energy and safe sanitation.

Literature Review

Social capital was first defined by Bourdieu (1986) as "the aggregate of the actual or potential resources that are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintances and recognition, or in other words, to membership in a group". He argued for individuals' social capital as dependent on (1) the size of network connections that the individual ''can effectively mobilize'' and (2) the amount and type(s) of capital (e.g., economic, cultural, or symbolic) possessed by each of those to whom she or he is related. Coleman (1988) subsequently conceptualized social capital as not just a single unit, but as various entities with two shared characteristics: (a) consisting of some feature of social structure, and (b) enabling actions of individuals operating within that framework. In underscoring the public good aspect of social capital, he also argued for trustworthiness of the social environment, and norms and effective sanctions as being central to the concept. Putnam (1993) built on Bourdieu's theory of social capital to theorize it as consisting of features such as networks, interpersonal trust, norms of reciprocity, and social engagement that build community and social participation. The amount of social capital in a community (e.g., neighborhood, town/city, state, nation), a collective feature generated through norms of reciprocity and trust among residents, has implications for a host of beneficial outcomes for that community.

The broad concept of social capital is further divided into structural and cognitive. The former assesses interpersonal exchanges within a social network and the influence of its reciprocity (Heaney and Israel 2008), while the latter gauges institutional, often unwritten, rules that communities themselves form to change ("rule out") or reinforce ("rule in") repetitive behavior (Ostrom 2005). Structural social capital can be operationalized as bridging, bonding or linking. Bridging social capital describes ties between heterogeneous groups that cut across class, race, ethnicity; it allows for different groups to exchange information and develop consensus (Narayan and Pritchett 1999). Bonding social capital refers to ties within social groups whose members share the same social identity, similar ethnicity, shared values i.e. groups are homogenous (Putnam 2001). Lastly, linking social capital exists when there are "norms of respect and networks of trusting relationships between people who are interacting across explicit, formal or institutionalized power or authority gradients in society" (Szreter and Woolcook 2004).

Studies have shown how households in developing countries provide informal insurance to each other (Ambrus *et al* 2014; De Weerdt and Dercon 2006; Fafchamps and

Lund 2003; Udry 1994). Financial networks such as loans and transfers aid in consumption smoothing, while kin networks support large financial investments (Kinnan and Townsend 2012). Banerjee *et al* (2013) argue for social networks as assisting in information flow ('diffusion centrality') versus the influence of neighbors' participation decisions ('endorsement effects') in Indian microfinance groups. Increased meeting frequency among microfinance group members leads to lower loan defaults (Feigenberg *et al* 2011), and receiving business counseling and financial training with a friend increases women's business activity (Field *et al* 2014).

Social networks positively affect adoption of contraceptives (Behrman, Kohler and Watkins 2002), family planning behavior (Paek *et al* 2008), HIV test results (Godlonton and Thornton 2012) and menstrual cups (Oster and Thornton 2012). Some studies find protective effects of bonding and bridging on self-rated health (Iwase *et al* 2012; Kim *et al* 2006). Others find limited effects of social learning on children's receipt of deworming drugs (Kremer and Miguel 2007) and associations between structural social capital (group membership and citizenship) and child nutritional status (De Silva and Harpham 2007). Development outcomes may have different associations with structural and cognitive social capital. For instance, utilization of antenatal care, professional delivery care and childhood immunizations have positive associations with bridging social capital; strong bonding ties negatively predict use of preventive care but positively predict professional delivery care among ever-married women (Story 2014).

Diffusion theory has helped explain how innovative technologies lead to societal changes and how societal constructs enable innovations and their transmission (Brown 2001; Rogers 1995). In the agricultural technology adoption literature, there is evidence of farmers learning from each other but also free-riding (Foster and Rosenzweig 1995; Munshi 2004). Number of adopters known to farmers increases their probability of adopting hybrid cocoa in Ghana (Boahene *et al* 1999), but there is an inverse U-shaped relationship between number of adopters among family and friends, and farmers' probability of adopting sunflowers in Mozambique (Bandiera and Rasul 2006) and new agricultural technologies in Ethiopia (Liverpool-Tasie and Winter-Nelson 2012). Using data from Tanzania, Isham (2002) demonstrates that households with ethnically established and participatory social connections are more likely to diffuse newly acquired information, and consequently adopt fertilizers. Social learning (BenYishay and Mobarak 2015; Carter, Laajaj and Yang 2014; Conley and Udry 2010) and social capital (Katungi *et al* 2008) are central to information exchange in agricultural research and extension services, diffusion of agricultural technology and fertilizer adoption.

In the EH literature, social learning through peer groups positively influences antimalarial treatment adoption in Tanzania (Adhvaryu 2014), latrine ownership in India (Shakya *et al* 2014; Shakya *et al* 2015) and ICS adoption in Mali (Bonan *et al* 2017).

Social learning through opinion leaders, however, leads households in Bangladesh to draw negative interpretations about ICS and social learning is more central for ICS with less noticeable benefits (Miller and Mobarak 2015). They argue that while marketing campaigns can initiate early ICS adoption, their sustained use depends on the technologies' alignment with local preferences. Engagement with opinion leaders and active community members affects adoption of solar disinfection technology for drinking water in Bolivia (Moser and Mosler 2008) and solar home system in Sri Lanka (McEachern and Hanson 2008), favoring of ICS but not actual purchase in Uganda (Beltramo *et al* 2014) and information sharing about ICS in Honduras (Ramirez *et al* 2014). More recently, Vulturius and Wanjiru (2017) use egocentric social network analysis and find that adoption of ICS in Kenya is higher when implementers targeted women's self-help groups and teachers and ICS users interacted with other users. At the community level, evidence from Peru suggests that in villages with high bonding social capital, household-level adoption of ICS is significantly higher (Adrianzén 2014).

According to the competing illnesses literature, among households that face multiple disease risks, with the decrease in one disease risk, the marginal utility of investing in a different prevention for reduction in another risk would increase i.e. there is complementarity of health inputs (Becker 2007; Dow *et al* 1997; Kaestner *et al* 2014). Despite the complementarities in EH risks (i.e. the linkages between lack of clean energy and unsafe water and sanitation), there are no studies that examine whether adoption of one EH technology predicts adoption of other related technologies.

Much of the evidence in the EH literature, especially clean energy adoption, has focused on social networks and peer relations on the initial uptake and sustained adoption, using qualitative (Rogers 2003; Bielecki and Wingenbach 2014) and quantitative methods (Beltramo *et al* 2015; Miller and Mobarak 2015). However, it is important to examine the complementary role of structural and cognitive social capital in development, as they measure different dimensions of the vast concept of social capital.

In filling the gap in the EH technology adoption literature, the goal of this paper is to examine (a) the effect of community-level social capital (structural and cognitive)[21] on household adoption of EH technologies; (b) whether this relationship varies by geographic location; and (c) whether there are complementarities in EH technology uptake. Relying on survey questions in the dataset, measures of social capital included are social networks, bridging and bonding groups, political participation, social cohesion and collective action.

[21]The inclusion of community-level social capital, as the key explanatory variable, is in keeping with Putnam's (1993) theoretical argument, and empirical studies from the health (Kim *et al* 2006; Shakya *et al* 2014, Shakya *et al* 2015) and clean energy literatures (Adrianzén 2014).

Data

This paper uses 2004-2005 (Round 1) and 2011-2012 (Round 2) nationally representative household panel data from the India Human Development Survey (Desai and Vanneman 2005, 2011-12). Round 1 surveyed 41,554 households across 1,503 villages and 971 urban neighborhoods, while Round 2 re-surveyed a vast majority of these households to survey a total of 42,152 households. Households were selected using a three-stage cluster sampling design in both rounds. The analytic sample in this paper comprises a balanced panel of 35,618 households in each survey round (N=71,236). Survey data in both rounds include EH indicators, detailed measures of social capital, household socioeconomics and consumption, demographics and information of household assets. Village surveys captured information on village structure, composition, employment, infrastructure, medical and educational facilities, land use, prices, and crop inputs and outputs.

Measures

The focus of this paper is on three dependent variables, namely, clean cooking (i.e. use of non-biomass stove and LPG cooking fuel), toilets and piped drinking water within house premises. Using two separate questions asked in the household survey on choice of cooking (type of stove, and type of cooking fuel), I create a dichotomous variable for clean cooking: households that use a non-biomass stove and LPG for cooking (coded '1', otherwise '0'). On safe sanitation, based on households' response to the type of toilet they have access to, I create a binary variable for households using latrines (coded '1' if using traditional pit latrine, semi-flush toilet or flush toilet; '0' if defecating in the open), and a categorical variable for type of toilet household has access to. Households are assigned code '1' if they have access to piped drinking water inside their dwelling, and '0' otherwise.

Social capital, the main explanatory variable of interest, is further divided into structural and cognitive social capital. Under structural social capital, indicators I include are:

(1) Social networks - These linking ties are measured by households' association with key influential people in their community. The specific questions asked in the surveys were: "Among your acquaintances and relatives, are there any who (a) are doctors/nurses or who work in hospitals and clinics, (b) are teachers, school officials or anybody who works in a school; (c) are in government service?" For each of these questions, responses are binary.

(2) Group participation - This is measured by household's membership in the following organizations: women's groups, self-help groups, credit/savings groups, youth clubs, trade/business organizations, religious groups and caste groups.

(3) Political participation - These indicators were measured by households' response to two questions: "Have you or anyone in the household attended a public

meeting called by the village *panchayat/nagarpalika*/ward committee in the last year?" and "Is anyone in the household an official of the village *panchayat/nagarpalika*/ward committee?" Responses to both these questions are binary.

Under cognitive social capital, I create indicators for:

(1) Social cohesion: The two survey questions that measure this, ask households: "In this village/neighborhood, do people generally get along with each other or is there some conflict or a lot of conflict?", and "In this village/neighborhood, how much conflict would you say there is among the communities/castes that live here?" For both questions, responses were coded '1' for 'lot of conflict, '2' for 'some conflict' and '3' for 'get along/no conflict'.

(2) Collective action: Households were asked, "In some communities, when there is a water supply problem, people bond together to solve the problem. In other communities, people take care of their own families individually. What is your community like?" Responses were coded '1' if household reported 'bond together to solve problem' and '0' if they reported 'each family solves individually'.

Using exploratory factor analysis, a factor score was calculated for every social capital indicator for each household. Each factor was then aggregated at the community level (villages in rural areas and neighborhoods in urban areas). Principal component factor method was used, and the first six factors were rotated using the promax rotation, as the factors are likely to be correlated. The first six factors clearly fall under the categories of social capital described in previous sections (Table B-1)[22]. Factor 1 (linking score) includes households' acquaintances in the health, education and government service sectors. Factor 2 (female-centric bridging score) includes households' participation in groups that largely comprise women i.e. women's group, self-help group and credit/savings group. Factor 3 (bonding score) comprises caste and religious group memberships. Social cohesion falls in Factor 4, with households' views of overall community cohesion, and caste cohesion in the community. Factor 5 (activity-based bridging score) comprises households' membership in youth/reading group and trade union. Finally, Factor 6 reflects political participation, and includes any household member's attendance at a public meeting, and household member elected/appointed as government representative/official.

Empirical Strategy

Inherent attributes of households and its members affect their "web of influence", that in turn could affect household behavior. As there could be different pathways (e.g. educated household members have more information about disease risks, membership in community groups creates awareness about new products that improve human health and welfare) through which social capital influences household

[22]Owing to high (0.8865) unique variance (i.e. uniqueness) of the 'collective action' question and its lower relevance in the factor model, this variable has been included independently in the analyses.

choice of EH technologies, it is important to first understand the characteristics that differentiate high social capital households from those with low social capital.

Using the household panel across two survey rounds, I first conduct household-level fixed effects (FE)[23] analysis to analyze the determinants of social capital.

$$(1)\ Y_{jt} = \beta_0 + \beta_1 Household\ characteristics_{jt} + \theta_t + \delta_j + \Omega_{jt} + \varepsilon_{jt}$$

Where Y_{jt} denotes household-level social capital indicators (linking, bridging, bonding, political participation, social cohesion and collective action) in household 'j' in time 't'; θ_t=1 if Round 2, 0 if Round 1; δ_j is household fixed effects; Ω_{jt} represents household-level time-varying characteristics; ε_{jt}=error term. Household characteristics included are, per capita log of monthly expenditure, household size, number of married women, highest male and female adult education, dependency ratio, demographics of the household head (age, sex), house ownership and hours of electricity available to the household.

Next, using household-level FE models again, I analyze the effect of social capital on household choice of EH technology (Equation 2). Household-level FE control for factors specific to the household that do not vary over time but could bias social capital estimates in a pooled ordinary least squares (OLS) regression model.

[23]Fixed effects model is preferred to the pooled OLS and random effects models following results from the Hausman and Breusch-Pagan tests.

$$(2)\ Y_{jct} = \beta_0 + \beta_1 Social\ capital\ indicators_{ct} + \theta_t + \delta_j + \Omega_{jct} + \varepsilon_{jct}$$

Where Y_{jct} denotes EH technology (clean cooking, toilets and piped drinking water) in household 'j', in community 'c', in time 't'; Community-level social capital indicators' scores=linking, bridging, bonding, political participation, social cohesion and collective action; Ω_{jct} represents household-level time-varying characteristics[24]; ε_{jct}=error term. In these models, β_1 is the coefficient of interest.

In order to examine the complementary effects of engaging in EH behaviors, another set of models is estimated extending the above equation, where β_1 and β_2 are the coefficients of interest:

$$(3)\ Y_{jct} = \beta_0 + \beta_1 Social\ capital\ indicators_{ct} + \beta_2 EH\ behaviors_{jct} + \theta_t + \delta_j + \Omega_{jct} + \varepsilon_{jct}$$

Where EH behaviors in household 'j', in community 'c', in time 't' include clean cooking, toilets, piped drinking water and safe treatment of drinking water[25].

As a robustness check, among rural households only where village surveys were administered, I replicate the household fixed effects models in Equations 2 and 3 and include village-level characteristics that could affect household choice of EH behaviors.

[24]These variables are the same as those included in Equation 1.

[25]This is a binary variable, coded '1' if households 'always' treated their drinking water, and '0' otherwise. Drinking water treatment methods asked in the survey are: boiling, filtering with a purchased filter, using Aquaguard (branded advanced water purifier) or adding chemicals.

For example, lack of village infrastructure could impede households' awareness of products and access to markets; thin markets for health-improving technologies could impose limitations on household purchase of EH products, even if households desired them. Prohibitive costs of EH technologies could be another impediment, as is consistently evidenced in the literature. Therefore, in addition to household characteristics controlled for in previous models, in a restricted sample of rural households with village-level data, I include years of cable television access in the village (as a proxy for media exposure), distance to nearest road (indicator for market access), distance to nearest bank branch/credit cooperative (proxy for access to credit facilities) and per unit price of LPG cylinder[26].

The following model (Equation 4) of household EH behavior is used:

$$(4)\ Y_{jct} = \beta_0 + \beta_1 Social\ capital\ indicators_{ct} + \beta_2 Village\ characteristics_{ct} + \theta_t + \delta_j + \Omega_{jct} + \varepsilon_{jct}$$

Where village characteristics in community 'c', in time 't' include years of cable television access in the village, distance to nearest road (in kilometers), distance to nearest bank branch/credit cooperative (in kilometers) and per unit price of LPG cylinder (in INR).

[26]Per unit price of LPG cylinder is included in the clean energy outcome only. Price of toilet construction and piped drinking water tariffs were not asked in the survey.

Extending the equation above, complementarities of EH behaviors were also examined. In all analyses, household FE models are run as a linear probability models (LPM) and are conducted with the full sample of households. Analyses with locational (rural-urban) subsamples are conducted as well (except for Equation 4 that is conducted for the rural sample only). In all models, standard errors are clustered at the primary sampling unit (PSU) level, in consistency with the IHDS three-stage survey design.

Results

Descriptive statistics

Outcome variables: There are significant increases in EH technologies between Round 1 and Round 2 (Table 3.1). Clean cooking increased significantly to 28.7% from 16.7%, with the increase being higher in rural areas (from 5% to 14.2%) than urban areas (from 39.3% to 56.7%). Toilet coverage doubled in rural areas (from 28.1% to 41.9%) and also significantly increased in the urban sample (74.5% to 83.1%). Piped drinking water access increased significantly in rural areas (from 30.4% to 34.7%) but reported significant decrease in urban areas (71.4% to 70.8%), as urban areas reported increase in use of tube wells and covered wells as drinking water sources.

Explanatory variables (Structural social capital): On social network measures, there are significant increases in household acquaintances in the education sector, for both rural (from 38.4% to 57.2%) and urban (from 41.2% to 64%) households, and the medical domain (increase of 24% for rural and 28.5% for urban samples) (Table 3.2). Linking ties with government officials decreased significantly for all samples, remaining below 40%. In factor analysis results, the networks factor for rural areas increased from -0.28 to 0.14, while that for urban areas increased from -0.10 to 0.38.

Two types of bridging groups emerged from the factor analysis: finance and economic development groups that largely comprise women (*Mahila Mandal* or women's groups, self-help groups i.e. SHGs and credit/savings groups), and those that are activity-based (youth/reading groups, and trade or business associations). There is higher increase in urban than rural households' membership in women's groups. Household membership in SHGs significantly increased, with higher increases reported in the rural (11.3% to 22.1%) versus urban households (6.1% to 14%). Membership of any household member in credit/savings groups also significantly increased but remained below 12%. The women-dominated bridging groups factor significantly increased for both groups, but the factor in Round 2 was higher for rural (0.20) than urban areas (0.02). Membership in youth/reading groups significantly decreased for both rural and urban areas, while membership in trader/business associations significantly increased. In Round 2, the activity-based bridging group factor was higher in urban (0.11) than rural households (-0.16).

Consistent with the literature, caste and religious groups emerged as bonding groups in the factor analysis. Membership in both groups significantly decreased, except for urban households' membership in religious groups. The negative bonding factor was lower in rural (-0.08) than urban areas (-0.05) in Round 2.

Political participation factor comprises household member attendance in any public meeting in the past year, and household member or acquaintance represented in any local government body. On the former, there is significant increase in rural households' participation (from 35.8% to 37.1%) but on the latter, there is significant decrease (12.7% to 5%). In urban households, there are significant decreases on both indicators (15% to 13%, and 5.6% to 1.8%, respectively). The political participation score decreases in both samples between Rounds (on average, from (0.10 to -0.10).

Explanatory variables (Cognitive social capital): Households' perceptions of village-level conflict resolution and tension between communities form the social cohesion measure. While there is significant increase in conflict resolution (increase from 2.38 to 2.46), there is also significant decrease in communal harmony (decrease from 2.65 to 2.49). The social cohesion factor significantly decreased in rural (from 0.01 to -0.07) and urban areas (0.10 to 0.02). There is significant decrease in household-reported collective action in communities, between 2004-2005 and 2011-2012.

Household characteristics: There are significant changes in many household characteristics in the 7-year period: per capita monthly household expenditures increased, household size and dependency ratio reduced, and highest adult male and female education levels increased (though female education is lower than that of males). Hours of electricity access increased for rural areas but declined for urban households. Overall, house ownership significantly increased, including in urban areas, but it remained almost unchanged in the rural sample. Number of married women in rural households significantly decreased but significantly increased in urban households. Female headship increased over the 7-year time frame, but education level of the household head declined over time.

Village characteristics: Among the 1,371 villages for which there are variables on market development and infrastructure, there are significant ($p<0.01$) increases in the four indicators used. Years of cable television access significantly increased from 2.06 to 6.67 years. Access to roads increased between the two survey rounds (distance reduced from 1.56 to 0.51 kilometers), but access to financial institutions reduced (distance increased from 4.46 to 4.93 kilometers). Adjusting for inflation, villages reported significant decrease in per unit price of LPG cylinder (from 45.32 INR to 34.04 INR).

Determinants of social capital

Structural social capital

In the full sample, there are significant ($p<0.01$) positive effects of bridging (both types), bonding, political participation, social cohesion and collective action on household-level linking score (Table 3.3). Except social cohesion, all other forms of social capital have positive effects ($p<0.01$) on female-focused and activity-centric bridging and bonding scores. While structural social capital measures have a strong positive effect ($p<0.01$) on political participation (particularly higher in the rural sample; see Table B-2), collective action has a significant negative effect ($p<0.01$) on the same. Household-level factors that positively affect structural social capital include monthly per capita expenditure, household size, and highest male and female education. There are strong negative effects of number of married women in the household and dependency ratio on both categories of bridging. Female-headed households have significantly lower linking, bonding and political engagement scores. There is considerable variation in these results in the rural-urban disaggregated samples (Tables B-2 and B-3). Bridging and collective action have a higher positive effect ($p<0.01$) on linking among urban households, while bonding and political engagement have higher effects ($p<0.01$) on linking in the rural sample. The effect of other forms of social capital on bonding are stronger in the urban sample, while the effects are stronger for political participation in the rural sample.

Cognitive social capital

Collective action has a significant ($p<0.01$) positive effect on social cohesion in the combined rural-urban sample (Table 3.3). Linking, female-centric bridging and social cohesion positively affect collective action, while activity-based bridging, bonding and political engagement have strong negative effects ($p<0.01$). The significant effects of other forms of social capital on social cohesion are stronger in the urban sample. In the aggregated sample, higher adult male education has strong positive effects on both social cohesion and collective action, while monthly per capita expenditure negatively affects only collective action.

Fixed effects results

Clean cooking

There is a significant positive effect (Table 3.4, Columns 3 and 5) of linking score on households' adoption of clean cooking across rural and urban samples ($p<0.01$). A unit increase in community linking score linearly increases the likelihood of household adoption of clean cooking by 1.6 percentage points in the rural sample and 5.8 percentage points in the urban sample. Another component of structural social capital, female bridging score, significantly increases clean cooking adoption among rural households only by 3.7 percentage points ($p<0.01$). Contrarily, community activity-based bridging linearly decreases rural households' likelihood of clean cooking adoption by 7 percentage points. Bonding groups have a weak positive effect on clean cooking among rural households only ($p<0.10$). A unit increase in community political participation score linearly decreases clean cooking adoption among urban households only by 10.7 percentage points ($p<0.01$). Collective action has a significant negative effect ($p<0.05$) on clean cooking adoption among the rural sample only.

On including related EH behaviors in the models, I find that the effect (size and significance) of social capital, across measures, remains the same (Table 3.4, Columns 4 and 6). Household toilet ownership significantly increases clean cooking adoption by 3.2 percentage points in rural areas and by 7.5 percentage points in the urban sample ($p<0.01$). Safe treatment of drinking water significantly increases clean cooking adoption by a higher magnitude than toilet ownership: 6.6 percentage points in the rural sample and 7.1 percentage points in the urban sample ($p<0.01$).

Toilet

Community linking score has a significant negative effect (a unit increase in linking score linearly decreases toilet adoption by 2.5 percentage points; $p<0.01$) on rural households' adoption of toilets (Table 3.5, Column 3), but not in the urban or aggregated samples. Activity-based bridging groups have a significantly positive effect on toilet ownership in the urban sample only (1.9 percentage points), (Table 3.5, Column 5). Caste- and religion-based group membership score significantly increases likelihood of toilet ownership by 1.7 percentage points in the full sample, and among rural households by 3.2 percentage points ($p<0.05$). Across samples, social cohesion has a significant positive effect on toilet ownership, with the effect being higher in urban households (2 percentage points; $p<0.01$) compared to rural households (1.3 percentage points; $p<0.10$). Surprisingly, collective action has a strong negative ($p<0.05$) effect on toilet ownership in the aggregated (2.5 percentage points) and urban samples (4.6 percentage points).

Clean cooking ownership has a higher significant positive effect ($p<0.01$) on toilet ownership in rural areas (5.2 percentage points) than urban areas (3.5 percentage points) (Table 3.5, Columns 4 and 6). However, piped drinking water access has a stronger positive effect ($p<0.01$) on toilet adoption in the urban sample (3.3 percentage points) compared to its rural counterparts (2.7 percentage points).

Piped drinking water

Among urban households only, women-centric bridging group membership has a strong ($p<0.01$) negative effect on households' piped drinking water access (4.7 percentage points), while political participation score has a strong positive effect of 4.1 percentage points (Table 3.6, Column 5). On cognitive social capital indicators, collective action positively affects ($p<0.10$) piped drinking water access in the total sample (2.7 percentage points). Toilet ownership linearly significantly ($p<0.01$) increases urban households' likelihood of piped drinking water access by 4.2 percentage points and rural households' access by 2.6 percentage points (Table 3.6, Columns 4 and 6).

Robustness checks

While the effect sizes are smaller, I find that the same measures of social capital that were significant in previous models (Tables 3.4-3,6) have strong effects on choice of

EH technologies in rural households, even after inclusion of village-level characteristics (Table 3.7). This is suggestive of the robustness of results from previous models. To elaborate further, village-level linking score has a strong positive effect ($p<0.01$) on clean cooking (1.2 percentage points) but not on toilet adoption in the rural sample. Village-level female-driven bridging score has strong positive effects ($p<0.01$) on clean cooking take-up (3.1 percentage points), but village-level activity-based bridging score has significant ($p<0.01$) negative effects on the same (3.5 percentage points). Similar to the fixed effects models without village characteristics, in models with village factors as well, village-level bonding score has strong ($p<0.01$) positive effects on rural households' toilet adoption (3.9 percentage points) and weak ($p<0.10$) positive effects on rural households' piped drinking water access (1.7 percentage points). The weak positive effect of social cohesion on rural households' choice of toilets (1.3 percentage points) is consistent across model specifications. While the strong negative effect of collective action on rural households' piped drinking water access is opposite and statistically significant compared to the results from the models without village characteristics, it is likely that rural households come together to solve drinking water problems in their communities, in the absence of piped drinking water provision.

Falsification tests

Falsification hypotheses are also tested to validate the relationship between social capital and household choice of EH technology. I test whether social capital affects household ownership of durable goods that are welfare-improving but unrelated to the EH domain. These goods include mixer/grinder (similar to a blender), refrigerator, pressure cooker, color television, electric fan, cellphone and scooter. In the full sample, only community-level bonding score has a significant ($p<0.01$) positive effect on mixer/grinder and fridge ownership[27]. However, these coefficient estimates are small and no two social capital measures have strong significant effects on the same outcome (Table 3.8).

Discussion

Social capital has strong positive effects on household choice of EH technologies, with variation in type of social capital and geographic setting. Among structural social capital measures, effects of information from people outside one's immediate social ambit-Granovetter's (1973) definition of "weak ties"- differ by location. Linking social capital has positive effects on household choice of clean cooking (across samples). The strong negative effect of linking ties on rural households' choice of latrines could be owing to network members' negative experiences with toilet adoption, similar to Miller and Mobarak (2015) finding of households' dependence on networks and opinion leaders for ICS (a new, clean energy product/technology) drawbacks, prior to investing in it. The evidence on gender-based group interaction and information dissemination

[27]These tests were conducted separately for rural and urban samples as well, and results are similar (results not presented).

varies by development outcome: Ramirez *et al* (2014) find women to be less active in communicating information about ICS, while Kumar *et al* (2017) find women's group-based programs to effectively create behavior change in infant and young child feeding practices. In this paper, the stronger positive effects of female bridging groups on clean cooking among rural households, may be attributed to the rural sample's higher bridging scores across both rounds and women's higher preferences for clean stoves, similar to Miller and Mobarak (2013) finding from rural Bangladesh. In line with literature that points to positive associations of development outcomes with bonding groups (Adrianzén 2014; Call and Jagger 2017; Kim *et al* 2006), this paper finds strong positive effects of bonding on toilet adoption and weak positive effects on clean cooking, particularly in rural areas. Ramirez *et al* (2014) argue that religious leaders in Honduras may have strengthened local information networks, thereby inhibiting adoption of ICS. However, in this paper, it is likely that Indian households in caste and religious groups have internalized behavior change given the proliferation of sanitation campaigns during the period of observation (2004-2012), and the cohesiveness of these groups has facilitated sharing of collective EH-improving goals. Additionally, similar to female bridging score, bonding score is also higher in the rural sample. While it is surprising that political participation has a significant negative effect on urban households' choice of clean cooking but significant positive effects on the same sample's piped drinking water access, it is important to consider that clean cooking, particularly

LPG, did not receive as much political traction as the push for clean water and sanitation did in the seven years between the surveys.

Behavioral experiments in randomized controlled trials (RCTs) around social norms and neighbor comparison messages have found significant effects on reducing household energy consumption (Alcott 2011; Ayres *et al* 2012; Nolan *et al* 2008; Schultz *et al* 2007), increasing latrine adoption (Clasen *et al* 2014; Dickinson *et al* 2015; Patil *et al* 2014; Pattanayak *et al* 2009; Pickering *et al* 2015) and reducing water use (Bernado *et al* 2014; Ferraro *et al* 2011; Ferraro and Price 2013). In this paper, albeit in a non-experimental setting, cognitive social capital has no consistent effect on household choice of clean cooking. However, the strong positive effect of social cohesion on toilet adoption finds support in results from community-led total sanitation (CLTS) RCTs that find positive impacts on toilet take-up (Clasen *et al* 2014; Dickinson *et al* 2015; Patil *et al* 2014; Pattanayak *et al* 2009; Pickering *et al* 2015). In the analytic sample, continual sanitation messaging (from CLTS campaigns, government and non-government programs) over time may have translated into collective engagement with positive behavior change. The opposite effects of collective action on toilet adoption (negative) and piped drinking water (positive) point to concerns around survey questions that attempt to encapsulate rules that guide collective action. Respondents may have interpreted the collective action question to be more appropriate in the context of water provision than sanitation. It may not necessarily follow from these results that households do not view sanitation as a 'problem' that they need to bond over to resolve. However, in the restricted rural sample with village characteristics, collective action has a strong negative effect on piped drinking water access. This may suggest that rural households are collectively resolving their drinking water problems through other sources, such as community tube wells or wells.

While social capital effects are robust to inclusion of EH technologies, there exist strong complementarities between the three EH technologies under consideration. Toilets have higher positive effects on clean cooking in the urban sample, while clean cooking has higher positive effects on toilets across rural areas. The higher positive effect of drinking water treatment on household choice of clean cooking, compared to that of toilet adoption on clean cooking, particularly in rural areas, may be indicative of pairing of EH behaviors around cooking (i.e. choice of clean cooking and type of water treatment such as boiling). Since the survey does not ask households different drinking water treatment methods used, this claim cannot be validated. Toilets and piped drinking water have strong positive effects on each other, especially in urban areas. This is expected since toilet construction and piped drinking water connections are linked to infrastructure support, which is relatively better provided in urban settings.

The strong positive effect of adult education[28] particularly that of females on clean cooking adoption, is similar to findings from Lewis and Pattanayak (2012) meta-analysis of ICS studies. Consistent with Coffey *et al* (2015) findings from rural India, I find that latrine take-up is positively affected by increase in number of married women. Electricity access has strong positive effects on toilet adoption and piped drinking water access, but strong negative effect on household choice of clean cooking. Though one would expect that infrastructure and markets for these public goods move together, it is likely that households in regions with access to, availability of and preference for electric stoves do not adopt LPG. Lewis *et al* (2015), for example, find sales of electric stoves to be higher, compared to other ICS, when households in Uttarakhand, India are given different ICS options.

These results should be interpreted with some considerations in mind. First, data are from a non-RCT context that does not involve behavioral or policy experiments intended to amplify social capital. This constrains the researcher to examine the complex sociological construct of social capital based on survey questions. As mentioned previously, a single collective action question, for example, may not encompass the operations of informal institutions within communities. Another survey-related limitation is the lack of data on time (date/month/year) when households

[28]Household characteristics' coefficients from fixed effects models not shown, for brevity.

switched behavior or started using a given EH technology. Information on timing would have enabled better analysis, as accrual of benefits from improved EH behavior is dependent on history of new technology use (Bandiera and Rasul 2002). Third, global positioning system (GPS) coordinates of households and community information sources would have allowed for measuring geographic distance between origins and beneficiaries of information; visual representation of spatial variation in social capital across communities would have improved analysis. Despite these data restraints, in using exploratory factor analysis, I create discrete indicators for social capital that are consistent with the literature (Chuang and Chuang 2008; Eriksson *et al* 2011; Perry *et al* 2008; Story 2014) and internally reliable. As described previously, in the EH realm, experiments have been designed to change social norms and examine its long-term impact on intervention uptake. Future experiments could consider combining policy behavioral experiments with social network analysis for a holistic understanding of the impact of both forms of social capital- structural and cognitive- on EH adoption and its long-term impacts.

Conclusion

The empirical evidence in this paper provides insights into the vital role that social capital can play in EH technology adoption, the latter being central to combating the twin problems of household air pollution and unsafe water and sanitation. While previous studies have examined the impact of social networks (Adhvaryu 2014;

Beltramo *et al* 2014; Bonan *et al* 2017; Miller and Mobarak 2015; Ramirez *et al* 2014) and social norms (Clasen *et al* 2014; Dickinson *et al* 2015; Patil *et al* 2014; Pattanayak *et al* 2009; Pickering *et al* 2015) on uptake of a single EH technology in specific settings, this paper provides evidence on the combined role of structural (social networks, group participation, political engagement) and cognitive (social cohesion, collective action) social capital in explaining various EH technologies across rural and urban India. While small in absolute terms, the positive social capital estimates in this paper point to the importance of building on the strengths of existing social groups and institutions to trigger behavior change. Vulturius and Wanjiru (2017) demonstrate higher ICS adoption when women's SHGs and teachers are targeted.

Community-led development interventions can have differing impacts depending on the nature of implementation, as evidenced in the sanitation literature. Teacher-provided CLTS, compared to CLTS using health workers and local leaders, in Ethiopia led to a lower decrease in open defecation (Crocker *et al* 2016), while resource agencies-implemented CLTS villages in Indonesia had higher toilet construction and intolerance towards open defecation compared to local governments-implemented CLTS villages (Cameron and Shah 2017). Leveraging existing social networks and community groups' efforts has the potential to sustain behavior change. Recent evidence from India finds social norms-based community interventions to have strong long-term impacts on sustained latrine adoption and cognitive development impacts, particularly for girls (Orgill 2017). Current national policy advances in clean cooking and safe sanitation in India could potentially disseminate information through social groups (e.g. SHGs) and existing group-based programs, such as the integrated child development services, and accredited social health activists. As the LPG schemes phase their district-wise rollout and state governments design their respective sanitation programs, there is potential for researchers to collaborate with state governments in designing experiments, to examine which social processes and groups are most effective in increasing LPG and toilet uptake and subsequently sustaining use.

Tables

Table 3.1. Summary statistics for outcome variables: Environmental health technologies[I]

	Total		Rural		Urban	
	IHDS-I (N=35,618)	IHDS-II (N=35,618)	IHDS-I (N=23,454)	IHDS-II (N=23,454)	IHDS-I (N=12,164)	IHDS-II (N=12,164)
Non-biomass stove	26.8	37.3	9.1	17.8	60.9	75.0
LPG mainly used for cooking	29.3	40.1	17.8	27.8	51.5	63.9
Clean cooking energy (use of LPG fuel and non-biomass stove)	16.7	28.7	5.0	14.2	39.3	56.7
Toilet ownership	44.0	56.0	28.1	41.9	74.5	83.1
Piped drinking water	44.4	47.0	30.4	34.7	71.4	70.8

NOTE: [I] All variables are significantly different across survey rounds (1% significance level).

Table 3.2. Summary statistics: Explanatory and control variables[I, II]

	Total		Rural		Urban	
	IHDS-I (N=35,618)	IHDS-II (N=35,618)	IHDS-I (N=23,454)	IHDS-II (N=23,454)	IHDS-I (N=12,164)	IHDS-II (N=12,164)
PANEL A: Explanatory variables - Social capital						
Structural social capital						
Linking						
Among your acquaintances and relatives, any in these professions (%):						
Health	31.2	56.7	29.1	53.1	35.1	63.6
Education	39.3	59.5	38.4	57.2	41.2	64.0
Government service	33.6	30.4	28.7	26.4	43.0	38.3
Anyone in the household belongs to these groups (%):						
Female-centric bridging groups						
Mahila mandal / Women's group	7.4	9.1	8.6	9.4	5.1	8.4
Self-Help Group	9.5	19.3	11.3	22.1	6.1	14.0
Credit/Savings	7.0	11.2	7.9	11.5	5.3	10.7
Activity-based bridging groups						
Youth/Sports/Reading	4.9	2.6	4.4	2.0	6.0	3.8
Trade Union/Business/Professional	4.7	5.3	3.0	3.3	8.1	9.1
Bonding groups						
Religious	13.6	11.6	14.4	11.2	12.1	12.4
Caste Association	12.8	8.8	14.0	8.8	10.4	9.0
Political participation						
Any household member attended public meeting in the last year (%)	28.7	28.9	35.8	37.1	15.0	13.0
Any household member is a government official (%)	10.3	3.9	12.7	5.0	5.6	1.8
Cognitive social capital						
Social cohesion						
People generally get along with each other (3=no conflict, 2=some conflict, 1=lot of conflict)	2.38 (0.74)	2.46 (0.71)	2.37 (0.74)	2.44 (0.70)	2.40 (0.73)	2.48 (0.72)
Castes and sub-castes in the community get along with each other (3=no conflict, 2=some conflict, 1=lot of conflict)	2.65 (0.57)	2.49 (0.66)	2.63 (0.58)	2.48 (0.66)	2.70 (0.54)	2.53 (0.66)

Collective action						
People bond to solve local problems (%)	57.2	72.6	59.0	74.0	53.7	70.0
Factor Analysis Scores (Household-level)						
Linking	-0.22 (0.98)	0.22 (0.97)	-0.28 (0.96)	0.14 (0.96)	-0.10 (1.01)	0.38 (0.96)
Female-centric bridging	-0.14 (0.89)	0.14 (1.08)	-0.07 (0.95)	0.20 (1.11)	-0.27 (0.73)	0.02 (1.02)
Activity-based bridging	0.07 (1.05)	-0.07 (0.94)	-0.02 (0.93)	-0.16 (0.78)	0.22 (1.24)	0.11 (1.17)
Bonding	0.07 (1.05)	-0.07 (0.94)	0.10 (1.09)	-0.08 (0.93)	0.01 (0.97)	-0.05 (0.96)
Political participation	0.10 (1.11)	-0.10 (0.87)	0.26 (1.19)	0.04 (0.94)	-0.21 (0.85)	-0.37 (0.64)
Social cohesion	0.04 (0.91)	-0.04 (1.08)	0.01 (0.91)	-0.07 (1.07)	0.10 (0.89)	0.02 (1.10)
PANEL B: Control variables						
Per capita monthly total expenditures (in INR)	1,679.66 (1762.97)	2302.82 (2680.99)	1377.97 (1427.65)	1951.55 (2197.68)	2261.38 (2158.10)	2980.13 (3322.37)
Number of married women	1.25 (0.71)	1.24 (0.74)	1.30 (0.75)	1.27 (0.75)	1.16 (0.62)	1.18 (0.69)
Number of household members	5.34 (2.52)	4.97 (2.41)	5.52 (2.66)	5.04 (3.49)	4.98 (2.19)	4.83 (2.23)
Highest male adult education (in years)	6.81 (5.13)	7.38 (5.30)	5.81 (4.90)	6.39 (5.11)	8.73 (5.01)	9.29 (5.12)
Highest female adult education (in years)	4.51 (4.99)	5.56 (5.33)	3.28 (4.33)	4.32 (4.83)	6.89 (5.31)	7.94 (5.43)
Dependency ratio	0.74 (0.70)	0.61 (0.66)	0.79 (0.73)	0.65 (0.70)	0.63 (0.64)	0.53 (0.59)
Female household head (%)	9.3	16.0	9.0	16.2	9.9	15.6
Age of household head (in years)	46.33 (11.72)	52.11 (12.15)	46.68 (11.78)	52.47 (12.26)	45.66 (11.58)	51.40 (11.91)
Own house (%)	90.9	91.6	98.0	98.1	77.1	79.2
Electricity access hours/day	12.51 (9.05)	13.36 (8.19)	9.85 (8.71)	11.36 (8.10)	17.62 (7.33)	17.22 (6.87)
Safe treatment of drinking water	8.3	12.6	4.9	8.9	14.9	19.8
PANEL C: Village variables						
			IHDS-I (N=1,371)	IHDS-II (N=1,371)		
Years of cable television access			2.05 (4.34)	6.67 (5.89)		
Distance to nearest road (in kilometers)			1.56 (4.05)	0.51 (2.10)		
Distance to nearest bank branch/credit cooperative (in kilometers)			4.46 (5.20)	4.93 (5.23)		
LPG price per unit (INR/kg)			45.32 (22.17)	34.03 (14.65)		

NOTE: [I] Standard deviation in parentheses for continuous variables. [II] All variables are significantly different across survey rounds (1% significance level), except religious group membership (urban sample only), attending public meeting (full sample only) and house ownership (rural sample only).

Table 3.3. Determinants of social capital (Full sample): Household FE regression results

	Structural social capital					Cognitive social capital	
	Linking	Female-centric bridging	Activity-based bridging	Bonding	Political participation	Social cohesion	Collective action
Structural social capital (household-level)							
Linking/Networks score		0.010**	0.050***	0.037***	0.059***	0.010**	0.057***
		(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.003)
Female-centric bridging groups score	0.019***		0.053***	0.071***	0.044***	-0.007	0.054***
	(0.004)		(0.007)	(0.006)	(0.005)	(0.005)	(0.003)
Activity-based bridging groups score	0.044***	0.045***		0.069***	0.025***	-0.002	-0.029***
	(0.004)	(0.006)		(0.005)	(0.006)	(0.005)	(0.003)
Bonding groups score	0.028***	0.058***	0.067***		0.029***	0.004	-0.042***
	(0.004)	(0.005)	(0.006)		(0.005)	(0.004)	(0.003)
Political participation score	0.052***	0.036***	0.025***	0.033***		0.003	-0.013***
	(0.004)	(0.005)	(0.005)	(0.005)		(0.005)	(0.003)
Cognitive social capital (household-level)							
Social cohesion score	0.017***	-0.004	-0.003	0.004	0.004		0.049***
	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)		(0.002)
Collective action	0.202***	0.174***	-0.125***	-0.168***	-0.063***	0.229***	
	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.011)	
Household characteristics							
Log of per capita monthly total expenditures	0.144***	0.045***	0.060***	0.051***	0.052***	0.008	-0.009**
	(0.008)	(0.009)	(0.009)	(0.009)	(0.010)	(0.009)	(0.004)
Number of married women	-0.009	-0.026***	-0.024**	-0.013	-0.018	-0.014	0.004
	(0.010)	(0.010)	(0.011)	(0.010)	(0.012)	(0.010)	(0.005)
Number of household members	0.021***	0.026***	0.018***	0.008**	0.020***	0.004	-0.003*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.002)
Highest male adult education	0.010***	0.002	0.006***	0.001	0.004**	0.004***	0.001**
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)
Highest female adult education	0.008***	0.005***	-0.001	0.000	0.002	0.002	-0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Dependency ratio	0.013*	-0.031***	-0.016**	-0.008	-0.015**	-0.009	0.003

	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.004)
Female household head	-0.043***	-0.011	-0.011	-0.042***	-0.083***	0.021	0.011
	(0.016)	(0.016)	(0.018)	(0.016)	(0.018)	(0.017)	(0.009)
Age of household head	0.001	-0.002***	-0.000	0.000	0.001	0.002**	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Round 2	-0.043***	-0.002	-0.022***	-0.011*	-0.040***	-0.055***	-0.034***
	(0.006)	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)	(0.003)
Constant	-1.373***	-0.448***	-0.416***	-0.244***	-0.381***	-0.318***	0.136***
	(0.072)	(0.076)	(0.082)	(0.078)	(0.085)	(0.077)	(0.039)
Observations	71,236	71,236	71,236	71,236	71,236	71,236	71,236
Adjusted R-squared	0.480	0.315	0.314	0.461	0.266	0.489	0.428

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Community-level measures of social capital are also included for respective household-level social capital outcomes and are positively significant (p<0.01).

Table 3.4. Effect of social capital on clean cooking: Household FE regression results

	Total		Rural		Urban	
	(1)	(2)	(3)	(4)	(5)	(6)
Structural social capital(community-level)						
Linking/Networks score	0.029***	0.029***	0.016**	0.017**	0.058***	0.057***
	(0.007)	(0.007)	(0.007)	(0.006)	(0.017)	(0.017)
Female-centric bridging groups score	0.020**	0.020**	0.037***	0.035***	0.001	0.004
	(0.009)	(0.009)	(0.010)	(0.010)	(0.019)	(0.019)
Activity-based bridging groups score	-0.027***	-0.026***	-0.070***	-0.069***	0.007	0.007
	(0.010)	(0.010)	(0.012)	(0.012)	(0.015)	(0.015)
Bonding groups score	0.006	0.004	0.011*	0.010*	-0.019	-0.022
	(0.006)	(0.006)	(0.006)	(0.006)	(0.014)	(0.014)
Political participation score	-0.025***	-0.024***	-0.004	-0.004	-0.107***	-0.107***
	(0.007)	(0.007)	(0.006)	(0.006)	(0.022)	(0.022)
Cognitive social capital (community-level)						
Social cohesion score	0.002	0.001	-0.003	-0.004	0.003	0.000
	(0.005)	(0.005)	(0.005)	(0.005)	(0.013)	(0.013)
Collective action	-0.021	-0.018	-0.035***	-0.033***	-0.015	-0.009
	(0.014)	(0.014)	(0.013)	(0.013)	(0.030)	(0.030)
Related EH behaviors (household-level)						
Toilet/individual household latrine		0.043***		0.032***		0.075***
		(0.007)		(0.007)		(0.017)
Piped drinking water		0.005		0.000		0.024
		(0.008)		(0.007)		(0.016)
Safe treatment of drinking water		0.072***		0.066***		0.071***
		(0.012)		(0.013)		(0.018)
Observations	71,236	71,236	46,908	46,908	24,328	24,328
Adjusted R-squared	0.073	0.078	0.081	0.086	0.093	0.099

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Household characteristics controlled: log of per capita monthly total expenditures, number of married women, number of household members, highest adult education (male and female, separately), dependency ratio, household head demographics (age, sex), house ownership and hours of daily electricity access.

Table 3.5. Effect of social capital on toilets: Household FE regression results

	Total		Rural		Urban	
	(1)	(2)	(3)	(4)	(5)	(6)
Structural social capital (community-level)						
Linking/Networks score	-0.019***	-0.020***	-0.026***	-0.027***	0.002	-0.000
	(0.007)	(0.007)	(0.009)	(0.009)	(0.010)	(0.010)
Female-centric bridging groups score	0.007	0.007	0.005	0.003	0.014	0.015
	(0.008)	(0.008)	(0.011)	(0.011)	(0.011)	(0.011)
Activity-based bridging groups score	0.004	0.005	-0.013	-0.009	0.018**	0.018**
	(0.006)	(0.006)	(0.009)	(0.009)	(0.008)	(0.008)
Bonding groups score	0.017***	0.017***	0.032***	0.031***	-0.007	-0.006
	(0.005)	(0.005)	(0.006)	(0.007)	(0.007)	(0.007)
Political participation score	-0.003	-0.003	-0.006	-0.006	0.010	0.013
	(0.009)	(0.009)	(0.010)	(0.010)	(0.016)	(0.016)
Cognitive social capital (community-level)						
Social cohesion score	0.017***	0.017***	0.013*	0.013*	0.021***	0.021***
	(0.005)	(0.005)	(0.007)	(0.007)	(0.007)	(0.007)
Collective action	-0.025**	-0.025**	-0.013	-0.012	-0.047***	-0.047**
	(0.012)	(0.012)	(0.016)	(0.016)	(0.018)	(0.018)
Related EH behaviors (household-level)						
Clean cooking		0.040***		0.054***		0.036***
		(0.007)		(0.011)		(0.008)
Piped drinking water		0.032***		0.026***		0.034***
		(0.007)		(0.010)		(0.009)
Safe treatment of drinking water		0.000		0.003		0.003
		(0.007)		(0.012)		(0.008)
Observations	71,236	71,236	46,908	46,908	24,328	24,328
Adjusted R-squared	0.079	0.082	0.095	0.098	0.057	0.061

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Household characteristics controlled: log of per capita monthly total expenditures, number of married women, number of household members, highest adult education (male and female, separately), dependency ratio, household head demographics (age, sex), house ownership and hours of daily electricity access.

Table 3.6. Effect of social capital on piped drinking water: Household FE regression results

	Total		Rural		Urban	
	(1)	(2)	(3)	(4)	(5)	(6)
Structural social capital (community-level)						
Linking/Networks score	-0.008	-0.007	-0.005	-0.005	-0.007	-0.007
	(0.008)	(0.008)	(0.011)	(0.011)	(0.011)	(0.012)
Female-centric bridging groups score	-0.018*	-0.019*	-0.004	-0.004	-0.047***	-0.047***
	(0.011)	(0.011)	(0.015)	(0.015)	(0.014)	(0.014)
Activity-based bridging groups score	-0.001	-0.001	-0.006	-0.005	0.002	0.002
	(0.008)	(0.008)	(0.012)	(0.012)	(0.010)	(0.010)
Bonding groups score	0.003	0.002	0.013*	0.012	-0.013	-0.012
	(0.006)	(0.006)	(0.008)	(0.008)	(0.010)	(0.010)
Political participation score	0.018*	0.018*	0.012	0.012	0.040**	0.041**
	(0.010)	(0.010)	(0.012)	(0.012)	(0.016)	(0.016)
Cognitive social capital (community-level)						
Social cohesion score	0.001	0.000	0.005	0.004	-0.005	-0.006
	(0.006)	(0.006)	(0.008)	(0.008)	(0.009)	(0.009)
Collective action	0.027*	0.029*	0.036*	0.037*	0.013	0.015
	(0.016)	(0.016)	(0.021)	(0.021)	(0.021)	(0.021)
Related EH behaviors (household-level)						
Clean cooking		0.005		0.014		0.015
		(0.008)		(0.014)		(0.010)
Toilet/individual household latrine		0.034***		0.000		0.043***
		(0.008)		(0.012)		(0.011)
Safe treatment of drinking water		0.003		0.026***		-0.004
		(0.009)		(0.010)		(0.010)
Observations	71,236	71,236	46,908	46,908	24,328	24,328
Adjusted R-squared	0.009	0.010	0.015	0.016	0.009	0.011

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Household characteristics controlled: log of per capita monthly total expenditures, number of married women, number of household members, highest adult education (male and female, separately), dependency ratio, household head demographics (age, sex), house ownership and hours of daily electricity access.

Table 3.7. Effect of social capital on EH technologies: Household FE results (Rural sample only)

	Clean cooking		Toilet		Piped DW	
	(1)	(2)	(3)	(4)	(5)	(6)
Structural social capital (community-level)						
Linking/Networks score	0.012**	0.012**	-0.012	-0.013	0.002	0.003
	(0.006)	(0.006)	(0.009)	(0.009)	(0.011)	(0.011)
Female-centric bridging groups score	0.033***	0.031***	0.002	0.001	-0.015	-0.015
	(0.011)	(0.011)	(0.012)	(0.012)	(0.017)	(0.017)
Activity-based bridging groups score	-0.035***	-0.035***	-0.011	-0.009	-0.008	-0.008
	(0.009)	(0.009)	(0.008)	(0.008)	(0.011)	(0.011)
Bonding groups score	0.004	0.003	0.039***	0.039***	0.017*	0.016*
	(0.006)	(0.006)	(0.007)	(0.007)	(0.009)	(0.009)
Political participation score	-0.008	-0.008	-0.008	-0.007	0.009	0.009
	(0.007)	(0.007)	(0.012)	(0.012)	(0.014)	(0.014)
Cognitive social capital (community-level)						
Social cohesion score	-0.010**	-0.010**	0.013*	0.013*	0.003	0.003
	(0.005)	(0.005)	(0.007)	(0.007)	(0.008)	(0.008)
Collective action	0.008	0.007	0.001	0.001	-0.049**	-0.049**
	(0.013)	(0.013)	(0.017)	(0.017)	(0.023)	(0.023)
Related EH behaviors (household-level)						
Clean cooking				0.052***		-0.003
				(0.012)		(0.013)
Toilet/individual household latrine		0.029***				0.025**
		(0.007)				(0.010)
Piped drinking water		-0.002		0.025**		
		(0.007)		(0.011)		
Safe treatment of drinking water		0.049***		0.005		0.013
		(0.014)		(0.014)		(0.017)
Observations	40,297	40,297	40,297	40,297	40,297	40,297
Adjusted R-squared	0.085	0.088	0.102	0.104	0.018	0.019

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. In addition to household characteristics included in previous models, village characteristics controlled for: years of cable TV access, distance to tarred road and bank branch, and LPG per unit price ('clean cooking' outcome only).

Table 3.8. Falsification tests-Effect of social capital on durable goods: Household FE regression results (Total sample)

	Mixer	Fridge	Pressure cooker	Color TV	Electric fan	Cellphone	Scooter
Structural social capital (community-level)							
Linking/Networks score	0.006*	-0.001	0.002	0.004	0.001	0.001	-0.000
	(0.003)	(0.003)	(0.003)	(0.005)	(0.003)	(0.006)	(0.003)
Female-centric bridging groups score	0.003	0.002	0.006	0.004	0.001	-0.003	-0.005
	(0.005)	(0.004)	(0.005)	(0.007)	(0.004)	(0.008)	(0.004)
Activity-based bridging groups score	-0.007*	-0.003	0.001	-0.001	0.002	-0.004	0.003
	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.007)	(0.004)
Bonding groups score	0.006**	0.008***	0.004	0.003	-0.002	0.001	0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.005)	(0.003)
Political participation score	0.003	-0.001	-0.001	0.006	0.004	0.007	0.004
	(0.004)	(0.003)	(0.004)	(0.006)	(0.004)	(0.007)	(0.004)
Cognitive social capital (community-level)							
Social cohesion score	0.000	0.000	0.004	0.002	-0.002	0.005	0.001
	(0.003)	(0.002)	(0.003)	(0.004)	(0.003)	(0.005)	(0.003)
Collective action	-0.008	-0.005	-0.002	-0.017*	0.002	-0.009	0.006
	(0.007)	(0.006)	(0.007)	(0.009)	(0.006)	(0.012)	(0.007)
Observations	71,236	71,236	71,236	71,236	71,236	71,236	71,236
Adjusted R-squared	0.001	0.001	0.001	0.000	0.001	0.001	0.001

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Household characteristics controlled: log of per capita monthly total expenditures, number of married women, number of household members, highest adult education (male and female, separately), dependency ratio, household head demographics (age, sex), house ownership, household bank account ownership and hours of daily electricity access. For all 7 durable goods, analyses were also done including EH technologies; the significance of results is similar and not presented here.

REFERENCES

Batha, E. (2015). Malawi bans child marriage, lifts minimum age to 18. Retrieved March 12, Adhvaryu, A. (2014). Learning, misallocation, and technology adoption: evidence from new malaria therapy in Tanzania. *The Review of Economic Studies*, 81(4), 1331-1365.

Adrianzén, M. A. (2014). Social capital and improved stoves usage decisions in the northern Peruvian Andes. *World Development*, *54*, 1-17.

Allcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics*, *95*(9-10), 1082-1095.

Ambrus, A., Mobius, M., & Szeidl, A. (2014). Consumption risk-sharing in social networks. *American Economic Review*, 104(1), 149-82.

Ayres, I., Raseman, S., & Shih, A. (2013). Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. *The Journal of Law, Economics, and Organization*, *29*(5), 992-1022.

Bandiera, O., & Rasul, I. (2006). Social networks and technology adoption in northern Mozambique. *The Economic Journal*, 116(514), 869-902.

Banerjee, A., Chandrasekhar, A. G., Duflo, E., & Jackson, M. O. (2013). The diffusion of microfinance. *Science*, *341*(6144), 1236498.

Becker, G. S. (2007). Health as human capital: synthesis and extensions. *Oxford Economic Papers*, *59*(3), 379-410.

Behrman, J. R., Kohler, H. P., & Watkins, S. C. (2002). Social networks and changes in contraceptive use over time: Evidence from a longitudinal study in rural Kenya. *Demography*, 39(4), 713-738.

Beltramo, T., Blalock, G., Levine, D. I., & Simons, A. M. (2015). Does peer use influence adoption of efficient cookstoves? Evidence from a randomized controlled trial in Uganda. *Journal of Health Communication*, *20*(sup1), 55-66.

BenYishay A. and A. M. Mobarak. 2015. Social Learning and Incentives for Experimentation and Communication. Conditionally Accepted, *Review of Economic Studies*.

Bernedo, M., Ferraro, P. J., & Price, M. (2014). The persistent impacts of norm-based messaging and their implications for water conservation. *Journal of Consumer Policy*, *37*(3), 437-452.

Bielecki, C., & Wingenbach, G. (2014). Rethinking improved cookstove diffusion programs: A case study of social perceptions and cooking choices in rural Guatemala. *Energy Policy*, *66*, 350-358.

Boahene, K., Snijders, T. A., & Folmer, H. (1999). An integrated socioeconomic analysis of innovation adoption: the case of hybrid cocoa in Ghana. *Journal of Policy Modeling*, 21(2), 167-184.

Bonan, J., Battiston, P., Bleck, J., LeMay-Boucher, P., Pareglio, S., Sarr, B. A., & Tavoni, M. (2017). Social interaction and technology adoption: experimental evidence from improved cookstoves in Mali. *Working Paper*.

Bourdieu, P. (1986). The forms of capital. In J. G. Richardson (Ed.), Handbook of theory and research for the sociology of education (pp. 241-258). New York, NY: Greenwood Press

Brown, L.A., 2001. Diffusion: geographical aspects. New International Encyclopedia of the Social and Behavioral Sciences, 3676–3681.

Cai, J., De Janvry, A., & Sadoulet, E. (2015). Social networks and the decision to insure. *American Economic Journal: Applied Economics*, *7*(2), 81-108.

Call, M., & Jagger, P. (2017). Social capital, collective action, and communal grazing lands in Uganda. *International Journal of the Commons*, 11(2).

Cameron, L.A. and Shah, M. (2017). Scaling Up sanitation: Evidence from an RCT in Indonesia, *IZA Discussion Papers*, No. 10619.

Carter, M. R., Laajaj, R., & Yang, D. (2014). *Subsidies and the persistence of technology adoption: Field experimental evidence from Mozambique* (No. w20465). National Bureau of Economic Research.

Census of India. 2011. Houses, household amenities and assets data 2001-2011: Visualizing through maps. Available at: http://censusindia.gov.in/2011-Common/NSDI/Houses_Household.pdf [Accessed on January 29, 2018]

Chuang, Y.-C., Chuang, K.-Y., (2008). Gender differences in relationships between social capital and individual smoking and drinking behavior in Taiwan. *Soc. Sci. Med*. 67, 1321–1330.

Chuang, Y., & Schechter, L. (2015). Social networks in developing countries. *Annu. Rev. Resour. Econ*., 7(1), 451-472.

Clasen, T., Boisson, S., Routray, P., Torondel, B., Bell, M., Cumming, O., ... & Schmidt, W. P. (2014). Effectiveness of a rural sanitation programme on diarrhoea, soiltransmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomized trial. *The Lancet Global Health*, 2(11), e645-e653.

Coffey, D., Spears, D., & Vyas, S. (2017). Switching to sanitation: understanding latrine adoption in a representative panel of rural Indian households. *Social Science & Medicine*, *188*, 41-50.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology*, *94*, S95-S120.

Conley, T. G., & Udry, C. R. (2010). Learning about a new technology: Pineapple in Ghana. *American Economic Review*, 100(1), 35-69.

Crocker, J., Geremew, A., Atalie, F., Yetie, M., & Bartram, J. (2016). Teachers and sanitation promotion: an assessment of community-led total sanitation in Ethiopia. *Environmental science & technology*, *50*(12), 6517-6525.

Dandona, L., Dandona, R., Kumar, G. A., Shukla, D. K., Paul, V. K., Balakrishnan, K., ... & Nandakumar, A. (2017). Nations within a nation: variations in epidemiological transition across the states of India, 1990–2016 in the Global Burden of Disease Study. *The Lancet*, *390*(10111), 2437-2460.

Desai, Sonalde, Reeve Vanneman, and National Council of Applied Economic Research, New Delhi. India Human Development Survey (IHDS), 2005. ICPSR22626-v11. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2016-02-16. https://doi.org/10.3886/ICPSR22626.v11

Desai, Sonalde, and Reeve Vanneman. India Human Development Survey-II (IHDS-II), 2011-12. ICPSR36151-v5. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2016-08-01. https://doi.org/10.3886/ICPSR36151.v5

De Silva, M. J., & Harpham, T. (2007). Maternal social capital and child nutritional status in four developing countries. *Health & Place*, *13*(2), 341-355.

De Weerdt, J., & Dercon, S. (2006). Risk-sharing networks and insurance against illness. *Journal of Development Economics*, 81(2), 337-356.

Dickinson, K. L., Patil, S. R., Pattanayak, S. K., Poulos, C., & Yang, J. H. (2015). Nature's call: impacts of sanitation choices in Orissa, India. *Economic Development and Cultural Change*, *64*(1), 1-29.

Dow, W. H., Philipson, T. J., & Sala-i-Martin, X. (1999). Longevity complementarities under competing risks. *American Economic Review*, 1358-1371.

Dupas, P. (2014). Short-run subsidies and long-run adoption of new health products: Evidence from a field experiment. *Econometrica*, *82*(1), 197-228

Eriksson, M., Ng, N., Weinehall, L., Emmelin, M., 2011. The importance of gender and conceptualization for understanding the association between collective social capital and health: a multilevel analysis from northern Sweden. *Soc. Sci. Med*. 73, 264–273.

Fafchamps, M., & Lund, S. (2003). Risk-sharing networks in rural Philippines. *Journal of Development Economics*, 71(2), 261-287.

Feigenberg, B., Field, E., & Pande, R. (2013). The economic returns to social interaction: Experimental evidence from microfinance. *The Review of Economic Studies*, rdt016.

Ferraro, P. J., Miranda, J. J., & Price, M. K. (2011). The persistence of treatment effects with norm-based policy instruments: evidence from a randomized environmental policy experiment. *American Economic Review*, *101*(3), 318-22.

Ferraro, P. J., & Price, M. K. (2013). Using nonpecuniary strategies to influence behavior: evidence from a large-scale field experiment. *Review of Economics and Statistics*, *95*(1), 64-73.

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford Jr, J. M. (2005). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet infectious diseases*, 5(1), 42-52.

Field, E., Jayachandran, S., Pande, R., & Rigol, N. (2014). Friends at Work: Can Peer Support Stimulate Female Entrepreneurship? *Unpublished manuscript, Northwestern Univ., Evanston, IL Article Location.*

Forouzanfar, M. H., Alexander, L., Anderson, H. R., Bachman, V. F., Biryukov, S., Brauer, M., ... & Delwiche, K. (2015). Global, regional, and national comparative risk assessment of 79 behavioral, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013.*The Lancet*, 386(10010), 2287-2323.

Foster, A. D., & Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of Political Economy*, 103(6), 1176-1209.

GBD 2016 Causes of Death Collaborators (2017). Global, regional and national age-sex specific mortality for 264 causes of death 1980-2016: systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, 390(10100), 1151-1210.

Godlonton, S., & Thornton, R. (2012). Peer effects in learning HIV results. *Journal of Development Economics*, 97(1), 118-129.

Government of India. (2014). Restructuring of the Nirmal Bharat Abhiyan into Swachh Bharat Mission. Press Information Bureau, Government of India Cabinet. (http://pib.nic.in/newsite/PrintRelease.aspx?relid=109988) (Accessed: March 8, 2018)

Government of India. (2018). LPG Schemes. Ministry of Petroleum and Natural Gas. (http://petroleum.nic.in/marketing/schemes/lpg-schemes) (Accessed: March 8, 2018)

Granovetter, M. (1973). The strength of weak ties. *Am. J. Sociol*. 78, 1360-1380.

Gurley, E. S., Homaira, N., Salje, H., Ram, P. K., Haque, R., Petri, W., ... & Azziz-Baumgartner, E. (2013). Indoor exposure to particulate matter and the incidence of acute lower respiratory infections among children: a birth cohort study in urban Bangladesh. *Indoor Air*, 23(5), 379-386.

Heaney, C.A. and Israel, B.A. (2008). Social networks and social support. In Glanz, Rimer and Viswanath. Glanz, K., Rimer, B. K., & Viswanath, K. (Eds.). *Health behavior and health education: theory, research, and practice* (pp. 189-210). San Francisco, CA: John Wiley & Sons.

Isham, J. (2002). The effect of social capital on fertilizer adoption: Evidence from rural Tanzania. *Journal of African Economies*, 11(1), 39-60.

Iwase, T., Suzuki, E., Fujiwara, T., Takao, S., Doi, H., & Kawachi, I. (2012). Do bonding and bridging social capital have differential effects on self-rated health? A community-based study in Japan. *J Epidemiology Community Health*, 66(6), 557-562.

Kaestner, R., Darden, M., & Lakdawalla, D. (2014). Are investments in disease prevention complements? The case of statins and health behaviors. *Journal of Health Economics*, 36, 151-163.

Karlan, D., Mobius, M., Rosenblat, T., & Szeidl, A. (2009). Trust and social collateral. *The Quarterly Journal of Economics*, 124(3), 1307-1361.

Katungi, E., Edmeades, S., & Smale, M. (2008). Gender, social capital and information exchange in rural Uganda. *Journal of International Development*, *20*(1), 35-52.

Kawachi, I., Subramanian, S. V., & Kim, D. (2008). Social capital and health (pp. 1-26). Springer New York

Kinnan, C., & Townsend, R. (2012). Kinship and financial networks, formal financial access, and risk reduction. *American Economic Review*, 102(3), 289-93.

Kim, D., Subramanian, S. V., & Kawachi, I. (2006). Bonding versus bridging social capital and their associations with self-rated health: a multilevel analysis of 40 US communities. *Journal of Epidemiology and Community Health*, *60*(2), 116-122.

Kremer, M., & Miguel, E. (2007). The illusion of sustainability. *The Quarterly Journal of Economics*, 122(3), 1007-1065.

Kumar, N., Scott, S., Menon, P., Kannan, S., Cunningham, K., Tyagi, P., ... & Quisumbing, A. (2017). Pathways from women's group-based programs to nutrition change in South Asia: A conceptual framework and literature review. *Global Food Security*.

Kurmi, O. P., Semple, S., Simkhada, P., Smith, W. C. S., & Ayres, J. G. (2010). COPD and chronic bronchitis risk of indoor air pollution from solid fuel: a systematic review and meta-analysis. *Thorax*, 65(3), 221-228.

Lewis, J. J., & Pattanayak, S. K. (2012). Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives*, *120*(5), 637.

Lewis, J. J., Bhojvaid, V., Brooks, N., Das, I., Jeuland, M. A., Patange, O., & Pattanayak, S. K. (2015). Piloting improved cookstoves in India. Journal of Health Communication, 20(sup1), 28-42.

Liverpool-Tasie, L. S. O., & Winter-Nelson, A. (2012). Social learning and farm technology in Ethiopia: Impacts by technology, network type, and poverty status. *The Journal of Development Studies*, 48(10), 1505-1521.

McEachern, M., & Hanson, S. (2008). Socio-geographic perception in the diffusion of innovation: Solar energy technology in Sri Lanka. *Energy Policy*, 36(7), 2578-2590.

Miller, G., & Mobarak, A. M. (2015). Learning about new technologies through social networks: Experimental evidence on nontraditional stoves in Bangladesh. *Marketing Science*, *34*(4), 480-499.

Moser, S., & Mosler, H. J. (2008). Differences in influence patterns between groups predicting the adoption of a solar disinfection technology for drinking water in Bolivia. *Social Science & Medicine*, 67(4), 497-504.

Mosler, H. J. (2012). A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. *International Journal of Environmental Health Research*, 22(5), 431-449.

Munshi, K. (2003). Networks in the modern economy: Mexican migrants in the US labor market. *The Quarterly Journal of Economics*, 118(2), 549-599.

Narayan, D., & Pritchett, L. (1999). Cents and sociability: Household income and social capital in rural Tanzania. *Economic Development and Cultural Change*, *47*(4), 871-897.

Nolan, J. M., Schultz, P. W., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2008). Normative social influence is underdetected. *Personality and social psychology bulletin*, *34*(7), 913-923.

Orgill, J. (2017). *Water, Sanitation, and Development: Household Preferences and Long-Term Impacts* (Doctoral dissertation).

Oster, E., & Thornton, R. (2012). Determinants of technology adoption: Peer effects in menstrual cup take-up. *Journal of the European Economic Association*, 10(6), 1263-1293.

Ostrom, E. (2005). Understanding the diversity of structured human interactions. In Ostrom, E. (Eds.). *Understanding Institutional Diversity* (pp. 3-29). Princeton, NJ: Princeton University Press.

Pachauri, S., & Rao, N. D. (2013). Gender impacts and determinants of energy poverty: are we asking the right questions? *Current Opinion in Environmental Sustainability*, 5(2), 205-215

Paek, H. J., Lee, B., Salmon, C. T., & Witte, K. (2008). The contextual effects of gender norms, communication, and social capital on family planning behaviors in Uganda: a multilevel approach. *Health Education & Behavior*, 35(4), 461-477.

Patil, S. R., Arnold, B. F., Salvatore, A. L., Briceno, B., Ganguly, S., Colford Jr, J. M., & Gertler, P. J. (2014). The effect of India's total sanitation campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. *PLoS Medicine*, 11(8), e1001709.

Pattanayak, S. K., Yang, J. C., Dickinson, K. L., Poulos, C., Patil, S. R., Mallick, R. K., ... & Praharaj, P. (2009). Shame or subsidy revisited: social mobilization for sanitation in Orissa, India. *Bulletin of the World Health Organization*, 87(8), 580-587.

Perry, M., Williams, R.L., Wallerstein, N., Waitzkin, H., 2008. Social capital and health care experiences among low-income individuals. *Am. J. Public Health* 98, 330–336

Pickering, A. J., Djebbari, H., Lopez, C., Coulibaly, M., & Alzua, M. L. (2015). Effect of a community-led sanitation intervention on child diarrhoea and child growth in rural Mali: a cluster-randomized controlled trial. *The Lancet Global Health*, *3*(11), e701-e711.

Prüss, A., Kay, D., Fewtrell, L., & Bartram, J. (2002). Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental health perspectives*, 110(5), 537.

Putnam, R. D. (1993). The prosperous community. *The American Prospect*, *4*(13), 35-42.

Putnam, R. D. (2001). *Bowling alone: The collapse and revival of American community*. Simon and Schuster.

Puzzolo, E., Stanistreet D., Pope, D., Bruce, N. & Rehfuess, E. (2013). Factors influencing the largescale uptake by households of cleaner and more efficient household energy technologies. London: EPPI-Center, Social Science Research Unit, Institute of Education, University of London.

Rabie, T., & Curtis, V. (2006). Handwashing and risk of respiratory infections: a quantitative systematic review. *Tropical medicine & international health*, 11(3), 258-267.

Ramirez, S., Dwivedi, P., Ghilardi, A., & Bailis, R. (2014). Diffusion of non-traditional cookstoves across western Honduras: A social network analysis. *Energy Policy*, 66, 379-389.

Rehfuess, E. A., Puzzolo, E., Stanistreet, D., Pope, D., & Bruce, N. G. (2014). Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environmental Health Perspectives (Online)*, *122*(2), 120.

Rogers, E.M. (1995). *Diffusion of Innovations*, 4th ed. Free Press, New York.

Rogers, E. M. (2003). *Diffusion of Innovations*. 5th ed. Free Press, New York.

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The constructive, destructive, and reconstructive power of social norms. *Psychological science*, *18*(5), 429-434.

Shakya, H. B., Christakis, N. A., & Fowler, J. H. (2014). Association between social network communities and health behavior: an observational sociocentric network study of latrine ownership in rural India. *American Journal of Public Health*, 104(5), 930-937.

Shakya, H. B., Christakis, N. A., & Fowler, J. H. (2015). Social network predictors of latrine ownership. *Social Science & Medicine*, 125, 129-138.

Smith, K. R., Samet, J. M., Romieu, I., & Bruce, N. (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax*, 55(6), 518-532.

Smith, K. R., Mehta, S., & Maeusezahl-Feuz, M. (2004). Indoor air pollution from household use of solid fuels. *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors*, World Health Organization Geneva, 2, 1435-1493.

Story, William T. (2014). Social capital and the utilization of maternal and child health services in India: A multilevel analysis. *Health & Place* 28 (2014): 73-84.

Szreter, S., & Woolcock, M. (2004). Health by association? Social capital, social theory, and the political economy of public health. *International Journal of Epidemiology*, *33*(4), 650-667.

Udry, C. (1994). Risk and insurance in a rural credit market: An empirical investigation in northern Nigeria. *The Review of Economic Studies*, 61(3), 495-526.

van Gemert, F., Kirenga, B., Chavannes, N., Kamya, M., Luzige, S., Musinguzi, P., ... & de Jong, C. (2015). Prevalence of chronic obstructive pulmonary disease and associated risk factors in Uganda (FRESH AIR Uganda): a prospective cross-sectional observational study. *The Lancet Global Health*, 3(1), e44-e51.

Venkataraman, C., Sagar, A. D., Habib, G., Lam, N., & Smith, K. R. (2010). The Indian national initiative for advanced biomass cookstoves: the benefits of clean combustion. *Energy for Sustainable Development*, 14(2), 63-72.

Vulturius, G., & Wanjiru, H. (2017). The role of social relations in the adoption of improved cookstoves. Stockholm Environment Institute.

Walker, C. L. F., Rudan, I., Liu, L., Nair, H., Theodoratou, E., Bhutta, Z. A., ... & Black, R. E. (2013). Global burden of childhood pneumonia and diarrhoea. *The Lancet*, 381(9875), 1405-1416.

Water Supply and Sanitation Collaborative Council. (2016). Has the Swachh Bharat Abhiyan brought about a paradigm shift in rural sanitation? (http://wsscc.org/2017/10/09/swachh-bharat-abhiyan-brought-paradigm-shift-rural-sanitation-wire/) (Accessed: March 8, 2018)

World Health Organization and UNICEF. (2017). “Progress on Drinking Water, Sanitation and Hygiene–2017 Update and SDG Baselines". Geneva: World Health Organization (WHO) and the United Nations Children’s Fund (UNICEF).

World Health Organization. (2018). “Household air pollution and health". Media Centre, Fact sheets. (http://www.who.int/mediacentre/factsheets/fs292/en/) (Accessed: March 14, 2018)

CHAPTER 4: HOUSEHOLD AIR POLLUTION (HAP), MICROENVIRONMENT AND CHILD HEALTH: STRATEGIES FOR MITIGATING HAP EXPOSURE IN URBAN RWANDA

Introduction

Approximately 3 billion people, mostly in low-income countries, use solid fuels (wood, agricultural residue, dung, charcoal and coal) for cooking and heating (WHO 2016). Though there has been a decline in the relative share of the global population using solid fuels (dropping from 62% to 41% between 1980 and 2010), owing to population growth and thin or missing markets for improved cooking fuels and technologies (GACC 2017), the absolute number of solid fuel users has remained high. Close to 646 million people using solid fuels reside in sub-Saharan Africa (SSA), and the absolute number of users is expected to continue to increase through 2030 (Bonjour *et al* 2015). Burning solid fuels in three-stone fires or other traditional stoves exposes households to health-damaging pollutants, namely fine particulate matter (PM2.5), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (Bruce *et al* 2000). The resulting household air pollution (HAP) accounts for 3.7-4.8 million deaths, as per WHO estimates, while the Global Burden of Disease (GBD) Study estimates between 2.2 million to 3.6 million deaths from HAP (Landrigan *et al* 2018). HAP-related illnesses responsible for millions of these deaths include stroke (34%), ischemic heart disease (26%), chronic obstructive pulmonary disease (22%), pneumonia (12%), and lung cancer (6%) (WHO 2016).

In low-income countries, acute lower respiratory infection is the major cause of death among children under 5 years (under-fives) (Smith *et al* 2014), and lower respiratory infection was the leading cause of death across all age groups in 2016 (GBD 2016 Causes of Death Collaborators 2017). Pneumonia, a type of acute respiratory infection (ARI), is one of the leading causes of death among under-fives (15%); in 2015, it accounted for approximately 920,000 deaths in this age group (WHO 2016). Over half of the premature deaths from pneumonia among under-fives were caused by HAP (WHO 2016). As children typically spend a large amount of time with mothers and caregivers who also have cooking responsibilities, under-fives experience relatively high levels of HAP exposure (Gordon *et al* 2014). Infants and young children are particularly susceptible to severe respiratory infections (e.g. inflamed lung airways and alveoli) from HAP pollutants due to their undeveloped respiratory defense mechanisms and airways (Smith *et al* 2014). Biomass fuel use is also associated with prevalence of anemia (Mishra and Retherford 2006) and stunting in under-fives (Mishra and Retherford 2006; Kyu *et al* 2009). In more recent evidence, solid fuel use leads to lower height-for-age, and increases probability of stunting and severe stunting in Indian children under 3 years (Balietti and Datta 2017).

Since 2010, 80.9 million clean or efficient stoves and fuels, that emit lower indoor emissions and use less fuel, respectively, have been distributed (GACC 2017). However, their sustained and exclusive adoption remains a challenge. Addressing market barriers to encourage production, distribution and use of clean cooking technologies is an ongoing, long-term goal for all stakeholders and partners in the clean cooking and energy sector. In the interim, changes to house construction (Bruce *et al* 2004) and modifications to cooking area ventilation (Yadama *et al* 2012) are alternative or additive solutions. Balakrishnan *et al* (2002) find type of fuel (fuelwood vs. kerosene or LPG) to be the most important determinant of HAP in rural southern India, in addition to cooking area location (indoor vs. outdoor) and kitchen ventilation. In Malawi, use of firewood or crop residue for cooking, compared to charcoal use, is associated with higher odds of primary cooks experiencing cardiopulmonary and neurologic symptoms (Das *et al* 2016). Jagger and Shively (2014) find a higher ARI incidence among under-fives in Ugandan households using fuelwood from non-forest areas, but the opposite correlation in households using crop residues for cooking. While type of fuel/stove is the most important determinant of kitchen CO in Bruce *et al* (2004) study in rural Guatemala, they also find significant positive associations between eave space size, kitchen volume and kitchen CO, but no independent relationship between kitchen volume and young (under 18 months) children's CO exposure.

Cooking location can have a large observed effect on exposure and health (Langbien 2017). Median exposure reductions of 57-73% have been observed when comparing indoor and outdoor kitchens (Rosa *et al* 2014). Others find 93-98% reductions in PM2.5 1-hour concentrations and 83-95% reductions in CO concentrations when comparing open versus closed kitchens, through increased air exchange rates in open kitchens (Grabow *et al* 2013). Land-use regression studies examining spatial differences in outdoor air pollution find population density to be one of the significant predictors of PM and other pollutants (Hoek *et al* 2008). Laboratory-based investigations suggest that improvements in ventilation (e.g. building design, wind speed and direction) may lead to reductions in exposure equivalent to those estimated for improved cookstoves (ICS) intervention studies (Ruth *et al* 2014). Studies examining this relationship have found no significant effect of increasing permeability of roof or walls on human health (Pitt *et al* 2006), while others find that additional ventilation is associated with a 12% reduction in tracheobronchial particle index in the household, after controlling for ICS stove (Yadama *et al* 2012).

The only structural factors included in Dherani *et al* (2008) meta-analyses on HAP and under-fives's risk of pneumonia, were stove type (improved vs. traditional) and cooking or heating location (inside vs. outside house). Under-five children in Malawi residing in improved homes (fired mud brick walls, tile roofing and concrete foundation) have significantly lower odds of experiencing respiratory, gastrointestinal or malaria-related illnesses, compared to those in traditional houses with mud brick walls, thatch roofing and hard packed mud floors (Wolff *et al* 2001). Cattaneo *et al* (2008) find that Mexico's *Piso Firme* program (that offered households with dirt floors a maximum of 538 square feet of concrete cement floors) significantly decreased incidence of parasitic infestations and diarrhea, prevalence of anemia, and significantly improved cognitive development among children aged 0-5 years. Northridge *et al* (2010) study in New York City find that children residing in private (vs. public) housing have significantly lower odds of asthma. Household crowding may predispose children to viral respiratory illnesses, and housing construction changes have increased indoor allergen exposure (Wright and Fisher 2003). Globally, solid fuel combustion from household cooking accounts for 12% of ambient fine particulate air pollution, the highest (37%) being in SSA (Chafe *et al* 2014). In a densely populated slum community in Bangladesh, Chowdhury *et al* (2012) find reductions in personal exposures from ICS, but high neighborhood PM2.5 concentrations, suggesting a need for community-wide improved energy solutions. Researchers have argued for the need to study the effects of exchange between outdoor and indoor microenvironments on area concentrations and personal exposures (Clark *et al* 2013).

Among school children in Nottingham, United Kingdom (UK) living within 150 meters of a main road, wheezing risk significantly increased with increasing main road proximity (Venn *et al* 2001). Gehring *et al* (2010) find significant positive correlations between traffic-linked air pollution (PM2.5, NO2, soot) at birth address and asthma-related symptoms among Dutch children observed from birth till 8 years. In southern California, McConnell *et al* (2010) find kindergarten and first-grade children with high asthma risk from modeled road traffic-related pollutants. Computer modeling studies show that trees and shrubs remove vast proportions of air pollutants (O3, PM10, NO2, SO2 and CO) that in turn improve urban air quality. Gaseous air pollutants are eliminated mainly through leaf stomata or plant surface, and absorption by trees (Nowak *et al* 2006). Using an atmospheric transport model, McDonald *et al* (2007) find that increasing tree cover in two UK conurbations reduces PM10 air concentrations. Nowak *et al* (2014) in their simulation study find that trees and forests in the United States removed 17.4 million tons of air pollution in 2010, and 670,000 incidences of ARI symptoms were avoided, primarily in urban areas.

While previous studies have considered some housing structure factors (cooking location, building design, roof/wall permeability, stove type) in areas of high HAP exposure, not all studies consider health end-points as the main outcomes of interest. Second, no study has considered the interplay of all the aforementioned factors; and third, none has been conducted in SSA. As the empirical evidence on the role of household structural factors and the neighborhood environment on human health, in areas of high HAP exposure, is limited and inconclusive, this paper estimates the association between microenvironment and young children's health in urban Rwandan households that primarily use biomass cooking fuel. Rwanda is the most densely populated country in SSA, with a population density of 481.7 per square kilometer (United Nations Statistics Division 2017); lower respiratory infection is the leading cause of years of life lost (GBD 2016 Causes of Death Collaborators 2017), and over 95% of the population use biomass for cooking (GACC 2016). Though Rwanda made significant progress in achieving an under-five mortality rate of 54/1000 live births in 2013, stunting in under-fives is still high at 44% (WHO 2015). The Government of Rwanda has made strides in improving access to clean water and sanitation, and rural roads, and is now prioritizing increasing geographical access to health facilities (WHO 2015).

In addition to examining the association between the microenvironment and prevalence of child health symptoms, we test the hypothesis that in households where the primary caregiver of a young child is also the household primary cook, there is likely to be a stronger association between caregiver's CO exposure (as a proxy for child's exposure) and children's HAP-related health symptoms. In defining the household microenvironment, we consider crowding in the immediate vicinity of the household, cooking location, indicators of cooking area ventilation, distance to any road-paved or unpaved (as a proxy for dust and motor vehicle emissions) and percentage tree cover around households. We hypothesize positive associations between agglomerated dwellings, unventilated cooking areas, low quality kitchen structure, and proxies for environmental exposures, and HAP-specific measures of health.

Methodology

Data

We use baseline data from an ongoing randomized controlled trial of an improved household energy initiative in Gisenyi Sector, Rubavu District in Rwanda's Western Province. We collected data in June 2015 for 1462 urban households across 22 purposively selected *Umudugudus* (neighborhoods/sub-divisions) in 2 cells[29] (Bugoyi and Kivumu) of Gisenyi town. The sample for this paper includes 694 under-fives residing in 529 households.

At baseline, an extensive survey was administered, with 17 modules including household demographics; physical characteristics of housing and kitchen structure, and cooking technology; health of children and primary cooks; cooking history of primary cooks; time use and preferences; and household expenditure. For each household, we also collected GPS coordinates and objectively measured 24-hour CO exposure of the

[29]Cells are the second-lowest level of administration in Rwanda, above village. The political-administrative units above cell are sector, district and province.

primary cook. The primary cooks wore the CO data logger[30] (EL-USB-CO, Lascar Electronics) by use of a lanyard or a clip, continuously for 24 hours, except while bathing and sleeping. Of the full sample of 1462 households, 28 households refused to participate in the CO monitoring. Valid CO exposure information was collected from 78.7% of the study households (N=1150). The remaining CO data files downloaded from the CO data loggers were unusable owing to batteries of data loggers dying prior to the end of the 24-hour monitoring period and inability to match CO data loggers' files with the database. The data loggers recorded CO concentrations once per minute. From each of the data files, a 24-hour average and hourly averages were calculated for each household with children under five (N=529).

Geospatial information about paved and unpaved roads for the study area were obtained from open access OpenStreetMap (OSM) data (OpenStreetMap contributors 2015). OSM is volunteered geographic information containing extensive vector data for many African countries. The validity and completeness of the data were assessed using a map compare tool (http://tools.geofabrik.de/mc) and by overlaying the extracted vector information on the available Google satellite imagery. The paved and unpaved

[30]The CO data loggers record readings from 0 to 1000 ppm in 0.5 ppm increments and have a reported accuracy of ±7 ppm. All of these loggers were calibrated before and after the three-month field sampling period. Calibration involved placing the CO data loggers in a sealed chamber that had a small mixing fan, an inlet line for a calibration gas (200 ppm CO in air), and an outlet line to a fume hood. A correction factor was developed for each data logger based on its average maximum readings relative to the calibration gas before and after the field sampling period.

roads were differentiated using attribute information stored in the feature tags as 'surface'='paved' or 'surface'='unpaved'. The distance to the nearest paved, unpaved and any road for each household was calculated using the 'Near' tool in the ArcGIS toolbox (ArcGIS version 10.3). The tree cover data were extracted from the freely available (ftp://ftp.glcf.umd.edu/glcf/LandsatTreecover/WRS2) LandSat WRS2 30m percentage tree cover data for 2015 (Sexton *et al* 2013). The percentage of tree cover around each household (30-meter resolution) was calculated using the 'Extract values to point' tool in the ArcGIS toolbox (ArcGIS version 10.3) by assigning the pixel value to the household point located in the corresponding pixel. Figure 4.1 shows our sampled villages, their proximity to roads and tree cover in the study area.

Measures

The binary outcomes for analysis, asked to the mother or the person most knowledgeable about an under-five, based on 2-weeks recall include prevalence of the following HAP-related health symptoms: respiratory infection, illness with cough, difficulty breathing and dry eyes. The only non-HAP-related health symptom we include in our analysis is fever.

The main explanatory variables indicative of housing structure and cooking location are (a) type of dwelling, (b) cooking location, and (c) kitchen floor material. For households that do not cook fully outdoors, we include specifics on cooking area ventilation, namely, (a) kitchen roof presence, (b) gap between walls and ceiling, (c) number of windows, (d) presence of ventilation holes, and (e) presence of active chimney to remove cooking area smoke. We include the main type of stove used in the past 30 days as a key determinant of HAP exposure, and determinants of other environmental exposures such as distance (in meters) to the nearest road (paved or unpaved road)[31] and tree cover. We also control for individual-level characteristics such as age, sex, and health card availability of child (suggesting access to healthcare); and age, sex, and education level of the main respondent (as a proxy for household head). Household characteristics controlled for include log of per capita total expenditure in the past 4 weeks, household size, and weekly charcoal use per capita. For 367 children where the caregiver is the primary cook in the household, caregiver's CO exposure is the main explanatory variable.

Empirical strategy

First, we use a logit model to estimate the likelihood of caregiver-reported health symptoms for children using the following equation:

$$P_r(Y_{ij} = 1 | X) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 Dwelling\ type, cooking\ area\ structure + \beta_2 Environmental\ exposure\ variables + \Omega_i + \alpha_j + \varepsilon_{ij})}}$$

[31] Though we have data on distance to tarmac road and dust road, we use 'distance to any road' instead, as majority households (98%) are closer to an unpaved road than a paved road (see Figure 4.1). As of September 2017, i.e. 2 years after this data were collected, all roads in the study area were tarred.

Where Y_{ij} denotes a health symptom for child 'i' in household 'j'; Ω_i represents confounding variables at the individual-level, α_j denotes potential household-level confounding variables and ε_{ij} is the error term.

Second, in the model above, we include a continuous variable for the log of daily average CO concentration of the caregiver as the main explanatory variable. We run both models in the full sample without cooking area specifics, and in the sub-sample of households not cooking fully outdoors, with specific cooking area variables.

Results

Descriptive statistics

We find high prevalence of illness with cough (36.2%) and illness with fever (29.1%) in our sample of under-fives (Table 4.1a). The cardiopulmonary symptom of difficulty breathing was prevalent among 20.2% children, and respiratory infection was least prevalent at 12.2%. As there are no statistically significant differences in symptom prevalence among younger (0-23 months) and older (24-59 months) under-fives[32], we do not analyze these age groups separately.

The average per capita monthly total expenditure is RWF 56,551 (~$66.9), average household size is 6, 94.3% households use a portable or fixed charcoal stove, and on average households use 3 kg of charcoal per capita per week (Table 4.1b). The majority

[32] We use the WHO and CDC classification of growth curves for younger and older children, respectively (https://www.cdc.gov/mmWr/preview/mmwrhtml/rr5909a1.htm).

of main respondents are women (88.7%), the average age is 33.6 years, 42.2% have attained secondary education and 61.1% are aware of the negative health consequences from burning biomass fuels in traditional stoves. The average age of under-fives is 27.2 months, 49% are girls and 92% children have a health card. More than half of the households in the sample (57.7%) reside in group of multiple enclosed dwellings[33], followed by group of single dwellings (21.4%). Over 55% households primarily cook in a designated kitchen outside their dwelling, close to 21% cook fully inside their dwelling, while 13% cook fully outdoors. An approximately equal share of households has cemented (41.6%) and brick floors (40.5%) in their cooking area. Among households that do not cook fully outdoors, 70% have a kitchen roof; in the cooking area, 19% have a gap between walls and ceilings, 43% have ventilation holes, and only 4% have an active chimney to remove smoke. On average, households have less than one window in their designated kitchen.

Households, on average, are 9 meters away from the nearest road (either paved or unpaved), and have 7.3% tree cover in their surrounding area. Primary caregivers' daily average CO concentration is 6.8 parts per million (ppm). In addition to 24-hour average CO concentrations, hourly average CO concentrations were calculated for each

[33] Group of single enclosed dwellings are single households within a shared, walled compound. Group of multiple enclosed dwellings include multiple housing structures within a common, walled compound. These classifications were taken from the Rwanda Integrated Household Living Conditions Survey administered by the National Institute of Statistics of Rwanda.

hour of the day for each caregiver. Community patterns were determined by compiling hourly averages across all caregivers as shown in Figure 4.2. We find that, on average across the community, the caregivers' CO exposures are low overnight and in the early morning with peaks mid-day and in the early evening. The WHO hourly average air quality guidelines (AQG) for CO is 35 mg/m^3 (equivalent to 36.4 ppm in Gisenyi). While only 4.1% of all of the caregivers' hourly average concentrations, over the 24-hour monitoring period, exceeded the WHO AQG, 35.8% of the caregivers were exposed to CO concentrations exceeding the WHO AQG for at least one hour during the same period.

Regression results

We find a strong positive association between group of multiple enclosed dwellings, relative to single house, and under-five children's HAP-related symptoms (respiratory infection, difficulty breathing and dry eyes) and the non-HAP-related fever symptom experienced in the past 2 weeks (Table 4.2). Multiple house and group of single enclosed dwellings, compared to single house, have strong positive associations with dry eyes only. Relative to cooking fully outdoors, cooking partially outdoors (e.g. in the verandah) has a weak negative association with children experiencing illness with cough. Consistent with the literature, we find that cooking indoors is associated with significantly higher prevalence of most health symptoms. In the truncated sample of households not cooking fully outdoors, cooking either in a designated kitchen outside the main dwelling, or cooking fully inside the main house is associated with significantly higher likelihood of children experiencing illness with cough, difficulty breathing and fever.

Compared to children in households with beaten earth floor in cooking areas, those in households with clay tiled floors have higher likelihood (weak significance) of experiencing respiratory infection. In the sub-sample of households not cooking fully outdoors, cemented cooking area floors have a weak protective effect on children's respiratory infection symptom, relative to earth floors; there is a significant positive association between gap in walls and ceiling in cooking areas and difficulty breathing. While there is a strong positive association between number of windows and respiratory infection, there is a very strong negative association between cooking area ventilation holes and illness with cough, difficulty breathing and fever.

We find a weak positive association between distance to any road and prevalence of respiratory infection in the full sample of under-fives, but a strong positive association in the truncated sample of under-fives in households that do not cook fully outdoors. In the sub-sample, tree cover has a strong positive association with prevalence of respiratory infection and difficulty breathing but weak positive association with prevalence of dry eyes.

On including an objective measure of HAP exposure (24-hour average CO concentration in ppm) of the primary caregiver, to examine its relationship with child health symptoms (Table 4.3), we find strong positive associations between log of caregiver's daily average CO concentration, and difficulty breathing and dry eyes. Contrary to what we would expect, in the sub-sample, presence of an active chimney in the cooking area, significantly increases children's likelihood of experiencing respiratory infection. Distance to the nearest road significantly increases children's likelihood of experiencing all HAP-related symptoms except illness with cough. Tree cover has strong positive associations with respiratory infection and difficulty breathing. Similar to the model without average CO concentration, the significance of the associations between child health symptoms, and dwelling type, cooking location, kitchen floor material, gap between walls and ceiling in the cooking area, and presence of ventilation holes persist.

Discussion and Conclusion

The importance of studying the association between housing structure and neighborhood environment is two-fold. First, the results have pertinent implications for policy-makers as they consider infrastructure-related interventions to reduce HAP exposure, in conjunction with promoting improved access to modern household energy services. Second, in exploring the role of the neighborhood on human health in the context of HAP, there is potential for community-level interventions.

We find that (a) residing in agglomerated dwelling structures, (b) cooking indoors, (c) presence of a gap between walls and ceiling in the cooking area, and (d) more tree cover significantly increase children under-five's probability of experiencing health symptoms in the short-term (2 weeks) recall period. On the other hand, children residing in households with (a) cooking area ventilation holes and (b) cemented floors in the cooking area are significantly less likely to experience many HAP-related health symptoms.

Our finding that cement floors have a protective effect on child health (respiratory infection) is similar to Cattaneo *et al* (2008) finding of reduction in intestinal parasites that are not treatable with common deworming drugs found in developing countries, among low-income urban Mexican households. Consistent with the urban planning and public health literature on housing improvements being critical to health (Northridge *et al* 2003), housing improvements such as cemented floors to improve child health, is a key policy recommendation. Our finding that cooking indoors, relative to outdoor cooking, significantly increases children's likelihood of experiencing HAP-related illnesses, is similar to results from Langbien (2017) that outdoor cooking significantly reduces respiratory diseases among children aged 0-4 years, in 30 developing countries. A second policy recommendation would be to promote outdoor (full or partial) cooking, during favorable seasons, in alignment with households' existing cooking practices.

Contrary to Bruce *et al* (2004) findings, we find that number of windows have a significant positive association with respiratory infection. Our finding that number of windows and ventilation holes have opposing associations with the likelihood of children experiencing health symptoms may be due to differences in size of these structures, and frequency of keeping windows open. It is likely that in some households, though there is an active chimney, owing to poor house construction (lack of concrete material), smoke removed from the chimney may be circulating back into the house owing to porous walls. Echoing Langbien (2017), we argue for the need to study pollutant exposure and its impact on human health under various ventilation conditions and cooking locations.

Our results of a positive relationship between distance to any road and prevalence of health symptoms in most models, is contrary to Venn *et al* (2001) finding that increasing proximity to a main road increases the risk of wheezing. It is likely that proximity to roads may not be a good proxy for traffic-related air pollutants. One explanation for the counter-intuitive strong positive relationship between tree cover in the area surrounding households and prevalence of health symptoms, contrary to Nowak *et al* (2014) findings from the United States, could be insufficient air ventilation and low pollutant dispersal owing to scattered non-dense vegetation (Wang *et al* 2014). Our results correspond to Musafiri *et al* (2011) finding that allergens (house dust mite and grass pollen mix) are a risk factor for asthma in rural and urban Rwanda. With changing climate and rising CO_2 emissions, pollen production and correspondingly allergenicity may increase (Ziska and Beggs 2012). In our geographically small and densely populated study area, it is also likely that tree cover does little to reduce HAP exposure, particularly CO.

Our study is not without its limitations. First, the cross-sectional nature of our analysis does not allow for making causal claims. Relatedly, we are unable to control for children's poor health endowment. Second, owing to binary caregiver-reported health symptoms, and small number of data points for exposure concentrations, we are unable to analyze the spatial autocorrelation in our sample. Third, though CO concentration coefficients are significant for some health symptoms, it is likely that caregiver's CO exposure does not fully capture child's CO exposure. Fourth, though there is no multicollinearity in our regression models, cooking area dimensions would have better characterized well-ventilated structures.

Our analysis highlights the importance of understanding the relationship between structural factors about dwelling and cooking area, and child health. In areas of high HAP exposure as Rwanda, where there is near universal dependence on solid fuels for cooking, and provision of improved energy services is in its nascent stages, improvements in the microenvironment of the vulnerable population of under-fives, is central to reducing HAP-related health symptom prevalence. Housing structure improvements such as cemented kitchen floors and behavioral strategies of encouraging outdoor cooking where possible and favorable, subject to seasonality, are suggestive policy interventions governments could undertake to reduce prevalence of negative health outcomes.

Tables and Figures

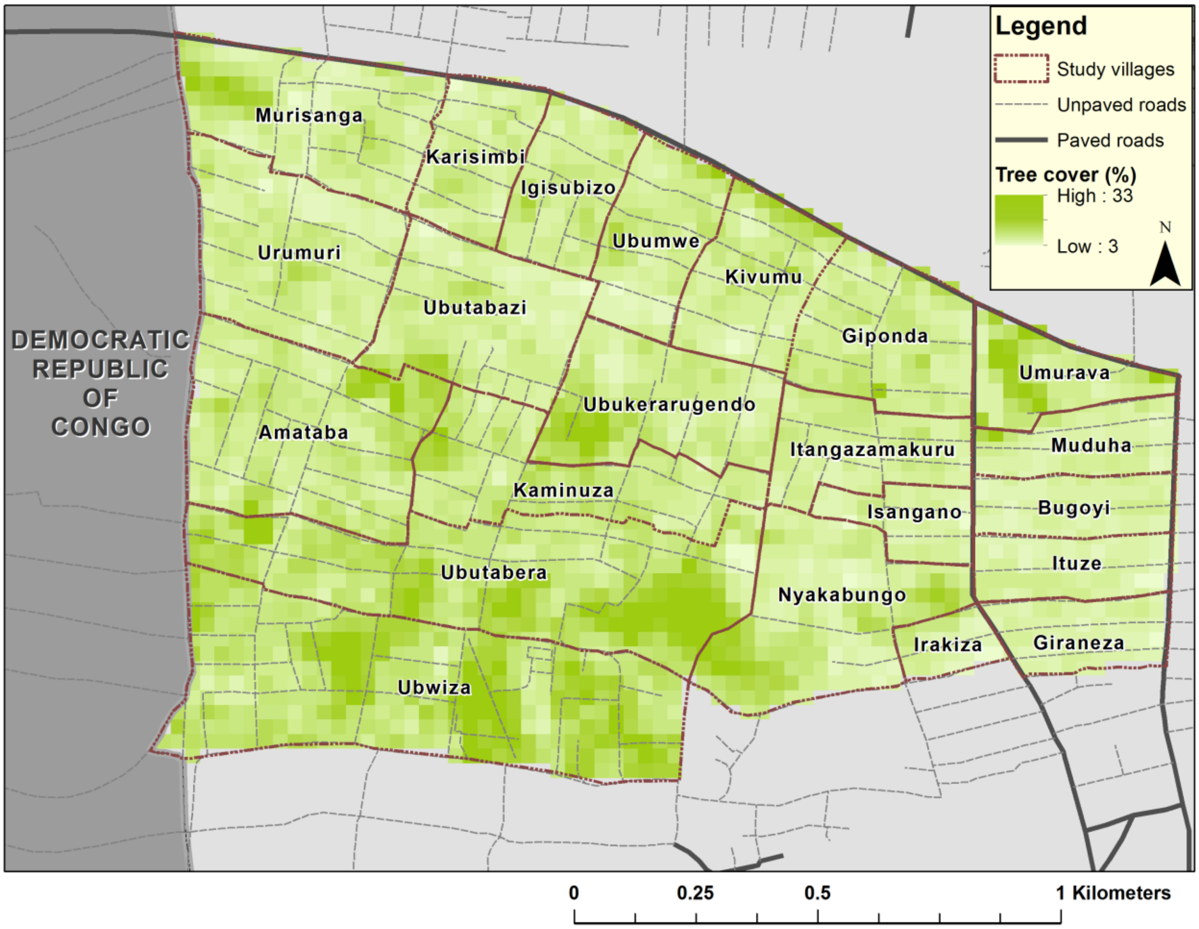

Figure 4.1. Map of study area in Gisenyi, Rwanda.

Table 4.1. Summary statistics: Baseline results

a. Dependent Variables: Health symptoms of children under 5 years (N=694)			
HAP-related			%
Respiratory infection			12.25
Illness with cough			36.17
Difficulty breathing			20.17
Dry eyes			14.41
Other			
Illness with fever			29.11

b. Independent Variables	Mean	SD	N
Household characteristics			
Per capita monthly total expenditures (in RWF) [1 RWF=0.0012 USD]	56,550.80	40,584.28	529
Household size (mean)	5.94	2.6	529
Most used stove for cooking in the past 30 days (%)			
Traditional 3 stone (open fire)	2.84		529
Portable charcoal stove	73.16		529
Fixed charcoal stove	21.17		529
Improved stove (Electric stove, gas cooker, biogas)	2.83		529
Per capita weekly charcoal use (in kgs)	2.97	2.39	529
Main respondent characteristics			
Age (in years)	33.56	10.57	529
Female (%)	88.66		529
Education level (%)			
No education	6.05		529
Pre-primary or primary	19.28		529
Secondary	42.16		529
University	32.51		529
Awareness that smoke from burning biomass is harmful to human health (%)	61.06		529
Child characteristics			
Age (in months)	27.18	16.28	694
Female (%)	49.42		694
Availability of health card for child (%)	91.93		694
Housing structure			
Dwelling type (%)			
Single house	15.31		529
Multiple house	5.67		529
Group of multiple enclosed dwellings	57.66		529
Group of single enclosed dwellings	21.36		529
Cooking location (%)			
Fully outdoors	12.67		529
Partially outdoors	10.78		529
Kitchen structure outside dwelling	55.2		
Cooking inside dwelling	21.36		529

Cooking area structure			
Main material used in floors of cooking area (%)			
Beaten earth	17.96		529
Clay tiles, bricks and other materials	40.45		529
Cement	41.59		529
Kitchen roof presence (%)	70.34		462
Gap between walls and ceiling (%)	18.83		462
Number of windows (mean)	0.66	0.66	462
Ventilation holes (%)	42.6		462
Presence of active chimney to remove smoke (%)	4.3		462
Household environmental exposure			
Nearest distance to any road (in meters)	8.83	8.09	529
Nearest distance to paved road (in meters)	11.48	12.65	529
Nearest distance to unpaved road (in meters)	11.92	13.47	529
Adjacent tree cover (%)	7.33	2.23	529
Primary caregiver* exposure concentration			
Daily average CO concentration (in ppm)	6.77	9.42	282

*These are unique primary caregivers of children under 5, who are also primary cooks in the household.

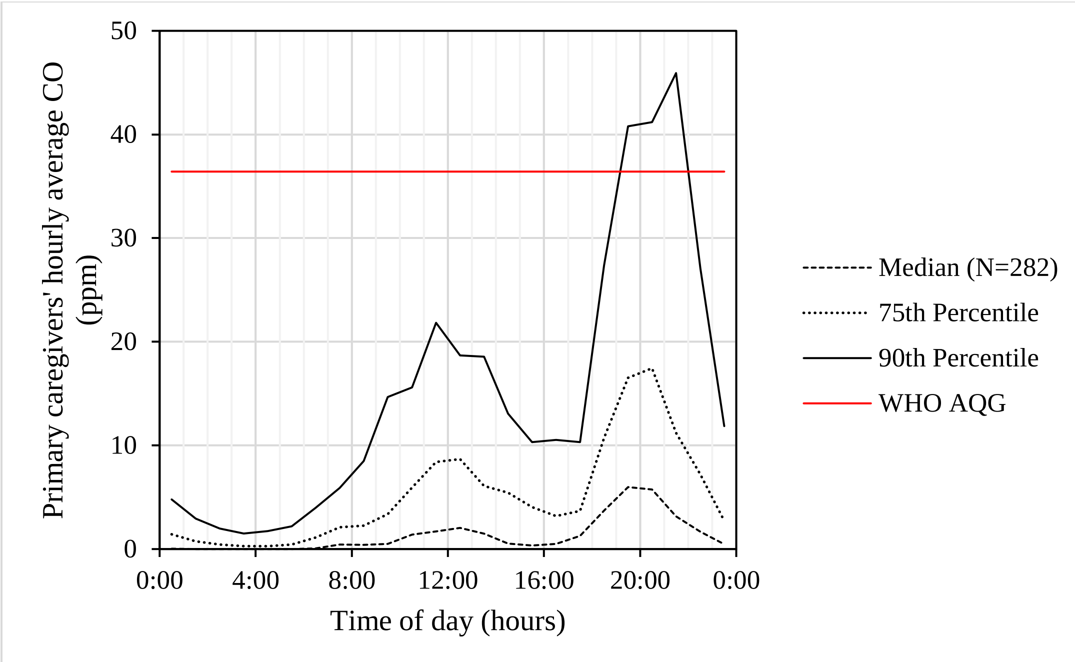

Figure 4.2. Average hourly CO concentrations of under-fives' primary caregivers, by time of day.

Table 4.2. Association between microenvironment, environmental exposure & under-fives' health symptoms

Dependent variables	HAP-related								Other	
	Respiratory infection†		Illness with cough†		Difficulty breathing†		Dry eyes†		Fever†	
<u>Explanatory variables</u>										
Housing structure										
Dwelling type										
Multiple house	0.44	0.41	0.33	0.35	0.89*	0.85	1.31**	1.32**	0.27	0.33
	(0.83)	(0.86)	(0.43)	(0.45)	(0.51)	(0.52)	(0.55)	(0.56)	(0.47)	(0.49)
Group of multiple enclosed dwellings	1.89***	1.88***	0.57**	0.56*	1.05***	1.03***	0.71*	0.87**	0.64**	0.82**
	(0.61)	(0.65)	(0.28)	(0.29)	(0.36)	(0.38)	(0.41)	(0.43)	(0.31)	(0.32)
Group of single enclosed dwellings	0.88	0.86	0.48*	0.48	0.63*	0.62	0.96**	1.00**	0.65**	0.63*
	(0.58)	(0.62)	(0.29)	(0.30)	(0.37)	(0.39)	(0.44)	(0.45)	(0.33)	(0.34)
Cooking location										
Partially outdoors	0.54		-0.65*		-0.17		-0.24		-0.50	
	(0.51)		(0.37)		(0.46)		(0.46)		(0.41)	
Kitchen structure outside dwellings	0.81	0.72	0.44	1.12**	0.72*	1.47**	-0.43	0.09	0.50	1.59***
	(0.50)	(0.79)	(0.33)	(0.47)	(0.42)	(0.58)	(0.42)	(0.75)	(0.37)	(0.54)
Cooking inside dwelling	0.90**	0.00	0.57*	1.29***	0.53	0.99**	0.27	0.40	0.55*	1.37***
	(0.45)	(0.48)	(0.30)	(0.37)	(0.37)	(0.43)	(0.38)	(0.47)	(0.32)	(0.40)
Cooking area structure										
Main floor material										
Clay tiles, bricks and other materials	0.66*	0.06	0.30	0.32	0.17	-0.10	0.50	-0.52	0.21	0.48
	(0.37)	(0.70)	(0.31)	(0.45)	(0.37)	(0.58)	(0.42)	(0.87)	(0.31)	(0.48)
Cement	-0.51	-0.78*	0.11	0.21	0.06	0.08	0.30	0.15	-0.03	0.12
	(0.39)	(0.44)	(0.25)	(0.26)	(0.29)	(0.31)	(0.39)	(0.43)	(0.25)	(0.27)
Kitchen roof		-1.22		0.08		-0.70		-1.32		-0.12
		(1.00)		(0.52)		(0.71)		(1.05)		(0.62)
Gap between walls and ceiling		0.46		0.44*		0.64**		0.35		0.45*
		(0.37)		(0.23)		(0.27)		(0.33)		(0.25)
Number of windows		0.51**		0.15		-0.06		0.39*		0.10
		(0.23)		(0.16)		(0.19)		(0.23)		(0.17)
Ventilation holes		-0.16		-0.64***		-0.69***		-0.38		-0.91***
		(0.31)		(0.19)		(0.24)		(0.27)		(0.21)
Presence of active chimney		0.37		0.34		0.19		-0.47		-0.14
		(0.64)		(0.46)		(0.62)		(0.94)		(0.53)

Environmental exposure										
Distance to nearest road	0.03*	0.03**	0.01	0.01	-0.00	-0.01	0.00	0.00	-0.01	-0.02
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Tree cover	0.14**	0.17**	0.06	0.02	0.18***	0.17***	0.11**	0.12*	-0.06	-0.08
	(0.06)	(0.08)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.07)	(0.05)	(0.06)
Constant	-3.67	-1.98	1.05	1.75	-0.81	-0.98	-5.77**	-5.44*	-1.60	-1.88
	(2.99)	(3.39)	(1.96)	(2.24)	(2.40)	(2.80)	(2.82)	(3.17)	(2.11)	(2.36)
Observations	694	612	694	612	694	612	694	612	694	612

*** p<0.01, ** p<0.05, * p<0.1; † Column 1 for each health outcome includes fully outdoor cooking, and Column 2 excludes fully outdoor cooking.

1. The referent categories for dwelling type and kitchen floor are: single house and beaten earth, respectively. For cooking location, fully outdoor cooking and partially outdoor cooking are the referent categories in Models 1 and 2 of each symptom, respectively.

2. Stove type controlled for as a determinant of HAP exposure.

3. Household-level characteristics controlled for include: log of per capita total expenditure in the past 4 weeks (in RWF), household size, and per capita weekly charcoal use (in kg).

4. Child characteristics controlled for include: age (in months), sex, and health card availability. Main respondent characteristics controlled for include: age, sex and education level.

Table 4.3. Association between microenvironment, environmental and CO exposures & under-fives' health symptoms

Dependent variables	HAP-related								Other	
	Respiratory infection†		Illness with cough†		Difficulty breathing†		Dry eyes†		Fever†	
<u>Explanatory variables</u>										
Pollutant exposure										
Log of daily average CO concentration of caregiver	0.11	0.22	0.16	0.24	0.40***	0.48***	0.36**	0.36*	-0.08	-0.11
	(0.19)	(0.25)	(0.13)	(0.15)	(0.15)	(0.18)	(0.17)	(0.19)	(0.15)	(0.17)
Housing structure										
Dwelling type										
Multiple house	1.18	1.23	-0.85	-0.84	-0.02	-0.21	1.09	1.27	0.23	0.34
	(1.62)	(1.86)	(0.59)	(0.66)	(0.69)	(0.81)	(0.74)	(0.93)	(0.61)	(0.70)
Group of multiple enclosed dwellings	2.69**[r]	2.93**[r]	-0.20	-0.28	0.68	0.62	0.47	0.85	0.47	0.67
	(1.18)	(1.34)	(0.37)	(0.40)	(0.44)	(0.46)	(0.61)	(0.76)	(0.44)	(0.53)
Group of single enclosed dwellings	2.32*	2.43*	-0.47	-0.27	-0.31	-0.32	1.10	1.51*[r]	1.03**[r]	1.39**[r]
	(1.23)	(1.43)	(0.45)	(0.49)	(0.56)	(0.57)	(0.70)	(0.82)	(0.51)	(0.58)
Cooking location										
Partially outdoors	0.35		-0.73		-0.18		-0.35		-0.58	
	(0.77)		(0.47)		(0.61)		(0.62)		(0.57)	
Kitchen structure outside dwellings	1.72**	0.99	0.48	1.11*[r]	0.70	1.03	0.28	1.19	1.48***	2.66***[r]
	(0.71)	(1.32)	(0.49)	(0.61)	(0.67)	(0.78)	(0.68)	(0.89)	(0.56)	(0.71)
Cooking inside dwelling	0.84	0.12	0.35	1.43***[r]	0.36	0.89	0.10	0.77	0.72	2.29***[r]
	(0.67)	(0.82)	(0.40)	(0.50)	(0.52)	(0.60)	(0.52)	(0.61)	(0.45)	(0.56)
Cooking area structure										
Main floor material										
Clay tiles, bricks and other materials	1.07**[r]	0.59	0.30	1.32*	-0.05	0.51	0.98	1.02	0.92*	1.32*
	(0.53)	(1.64)	(0.45)	(0.71)	(0.58)	(0.93)	(0.63)	(1.15)	(0.51)	(0.77)
Cement	-0.97*	-1.54**[r]	-0.09	0.20	-0.09	0.12	-0.05	-0.17	-0.47	-0.33
	(0.56)	(0.69)	(0.36)	(0.40)	(0.43)	(0.47)	(0.54)	(0.56)	(0.37)	(0.42)
Kitchen roof		-0.38		1.36*		0.53		-0.27		0.54
		(2.38)		(0.76)		(1.06)		(1.50)		(0.87)
Gap between walls and ceiling		1.29**		0.78**[r]		0.77**[r]		0.05		0.28
		(0.54)		(0.35)		(0.38)		(0.48)		(0.44)
Number of windows		0.53		-0.23		-0.14		-0.03		-0.47
		(0.41)		(0.25)		(0.27)		(0.32)		(0.29)
Ventilation holes		-0.65		-1.01***[r]		-0.79**[r]		-0.37		-1.31***[r]
		(0.44)		(0.30)		(0.32)		(0.37)		(0.32)

Presence of active chimney		1.81**		0.31		1.14		-0.56		-0.74
		(0.70)		(0.80)		(0.76)		(1.06)		(0.80)
Environmental exposure										
Distance to nearest road	0.06** r	0.08*** r	0.01	0.01	0.04**	0.04**	0.04*	0.04**	-0.00	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Tree cover	0.24*** r	0.35*** r	0.12*	0.11	0.30*** r	0.37*** r	0.01	0.08	-0.13	-0.19
	(0.09)	(0.11)	(0.06)	(0.08)	(0.07)	(0.09)	(0.07)	(0.10)	(0.10)	(0.13)
Constant	-12.57***	-11.75**	2.67	2.18	-2.36	-1.88	-6.53*	-9.76***	1.49	-0.95
	(4.78)	(5.16)	(2.57)	(3.10)	(3.11)	(3.66)	(3.53)	(3.69)	(2.64)	(3.24)
Observations	367	321	367	321	367	321	367	321	367	321

*** p<0.01, ** p<0.05, * p<0.1; † Column 1 for each health outcome includes fully outdoor cooking, and Column 2 excludes fully outdoor cooking.

1. Coefficients marked ‘r’ are robust in the alternate specification without log of daily average CO concentration of the caregiver.
2. The referent categories for dwelling type and kitchen floor are: single house and beaten earth, respectively. For cooking location, fully outdoor cooking and partially outdoor cooking are the referent categories in Models 1 and 2 of each symptom, respectively.
3. Stove type controlled for as a determinant of HAP exposure.
4. Household-level characteristics controlled for include: log of per capita total expenditure in the past 4 weeks (in RWF), household size, and per capita weekly charcoal consumption (in kg).
5. Child characteristics controlled for include: age (in months) and sex. Caregiver characteristic controlled for: perception about negative health impacts from traditional cooking practices.

REFERENCES

Balakrishnan, K., Parikh, J., Sankar, S., Padmavathi, R., Srividya, K., Venugopal, V., Prasad, S., & Pandey, V. L. (2002). Daily average exposures to respirable particulate matter from combustion of biomass fuels in rural households of southern India. *Environmental Health Perspectives*, *110*(11), 1069.

Balietti, A. & Datta, S. (2017). The impact of indoor solid fuel use on the stunting of Indian children. *Working Paper*. Available at: http://www.ancabalietti.net/wp-content/uploads/2017/04/Datta_Balietti_March2017.pdf [Accessed on September 28, 2017]

Bonjour, S., Adair-Rohani, H., Wolf, J., Bruce, N. G., Mehta, S., Prüss-Ustün, A., Lahiff, M., Rehfuess, E.A., Mishra, V., & Smith, K. R. (2015). Solid fuel use for household cooking: country and regional estimates for 1980-2010. *Environmental Health Perspectives* (Online), 121(7), 784.

Bruce N, Perez-Padilla R and Albalak R 2000 Indoor air pollution in developing countries: a major environmental and public health challenge. *Bull. World Health Organ*. 78 1078–92.

Bruce, N., McCracken, J., Albalak, R., Schei, M., Smith, K. R., Lopez, V., & West, C. (2004). Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children. *Journal of Exposure Science and Environmental Epidemiology*, *14*, S26-S33.

Cattaneo, M. D., Galiani, S., Gertler, P. J., Martinez, S., & Titiunik, R. (2009). Housing, health, and happiness. *American Economic Journal: Economic Policy*, *1*(1), 75-105.

Chafe, Z. A., Brauer, M., Klimont, Z., Van Dingenen, R., Mehta, S., Rao, S., Riahi, K., Dentener, F., & Smith, K. R. (2014). Household cooking with solid fuels contributes to ambient PM2. 5 air pollution and the burden of disease. *Environmental Health Perspectives*, 122(12), 1314.

Chowdhury, Z., Le, L. T., Masud, A. A., Chang, K. C., Alauddin, M., Hossain, M., Zakaria, A.B.M., & Hopke, P. K. (2012). Quantification of indoor air pollution from using cookstoves and estimation of its health effects on adult women in northwest Bangladesh. *Aerosol Air Qual Res*, 12(4), 463-475.

Clark, M. L., Peel, J. L., Balakrishnan, K., Breysse, P. N., Chillrud, S. N., Naeher, L. P., Rodes, C.E., Vette, A.F., & Balbus, J. M. (2013). Health and household air pollution from solid fuel use: the need for improved exposure assessment. *Environmental Health Perspectives*, 121(10), 1120.

Das, I., Jagger, P., & Yeatts, K. (2017). Biomass cooking fuels and health outcomes for women in Malawi. *Ecohealth*, 14(1), 7-19.

Dherani, M., Pope, D., Mascarenhas, M., Smith, K. R., Weber, M., & Bruce, N. (2008). Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. *Bulletin of the World Health Organization*, *86*(5), 390-398C.

Global Alliance for Clean Cookstoves. (2016). Country Profiles. Available at: http://cleancookstoves.org/country-profiles/32-rwanda.html [Accessed on February 7, 2017]

Global Alliance for Clean Cookstoves. (2017). 2017 Progress Report. Driving Demand. Delivering Impact Available at: http://cleancookstoves.org/binary-data/RESOURCE/file/000/000/536-1.pdf [Accessed on December 21, 2017]

GBD 2016 Causes of Death Collaborators (2017). Global, regional and national age-sex specific mortality for 264 causes of death 1980-2016: systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, 390(10100), 1151-1210.

Gehring, U., Wijga, A. H., Brauer, M., Fischer, P., de Jongste, J. C., Kerkhof, M., Oldenwening, M., Smit, H.A., & Brunekreef, B. (2010). Traffic-related air pollution and the development of asthma and allergies during the first 8 years of life. *American Journal of Respiratory and Critical Care Medicine*, 181(6), 596-603.

Gordon, S. B., *et al* (2014). Respiratory risks from household air pollution in low and middle income countries. *The Lancet Respiratory Medicine*, 2(10), 823-860.

Grabow, K., Still, D., & Bentson, S. (2013). Test kitchen studies of indoor air pollution from biomass cookstoves. *Energy for Sustainable Development*, 17(5), 458-462.

Hoek, G., Beelen, R., De Hoogh, K., Vienneau, D., Gulliver, J., Fischer, P., & Briggs, D. (2008). A review of land-use regression models to assess spatial variation of outdoor air pollution. *Atmospheric Environment*, 42(33), 7561-7578.

Jagger, P. & Shively, G. (2014). Land use change, fuel use and respiratory health in Uganda. *Energy Policy*, 67, 713-726.

Kyu, H. H., Georgiades, K., & Boyle, M. H. (2009). Maternal smoking, biofuel smoke exposure and child height-for-age in seven developing countries. *International Journal of Epidemiology*, 38(5), 1342-1350.

Langbein, J. (2017). Firewood, smoke and respiratory diseases in developing countries—The neglected role of outdoor cooking. *PloS One*, 12(6), e0178631.

Landrigan, P. J., *et al* (2018) The Lancet Commission on pollution and health." *The Lancet* 391 462-512.

McConnell, R., Islam, T., Shankardass, K., Jerrett, M., Lurmann, F., Gilliland, F., & Gauderman, J. (2010). Childhood incident asthma and traffic-related air pollution at home and school. *Environmental Health Perspectives*, 118(7), 1021.

McDonald, A. G., Bealey, W. J., Fowler, D., Dragosits, U., Skiba, U., Smith, R. I., Donovan, R.G., Brett, H.E., Hewitt, C.N., & Nemitz, E. (2007). Quantifying the effect of urban tree planting on concentrations and depositions of PM 10 in two UK conurbations. *Atmospheric Environment*, *41*(38), 8455-8467.

Mishra, V., & Retherford, R. D. (2006). Does biofuel smoke contribute to anaemia and stunting in early childhood? *International Journal of Epidemiology*, 36(1), 117-129.

Musafiri, S., Van Meerbeeck, J., Musango, L., Brusselle, G., Joos, G., Seminega, B., & Rutayisire, C. (2011). Prevalence of atopy, asthma and COPD in an urban and a rural area of an African country. *Respiratory Medicine*, *105*(11), 1596-1605.

Northridge, M. E., Sclar, E. D., & Biswas, P. (2003). Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities. *Journal of Urban Health*, 80(4), 556-568.

Northridge, J., Ramirez, O. F., Stingone, J. A., & Claudio, L. (2010). The role of housing type and housing quality in urban children with asthma. *Journal of Urban Health*, *87*(2), 211-224.

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening*, *4*(3), 115-123.

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution*, *193*, 119-129.

OpenStreetMap contributors. (2015) Planet dump [Data file from $date of database dump$]. Retrieved from https://planet.openstreetmap.org

Pitt, M. M., Rosenzweig, M. R., & Hassan, M. N. (2006, June). Sharing the burden of disease: Gender, the household division of labor and the health effects of indoor air pollution in Bangladesh and India. *In Stanford Institute for Theoretical Economics Summer Workshop, Vol. 202*.

Rosa, G., Majorin, F., Boisson, S., Barstow, C., Johnson, M., Kirby, M., Ngabo, F., Thomas, E. & Clasen, T. (2014). Assessing the impact of water filters and improved cook stoves on drinking water quality and household air pollution: a randomized controlled trial in Rwanda. *PLoS One*, 9(3), e91011.

Ruth, M., Maggio, J., Whelan, K., DeYoung, M., May, J., Peterson, A., & Paterson, K. (2014). Kitchen 2.0: Design guidance for healthier cooking environments. *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, 151 169.

Sexton, J. O., Song, X.-P., Feng, M., Noojipady, P., Anand, A., Huang, C., Kim, D.-H., Collins, K.M., Channan, S., DiMiceli, C., Townshend, J.R.G. (2013). Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS Vegetation Continuous Fields with lidar-based estimates of error. *International Journal of Digital Earth*, 6 427-48.

Smith, K. R. *et al* (2014). Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Annual Review of Public Health*, 35, 185-206.

United Nations Statistics Division. 2017. Available at: http://data.un.org/CountryProfile.aspx?crName=RWANDA [Accessed on February 7, 2017]

Venn, A. J., Lewis, S. A., Cooper, M., Hubbard, R., & Britton, J. (2001). Living near a main road and the risk of wheezing illness in children. *American Journal of Respiratory and Critical Care Medicine*, *164*(12), 2177-2180.

Wang, Y., Bakker, F., De Groot, R., & Wörtche, H. (2014). Effect of ecosystem services provided by urban green infrastructure on indoor environment: A literature review. *Building and Environment*, 77, 88-100.

Wolff, C. G., Schroeder, D. G., & Young, M. W. (2001). Effect of improved housing on illness in children under 5 years old in northern Malawi: cross sectional study. *BMJ*, *322*(7296), 1209-1212.

World Health Organization: Geneva (2015). Success factors for women's and children's health: Rwanda. Available from:

http://www.who.int/pmnch/knowledge/publications/rwanda_country_report.pdf [Accessed on April 12, 2016]

World Health Organization: Geneva (2016). Pneumonia Factsheet. Available from: http://www.who.int/mediacentre/factsheets/fs331/en/ [Accessed on September 20, 2016]

Wright, R. J. and Fisher, E. B. (2003). Putting asthma into context: community influences on risk, behavior, and intervention *In Neighborhoods and Health (233–64)* ed I. Kawachi and L. F. Berkman (New York City, NY: Oxford University Press)

Yadama, G. N., Peipert, J., Sahu, M., Biswas, P., & Dyda, V. (2012). Social, economic, and resource predictors of variability in household air pollution from cookstove emissions. *PloS One*, *7*(10), e46381.

Ziska, L. H. and Beggs, P. J. (2012) Anthropogenic climate change and allergen exposure: the role of plant biology *J. Allergy. Clin. Immunol*. 129 27–32

APPENDIX A: ADDITIONAL TABLES FROM CHAPTER 2

Table A-1. Women's bargaining power and household EH behavior adoption (Pooled OLS estimates): Summary of coefficients

	Rural (N=34,560)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.029***	0.011	-0.008	0.011**	-0.012
	(0.006)	(0.009)	(0.009)	(0.006)	(0.008)
House co-ownership/rental agreement	0.018***	0.006	0.024**	-0.013**	0.063***
	(0.006)	(0.009)	(0.011)	(0.005)	(0.010)
Autonomy score	-0.002	0.007	0.015*	0.002	-0.002
	(0.005)	(0.008)	(0.009)	(0.004)	(0.008)
Adjusted R-squared	0.142	0.285	0.237	0.069	0.270
	Urban (N=15,332)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.009	-0.005	0.030***	0.033***	-0.015*
	(0.012)	(0.009)	(0.011)	(0.010)	(0.009)
House co-ownership/rental agreement	0.021	0.037***	-0.014	0.002	0.021**
	(0.013)	(0.010)	(0.013)	(0.010)	(0.010)
Autonomy score	-0.001	-0.040***	0.028**	0.013	-0.012
	(0.011)	(0.009)	(0.011)	(0.008)	(0.010)
Adjusted R-squared	0.169	0.214	0.137	0.118	0.240

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses. Household-level (household size, dependency ratio, log of per capita monthly expenditure, hours of daily electricity access, female-headed household, family member has bank account) and individual-level (age, years of completed education, age gap between woman and household head, education gap between woman and household head, has at least one child, first born is a boy, number of hours worked in the past year, relationship to household head) factors have been included in all the models.

Table A-2. Women's bargaining power and EH behavior adoption by caste category (Household FE estimates): Summary of coefficients

	General (N=15,444)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.009	0.008	-0.010	0.022	0.004
	(0.019)	(0.017)	(0.015)	(0.017)	(0.017)
House co-ownership/rental agreement	0.005	0.004	0.017	0.013	0.018
	(0.019)	(0.017)	(0.016)	(0.017)	(0.018)
Autonomy score	0.010	-0.023	0.009	-0.012	0.008
	(0.018)	(0.015)	(0.016)	(0.015)	(0.017)
Adjusted R-squared	0.683	0.758	0.788	0.621	0.667
	OBC (N=20,120)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.020	0.013	0.007	0.027**	-0.010
	(0.015)	(0.014)	(0.015)	(0.012)	(0.018)
House co-ownership/rental agreement	0.024*	0.010	0.011	-0.006	0.044**
	(0.015)	(0.013)	(0.019)	(0.011)	(0.020)
Autonomy score	-0.021	-0.002	-0.005	0.000	0.004
	(0.013)	(0.014)	(0.013)	(0.010)	(0.017)
Adjusted R-squared	0.695	0.800	0.786	0.602	0.677
	SC (N=10,708)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.008	0.020	0.010	0.024	0.023
	(0.020)	(0.024)	(0.021)	(0.017)	(0.025)
House co-ownership/rental agreement	0.015	-0.008	0.004	0.006	-0.011
	(0.020)	(0.021)	(0.027)	(0.014)	(0.028)
Autonomy score	-0.020	0.012	-0.030	-0.003	-0.013
	(0.015)	(0.017)	(0.019)	(0.011)	(0.021)
Adjusted R-squared	0.667	0.765	0.774	0.579	0.692
	ST (N=3,620)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.003	0.035	0.030	0.033	-0.013
	(0.024)	(0.033)	(0.042)	(0.028)	(0.047)

House co-ownership/rental agreement	0.005	-0.043	-0.008	-0.015	0.026
	(0.025)	(0.033)	(0.044)	(0.023)	(0.052)
Autonomy score	-0.019	-0.015	0.005	-0.004	0.065
	(0.019)	(0.026)	(0.025)	(0.022)	(0.046)
Adjusted R-squared	0.675	0.770	0.799	0.611	0.637

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses. Household-level (household size, dependency ratio, log of per capita monthly expenditure, hours of daily electricity access, female-headed household, family member has bank account) and individual-level (age, years of completed education, age gap between woman and household head, education gap between woman and household head, has at least one child, first born is a boy, number of hours worked in the past year, relationship to household head) factors have been included in all the models.

Table A-3. Women's bargaining power and EH behavior adoption by zone (Household FE estimates): Summary of coefficients

	North (N=10,726)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	-0.002	0.049**	-0.021	0.008	0.045**
	(0.020)	(0.022)	(0.023)	(0.020)	(0.022)
House co-ownership/rental agreement	0.013	-0.028	-0.001	0.009	0.009
	(0.025)	(0.024)	(0.027)	(0.018)	(0.020)
Autonomy score	-0.035*	-0.028	-0.007	-0.030*	0.004
	(0.020)	(0.023)	(0.023)	(0.016)	(0.023)
Adjusted R-squared	0.725	0.771	0.719	0.621	0.704
	South (N=11,570)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.035	0.000	-0.000	0.023	0.016
	(0.024)	(0.019)	(0.025)	(0.018)	(0.027)
House co-ownership/rental agreement	-0.010	-0.004	0.033	-0.012	0.011
	(0.020)	(0.015)	(0.029)	(0.017)	(0.025)
Autonomy score	0.006	-0.000	0.010	0.014	0.000
	(0.019)	(0.017)	(0.023)	(0.015)	(0.024)
Adjusted R-squared	0.661	0.820	0.687	0.647	0.650
	East (N=9,080)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	-0.015	0.021	0.012	0.028	-0.038
	(0.024)	(0.023)	(0.023)	(0.019)	(0.028)
House co-ownership/rental agreement	0.001	0.014	-0.008	-0.009	-0.047
	(0.027)	(0.027)	(0.025)	(0.023)	(0.034)
Autonomy score	0.017	0.013	0.005	0.012	0.043*
	(0.019)	(0.019)	(0.018)	(0.015)	(0.026)
Adjusted R-squared	0.772	0.811	0.797	0.626	0.708
	West (N=7,200)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	0.006	-0.011	0.031	0.057*	0.033
	(0.032)	(0.030)	(0.025)	(0.031)	(0.029)
	0.081***	0.076**	-0.016	0.082***	0.119***

	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
House co-ownership/rental agreement	(0.029)	(0.031)	(0.032)	(0.025)	(0.036)
Autonomy score	-0.004	-0.059**	-0.038	-0.027	0.070**
	(0.026)	(0.028)	(0.027)	(0.027)	(0.032)
Adjusted R-squared	0.636	0.737	0.763	0.579	0.601

	Central (N=10,462)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	-0.005	0.009	0.002	-0.002	-0.033
	(0.017)	(0.018)	(0.013)	(0.012)	(0.023)
House co-ownership/rental agreement	-0.006	0.008	0.011	-0.009	0.036
	(0.017)	(0.017)	(0.014)	(0.011)	(0.030)
Autonomy score	0.000	0.002	0.002	0.006	-0.011
	(0.015)	(0.016)	(0.013)	(0.010)	(0.025)
Adjusted R-squared	0.732	0.825	0.826	0.614	0.720

	North-East (N=854)				
	EH technologies			WaSH behaviors	
	Clean cooking	Toilet	Piped DW	DW treatment	HW with soap
Bank account co-ownership	-0.075	0.034	-0.034	0.209**	-0.145
	(0.076)	(0.045)	(0.081)	(0.102)	(0.092)
House co-ownership/rental agreement	0.039	0.001	0.138**	0.146	0.072
	(0.095)	(0.046)	(0.062)	(0.102)	(0.092)
Autonomy score	-0.001	-0.005	0.043	0.024	-0.078
	(0.068)	(0.053)	(0.046)	(0.075)	(0.082)
Adjusted R-squared	0.710	0.641	0.770	0.621	0.634

NOTE: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses. Household-level (household size, dependency ratio, log of per capita monthly expenditure, hours of daily electricity access, female-headed household, family member has bank account) and individual-level (age, years of completed education, age gap between woman and household head, education gap between woman and household head, has at least one child, first born is a boy, number of hours worked in the past year, relationship to household head) factors have been included in all the models.

APPENDIX B: ADDITIONAL TABLES FROM CHAPTER 3

Table B-1**.** Raw factor loadings for social capital dimensions

	Linking	Female-centric bridging	Bonding	Social cohesion	Activity-based bridging	Political participation	Uniqueness
Factor variance	1.9036	1.7103	1.5858	1.4892	1.3733	1.3035	
Percentage of total variable explained	12.69	11.40	10.57	9.93	9.16	8.69	
Survey Items							
Among your acquaintances and relatives, any in these professions:							
Health	**0.8236**	-0.0134	-0.0067	-0.0524	-0.0396	-0.0198	0.3365
Education	**0.8328**	-0.0121	0.0081	-0.0388	-0.0247	0.0298	0.3084
Government service	**0.6440**	-0.0290	0.0338	0.0762	0.1276	0.0195	0.5299
Anyone in the household belongs to these groups:							
Mahila mandal / Women's group	-0.0005	**0.6474**	0.0024	-0.0172	0.0928	0.0727	0.5389
Self-Help Group	-0.0525	**0.7791**	-0.0534	-0.0133	-0.0036	0.0021	0.4084
Credit/Savings	0.0159	**0.7219**	0.0815	0.0027	-0.0298	-0.0708	0.4648
Religious	0.0373	-0.0629	**0.8517**	0.0064	0.0191	0.0073	0.2731
Caste Association	-0.0193	0.0806	**0.8413**	0.0074	-0.0408	-0.0136	0.2818
Youth/Sports/Reading	-0.0458	0.0265	-0.0275	-0.0167	**0.7810**	0.0939	0.3802
Trade Union/Business/Professional	0.0412	0.0028	0.0051	0.0216	**0.7747**	-0.1153	0.3877
Any household member attended public meeting in the last year	0.0263	0.1226	0.0376	0.0146	-0.0332	**0.7305**	0.4191
Any household member is a government official	0.0009	-0.1005	-0.0339	0.0004	0.0078	**0.8142**	0.3496
People generally get along with each other in your community	0.0059	0.0118	0.0259	**0.8525**	0.0043	0.0133	0.2703
Castes and sub-castes in the community get along	-0.0610	-0.0336	-0.0120	**0.8576**	0.0002	-0.0013	0.2664
People bond to solve local problems	0.2077	0.1664	-0.1438	0.1146	-0.1240	-0.0588	0.8865

NOTE: N=71, 236 survey responses. Factor loadings of 0.6 and above are highlighted in bold text. Loadings produced using oblique rotation following principal component analysis. Resulting factors are correlated across household-years.

Table B-2. Determinants of social capital (Rural sample): Household FE regression results

	Structural social capital					Cognitive social capital	
	Linking	Female-centric bridging	Activity-based bridging	Bonding	Political participation	Social cohesion	Collective action
Structural social capital (household-level)							
Linking/Networks score		0.009*	0.037***	0.041***	0.075***	0.007	0.055***
		(0.005)	(0.005)	(0.006)	(0.007)	(0.006)	(0.003)
Female-centric bridging groups score	0.018***		0.050***	0.068***	0.049***	-0.015***	0.051***
	(0.005)		(0.007)	(0.007)	(0.007)	(0.006)	(0.003)
Activity-based bridging groups score	0.040***	0.057***		0.066***	0.035***	-0.002	-0.041***
	(0.006)	(0.009)		(0.008)	(0.009)	(0.007)	(0.004)
Bonding groups score	0.031***	0.058***	0.047***		0.031***	-0.001	-0.038***
	(0.005)	(0.006)	(0.006)		(0.006)	(0.006)	(0.003)
Political participation score	0.055***	0.035***	0.022***	0.029***		0.006	-0.010***
	(0.005)	(0.005)	(0.005)	(0.005)		(0.005)	(0.003)
Cognitive social capital (household-level)							
Social cohesion score	0.017***	-0.008*	-0.004	-0.002	0.007		0.046***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)		(0.003)
Collective action	0.196***	0.176***	-0.137***	-0.166***	-0.063***	0.221***	
	(0.012)	(0.012)	(0.012)	(0.013)	(0.014)	(0.015)	
Household characteristics							
Log of per capita monthly total expenditures	0.121***	0.046***	0.047***	0.055***	0.062***	0.002	-0.006
	(0.009)	(0.011)	(0.009)	(0.011)	(0.013)	(0.011)	(0.005)
Number of married women	0.008	-0.026**	-0.025**	-0.019	-0.027*	-0.008	-0.000
	(0.012)	(0.012)	(0.011)	(0.012)	(0.016)	(0.012)	(0.006)
Number of household members	0.015***	0.023***	0.017***	0.010***	0.025***	0.005	-0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.002)
Highest male adult education	0.011***	0.003*	0.006***	0.001	0.005**	0.004**	0.002**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Highest female adult education	0.006***	0.008***	-0.000	0.002	0.003	0.001	-0.001

	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Dependency ratio	0.002	-0.028***	-0.012	-0.011	-0.015	-0.010	0.005
	(0.008)	(0.008)	(0.007)	(0.008)	(0.010)	(0.008)	(0.004)
Female household head	-0.024	-0.011	0.007	-0.046**	-0.102***	0.024	0.017*
	(0.019)	(0.020)	(0.020)	(0.019)	(0.024)	(0.021)	(0.010)
Age of household head	-0.000	-0.002***	-0.001	0.000	0.002	0.001*	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Round 2	-0.032***	0.003	-0.010	-0.018**	-0.050***	-0.045***	-0.037***
	(0.007)	(0.008)	(0.008)	(0.008)	(0.009)	(0.008)	(0.004)
Constant	-1.142***	-0.423***	-0.291***	-0.271***	-0.460***	-0.277***	0.087*
	(0.084)	(0.098)	(0.085)	(0.093)	(0.113)	(0.094)	(0.047)
Observations	46,908	46,908	46,908	46,908	46,908	46,908	46,908
Adjusted R-squared	0.495	0.302	0.291	0.482	0.267	0.492	0.427

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Community-level measures of social capital are also included for respective household-level social capital outcomes and are positively significant (p<0.01).

Table B-3. Determinants of social capital (Urban sample): Household FE regression results

	Structural social capital					Cognitive social capital	
	Linking	Female-centric bridging	Activity-based bridging	Bonding	Political participation	Social cohesion	Collective action
Structural social capital (household-level)							
Linking/Networks score		0.009	0.076***	0.030***	0.029***	0.015*	0.060***
		(0.007)	(0.010)	(0.008)	(0.006)	(0.009)	(0.005)
Female-centric bridging groups score	0.022***		0.059***	0.078***	0.032***	0.012	0.063***
	(0.008)		(0.014)	(0.011)	(0.009)	(0.008)	(0.005)
Activity-based bridging groups score	0.047***	0.033***		0.072***	0.018***	-0.003	-0.016***
	(0.006)	(0.007)		(0.007)	(0.006)	(0.007)	(0.003)
Bonding groups score	0.023***	0.060***	0.110***		0.027***	0.012*	-0.048***
	(0.007)	(0.008)	(0.012)		(0.007)	(0.007)	(0.005)
Political participation score	0.041***	0.042***	0.050***	0.049***		-0.003	-0.025***
	(0.008)	(0.011)	(0.016)	(0.011)		(0.010)	(0.006)
Cognitive social capital (household-level)							
Social cohesion score	0.016**	0.004	-0.005	0.016**	0.000		0.053***
	(0.007)	(0.005)	(0.009)	(0.006)	(0.005)		(0.004)
Collective action	0.213***	0.173***	-0.103***	-0.173***	-0.061***	0.246***	
	(0.015)	(0.013)	(0.018)	(0.016)	(0.014)	(0.018)	
Household characteristics							
Log of per capita monthly total expenditures	0.190***	0.046***	0.087***	0.043***	0.035**	0.020	-0.016*
	(0.015)	(0.013)	(0.020)	(0.016)	(0.014)	(0.016)	(0.008)
Number of married women	-0.049***	-0.027	-0.023	0.001	0.000	-0.027	0.013
	(0.019)	(0.017)	(0.024)	(0.019)	(0.017)	(0.019)	(0.010)
Number of household members	0.038***	0.034***	0.025***	0.004	0.005	0.001	-0.008**
	(0.006)	(0.006)	(0.008)	(0.006)	(0.006)	(0.006)	(0.003)
Highest male adult education	0.008***	0.001	0.007**	0.003	0.001	0.003	-0.000
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)
Highest female adult education	0.010***	0.002	-0.002	-0.001	0.002	0.002	-0.001

	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)
Dependency ratio	0.040***	-0.036***	-0.031**	-0.003	-0.011	-0.008	-0.000
	(0.012)	(0.012)	(0.015)	(0.013)	(0.011)	(0.012)	(0.007)
Female household head	-0.085***	-0.014	-0.042	-0.031	-0.046*	0.012	-0.002
	(0.029)	(0.029)	(0.038)	(0.030)	(0.026)	(0.028)	(0.016)
Age of household head	0.002*	-0.002	0.000	-0.000	0.000	0.002*	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Round 2	-0.059***	-0.013	-0.050***	0.000	-0.020***	-0.074***	-0.033***
	(0.010)	(0.009)	(0.013)	(0.010)	(0.008)	(0.010)	(0.005)
Constant	-1.851***	-0.497***	-0.656***	-0.196	-0.209*	-0.393***	0.230***
	(0.134)	(0.121)	(0.177)	(0.140)	(0.121)	(0.135)	(0.072)
Observations	24,328	24,328	24,328	24,328	24,328	24,328	24,328
R-squared	0.454	0.344	0.341	0.416	0.267	0.483	0.432

NOTE: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Community-level measures of social capital are also included for respective household-level social capital outcomes and are positively significant (p<0.01).