The Role of Social Capital in the Adoption of Firewood Efficient Stoves in the Northern Peruvian Andes

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Abstract

This paper explores rural households' adoption of a new cooking technology in the Northern Peruvian Andes. It exploits a development intervention which distributed and installed, at no cost, firewood efficient stoves in the rural communities of Chalaco District. Using first hand data, collected from the beneficiary villages, this research investigates how village technology adoption patterns and village social capital mutually interact and influence the individual household's adoption decision. The results in this paper indicate that the effect of village adoption patterns on the household's adoption decision is significantly higher in villages with stronger social capital and that the marginal impact of social capital may be negative if village success in adoption is relatively low. It is also shown that only the proportion of adopters that did not experience problems with their own stoves has a positive impact on individual household adoption through its interaction with social capital, while the reverse is true for the village proportion of adopters experiencing problems with the new cooking technology. In this study measures of social capital were collected prior to the intervention; therefore, reverse causality should not be a critical issue in identifying the effects of this social variable. Village unobservable factors are not likely to drive the observed patterns in the data; this paper also shows that village success in adoption has a negative effect on the decision to uninstall the stove among beneficiary non users and that this effect is also increasing in village social capital. The results point to the importance of village social structures in the success of development interventions.

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1. Introduction

When a new technology is introduced in rural communities not only do individual and household factors (such as ability, wealth, risk aversion, etc.) affect the household's likelihood of technology adoption; but, and probably more importantly, network and village factors also appear to matter. In the recent years, the empirical development literature on technology adoption has specially focused on the presence of social factors related to social learning and information diffusion at the village level (Conley and Udry 2008, Bandiera and Rasul 2006, Munshi 2004, Isham 2002, Foster et al 1995). Almost all the papers in this literature focus on the adoption of agricultural technologies where, as has been broadly documented; experimentation, innovation and social learning play a crucial role. The main results in these works indicate that individual household's adoption is strongly influenced by the decisions of other households in the network of reference or in the village of residence. However, although a significant variety of issues related to social learning has been empirically explored in much detail[1], not enough attention has been given at understanding how the nature and intensity of village social structures influences social learning at initial stages of adoption; neither at how the initial performance of a new technology affects the type of effects village social links will have on the household's adoption decision.

This paper aims to help filling this gap and investigates how village adoption patterns and village social capital mutually interact and influence individual household's technology adoption decisions in rural areas of the Northern Peruvian Andes at early adoption stages. It exploits first hand data generated during a development intervention in the Chalaco District, in the Piura Region, during 2003 and 2004, which distributed and installed at no cost firewood efficient stoves[2]. This research proposes that the marginal impact of village adoption patterns and village social capital on the household's decision to adopt the new

[1] Such as the presence of strategic behaviour at early adoption stages (Bandiera and Rasul, 2006) or the impact heterogeneity in household characteristics may have on social learning (Munshi, 2004).

[2] Data on households' characteristics and social capital in the area of intervention was collected prior to improved stove distribution, and has been provided by Universidad de Piura (survey results were not available to NGO members at the time of stove distribution). Access to the stove full beneficiaries file and to a monitoring report performed 8-10 months after stove distribution which contains detailed information on patterns of adoption has been facilitated by the Peruvian NGO "MIRHASPERU".

improved stove is heterogeneous across villages. More precisely, the empirically results in this paper indicate that: a) the impact of village adoption patterns on the household's likelihood of adoption is increasing in village bonding social capital[3], defined as the nature and strength of the social relationships within the community (Woolcock, 1998); and that b) the marginal effect of bonding social capital on the household's likelihood of adoption is intrinsically linked to village initial adoption patterns. With respect to result b), it is shown in this paper that if the village level of success in improved stove adoption is relatively low, i.e. the proportion of beneficiaries using the improved stove without problems is small or the proportion of beneficiary users facing problems with the technology is relatively large; then, *"ceteris paribus",* bonding social capital is more likely to negatively influence the household's decision to adopt the new cooking device. In order to account for the heterogeneous effect of social capital and village adoption, the empirical estimations in this paper allow for an interaction term between the bonding social capital and the village adoption patterns measures[4]. A clear advantage of this research with respect to others that have also explored the role of village social structures on technology adoption decisions (i.e. Isham 2002), is that the social capital measures used in the main paper's estimations (village level of trust in local neighbours, village level of trust in local organizations, village communication index) were obtained in the months prior to the improved stove adoption process; then reverse causality should not be a critical issue in identifying the effect of village bonding links.

An important characteristic of this paper is that it focuses on the decision to use the improved stove as the main cooking device only among beneficiary households. In the context of the improved stove intervention in the Chalaco District this is a relevant group of study, as beneficiary households represent approximately 85% of all the households residing in the villages within the district. As it was mentioned before, the stove was distributed and installed without monetary cost and it is also known that beneficiary households were not required to immediately abandon their traditional stove technology

[3] Our results also indicate that bridging social capital decreases the impact of others adoption on individual household adoption, but this effect is not significant once the interaction term between village adoption and bonding social capital is accounted for.

[4] Up to my current knowledge no other paper has allowed for an interaction term between adoption patterns and social capital at the village level.

during improved stove distribution and installation. Information collected from recent visits to the area of intervention in 2008 indicates that approximately 96% of those households that initially asked for an improved stove received one.

One of the most important issues in studies related to social learning in the context of technology adoption is to properly define the household's reference group; that is the group of village neighbours the household obtains information and learns from. Some of the studies in the literature attempt to infer the presence of social influences by relating degrees of adoption at different geographic scales (Foster et al. 1995, Isham 2002, Munshi 2004) to the adoption decision by the household; in most of the cases the village is used as a proxy for the household's reference network. In more recent studies the reference group used in the estimations has been self-reported by the household (Conley and Udry 2008, Bandiera and Rasul 2006). Given the limitations of the improved stove adoption data and the paper's special focus on the adoption decision just among improved stove beneficiaries, this study uses the first approach and defines the village beneficiary households as the household's reference group. If true using self-reported reference groups may delineate with more precision the household informational network; for the case of the particular villages analyzed in this paper, in which the average number of households per village is relatively small (48 on average) and village membership is stable in time, the village beneficiaries may be a good approximate for the household's reference network. However, even if the reference group is appropriately defined, the researcher still has to deal with the main identification problems that are common to studies on social interactions and that have been clearly identified in the seminal work of Mansky (1993) and more recently discussed by Brock and Durlauf (2001, 2003, 2007).

Probably the most difficult problem in terms of identifying the presence of social learning in the context of technology adoption is the potential presence of unobservable (to the econometrician) network or village factors. Adoption decisions may be correlated among households in the village not because a social learning process is present, but just because households share certain unobservable preferences or characteristics or because they are subject to the same type of unobservable shocks and environments. In the cases where

the data is non experimental in nature or finding a suitable instrument is not feasible, the researcher convincingly needs to argue that no process other than social learning is likely drive the observed correlation between household adoption and village/network adoption. In this sense, many of the papers in the related literature attempt to exploit specific data characteristics and information to present additional evidence on patterns that are more likely to be caused by social learning and not by network unobservables (Bandiera and Rasul 2002, Munshi 2004). Also, when high quality data is available, it may actually be possible to control for those otherwise 'confounding' factors (Conley and Udry 2008).

In order to support the hypothesis that information diffusion is indeed the process behind the observed strong correlation between household and village improved stove adoption, in first place this research exploits the information in the stove adoption data to define two types of stove users: those that did not report problems by the time of the monitoring visits and those that did report problems using the new technology; in second place an interaction term between village adoption patterns and social capital is introduced in the main estimations. The results indicate that only the interaction term between the proportion of adopters without problems and the bonding social capital indicator has a positive and significant effect on the household's likelihood of adoption, while the reverse is true for adopters with problems. More importantly, this paper also explores the decision to uninstall the new stove among beneficiary non users, the results again point in the expected direction: an increase in the proportion of users that do not report problems with the improved stove reduces the likelihood of uninstalling the new stove mainly through its interaction with bonding social capital. The results in the paper are robust for different measures of village bonding social capital. This solid evidence suggests that it is unlikely that unobservable village factors are driving the main results in this study.

It also important to mention that the main specifications in this paper control for key geographical village variables that, as reported by NGO members, critically influenced improved stove performance and adoption, such as village altitude and road accessibility. The evidence indicates that the stove initial design was not appropriate to meet the dwelling heating needs of households in high altitude areas during winter months and that

village accessibility is likely to have influenced NGO effort during stove distribution and diffusion. The empirical estimation in the paper also controls for watershed location. Villages in certain watersheds have had more exposure to certain type of development experiences in the past, have different level of access to forest resources and, more importantly, it also known that the improved stove intervention was designed, implemented and coordinated at the watershed level. The estimations in this paper also provide interesting results on the individual household factors influencing adoption. Wealthier households and households that in the previous year participated in communal activities are more likely to adopt the new stove. Households with a higher number of adults are significantly less likely to adopt, probably because labor abundance decreases the cost of collecting firewood. Households that have at least one adult female member seem more likely to adopt the stove; probably because women value more the benefits promised by the new technology. No evidence was found on education or experience with other agricultural technologies to significantly affect adoption decisions.

This research's main contribution is to show that social capital plays an important role in the dissemination of technology information within the village, a role that has been largely attributed to this variable in the social capital literature (see for example Dasgupta 2005). Furthermore, this paper highlights that bonding social capital may have a negative impact on individual adoption if village success in adoption is relatively low. The paper develops as follows: section 2 describes the related literature, section 3 explains the improved stove program and the importance of experimentation and social learning during the adoption process, section 4 presents the data and some initial correlations between the likelihood of adoption and other relevant household and village variables, section 5 discusses the basic empirical equation, section 6 presents the main results and interprets them, section 7 focuses on the uninstalling decisions among beneficiary non users, section 8 discusses relevant identification issues and section 9 concludes.

2. Related Literature.

Isham (2002) also studies how village level measures potentially linked to village social capital influence rural household's technology adoption. His paper extends the model by

Feder and Slade (1984) to account for village social structures and uses cross sectional data on fertilizer usage in villages in Tanzania to show that the likelihood of fertilizer usage is higher in villages where fertilizer adoption and social capital are higher. More precisely, his paper shows that two measures potentially linked to village social capital: ethnically based and participatory social affiliations; positively influence the household's fertilizer adoption decisions. The main drawback in Isham's paper is related to the fact that in his study village social capital is very likely to have been influenced by the households' fertilizer adoption decision. It may have been the case that households adopting the new technology may have decided to invest more in their social relations, affecting in this way the level of village social capital. If this was the case, the social capital coefficients in his paper will not capture the causal effect of social capital on the decision to use fertilizer. In my study, the social capital measures were obtained prior to the stove adoption process; then reverse causality should not be an issue in identifying the effect of social links. Moreover, Isham argues that higher levels of village adoption and social capital imply that a higher amount of information on fertilizer usage is available in the village; however, his paper does not address the possibility that village unobservable factors may be the ones driving the correlations between individual adoption, village adoption and social capital. As I discussed in the introduction to this paper, in my study solid evidence is provided in order to support the hypothesis that social learning is indeed the generating process behind the mains patterns in the improved stove adoption data.

Up to some extent, my research is also relatively close to the work of Bandiera and Rasul (2006), which focuses as well on the household's adoption of a new technology (sunflower seeds in villages in Mozambique) at early adoption stages (during the first year of introduction). Bandiera and Rasul show that network effects at early adoption stages are U-shaped: the effect of network adoption on the household's likelihood to adopt is decreasing in the number of network adopters and may at some point be negative. They argue that their results suggest the presence of strategic behaviour at early periods of adoption: as others experience is a substitute for the household's own experience, the higher the number of adopters in its network the more likely the household is to postpone adoption and free ride on others experimentation. In my paper I also allow for nonlinear

effects of village adoption on individual adoption; the results show that the likelihood of adoption is indeed decreasing in the village proportion of stove adopters without problems and may at some point be negative. As in this paper, Bandiera and Rasul also argue that the strength of social ties matters; they find that the effect of adopters among family and friends is seven times higher than the effect of adopters in the same religion cohort. In this sense my results, which show that social effects are higher in villages with stronger bonding links; significantly add to the type of findings obtained in the literature.

In terms of dealing with identification issues, especially those associated to the presence of network and village unobservable factors, the related literature on social learning provides us with relevant examples on how in the absence of experimental data or a suitable instrumental variable, one can still exploit the information contained in the data to support the social learning hypothesis; which is in some sense what my paper intends to do. For example, in the paper we just discussed, Bandiera and Rasul (2002), argue that network unobserved correlates that are monotonically related to the number of network adopters and to the household's likelihood of adoption, are not likely to drive the strong U-shaped effect of network adoption on household adoption. However, they admit that unobserved heterogeneity may cause the observed non linear patterns, such as unobserved ability linearly correlated to network size but nonlinearly correlated to the household's likelihood of adoption[5]. In order to deal with this specific possibility, they identify some variables linked to the household's unobserved ability and include in their estimations an interaction term between an ability indicator and network adoption; they find that the U-shaped pattern is also present for households with potential higher ability. They also estimate the main regressions excluding the 25% of sampled households that are more likely to have a higher level of ability as defined by certain key variables (i.e. cashew productivity) and are still able to find the U-shaped effect of network adoption on individual household adoption.

[5] More precisely they note that households with higher ability are likely to have bigger networks, and that the likelihood to adopt may be nonlinearly correlated with ability as households with lower ability may have more difficulties in adopting the new technology while households with high ability may have more outside available options and are then also less likely to adopt.

Another interesting example can be found in a recent paper by Munshi (2004) on HYV wheat and rice acreage allocation during the green revolution in India. In this paper Munshi shows that wheat farmers tend to react to past acreage decisions taken by their village neighbours while rice farmers do not. As rice crops are more sensitive to farmers' characteristics, which may be imperfectly observable, in Munshi's opinion the results support the hypothesis that heterogeneity in population characteristics negatively affects social learning during the adoption of new technologies. In order to confirm that social learning is the process relating village outcomes to individual decisions, Munshi shows that the same patterns are observed in villages where both types of crops are present. Then, in his opinion, it is not likely that unobservable spatial characteristics intrinsically linked to "only wheat" or "only rice" villages are driving the observed results.

More recently, Udry and Conley (2008) also provide an original example of dealing with network unobservables in the context of social learning using observational data. They study how pineapple farmers in Ghana react to news related to pineapple productivity due to fertilizer usage by self reported reference neighbours[6]. The authors show that farmers tend to adopt the fertilizer usage levels of those reference neighbours experiencing surprisingly successful returns. To isolate the effect of social learning from unobservable network spatial shocks, they exploit the detailed geographical information in the data to construct an index measuring the difference between the household's past level of fertilizer use and the current level of fertilizer use by the household's geographically close reference neighbours, which are likely to be affected by the same spatial unobservable shocks. In the authors' opinion, this index controls for changes in fertilizer usage only attributable to unobservable spatial correlates, which in the end should allow identifying the impact of the proportion of neighbours experiencing successful returns in the regression for the household's change in fertilizer usage. Up to a given scope, my paper's approach in dealing with village unobservable factors is closely related to the approach followed by the previously mentioned papers. Exploiting the rich information contained in the stove adoption data, I show that only the proportion of adopters without

[6] In the survey used for their paper, pineapple farmers were asked to identify from a random sample of other farmers those of them to whom they talk and discuss about farming issues.

problems positively affects individual adoption through its interaction with social capital, while the reverse is true for the proportion of adopters with problems. More importantly, I also extend the social learning hypothesis to the improved stove uninstalling decision among beneficiary non users; the results are consistent with our initial findings and indicate that village successful adoption decreases the likelihood of uninstalling the improved stove among beneficiary non users mainly trough its interaction with bonding social links. These results suggest that it is unlikely that village unobservables are driving the main findings in the data.

3. The Program for the Sustainable Development of Mountain Ecosystems in Peru

Also known as the "Chalaco Program", it was conceived as a comprehensive development strategy in the Chalaco District, in the Northern Peruvian Andes. Financed by the Spanish International Cooperation Agency, the program initial design included interventions in the areas of agricultural production, natural resources management and women and children health related issues. The main intervention during the program's first year was distribution of firewood efficient stoves. This strategy was adopted as an immediate response to forest degradation[7] in the area and as a way to improve women and children health[8] by reducing indoor air pollution. Improved stoves were distributed and installed without cost in 37 of the 39 villages within the Chalaco District during the months of August to November 2003[9]. For stove distribution, the NGO MIRHASPERU contacted the most representative watershed and village organizations. With the support of these organizations, the NGO called to an open meeting in every village in which the NGO members explained attendants the stove distribution program and the benefits of stove usage. An improved stove was allocated to every household who asked for one; recent field visits during the summer of 2008 confirm this was indeed the case. The NGO provided beneficiaries with an iron frame and an aluminium chimney; the households were supposed to provide the mud bricks for building the combustion box and the stove

[7] In theory these improved stoves were supposed to reduce firewood usage by 40% if used properly. Nearly 95% of households in Chalaco district use firewood as main source of cooking energy and it was knew that firewood scarcity was a critical problem in the area at the time of the intervention (Vaquero, 2007).

[8] The stoves were built with an aluminum chimney designed to expel the combustion smoke out of the household dwelling and in this way help to reduce the incidence of respiratory and vision related illnesses.

[9] There are 39 villages in Chalaco District, located in 5 watersheds among 1000 m. and 3000 m. of altitude.

basement (see figures 1, 2 and 3). Stove installation was also done without pecuniary cost and it was supported by two village craftsmen selected by the village beneficiaries and trained by the NGO. Beneficiary households were not required to uninstall their traditional technology in order to get their new improved stoves installed.

A second stage of stove distribution was originally planned to provide the improved stove to those households that initially did not ask for one. However, due to administrative reasons and other program priorities, the second stage was postponed. The only way a household that initially did not received an improved stove could have had access to one, was by getting it transferred or sold from another household in the same village or in a close one. The 2004 stove monitoring interviews indicate that these cases were extremely rare. For example less than 0.5% of the total beneficiaries visited reported that they sold their improved stoves. Up to my current knowledge, all the households in every village received the same stove design as well as the same instructions for its installation, usage and maintenance. It is also know that the strategy was coordinated and implemented at the watershed level; then, controlling for village watershed location will be important in order to isolate the effect of potential differences in the quality and effort level of the NGO members allocated to different watersheds.

It is also important to mention that during monitoring visits some beneficiaries reported problems with their stove materials, mainly deformations in the iron frame and chimney. Given the artisan way of building the stove and the lack of evidence on materials quality inspection before stove diffusion, it is not unlikely that certain number of stoves was of inferior materials quality[10]. The evidence also suggest that these potential materials differences were ex-ante non observable neither to the NGO nor to the beneficiaries[11].

3.1 Social Learning/Information Diffusion during improved stove adoption

The improved stove technology introduced in the Chalaco District was originally designed for rural communities in the coastal areas of Piura Region, where the main role

[10] Almost 90% of the users with problems reported problems with the materials of the stove.
[11] However the responsible NGO argued that the main reason behind materials problems was the incorrect usage of the stove by the beneficiary households.

of a firewood stove is food preparation. In this coastal areas the weather is relatively warm during most part of the year and the type of firewood used is relatively uniform (mainly "algarrobo"). Up to my current knowledge, the original design was introduced in the villages of Chalaco District without major modification or adjustment. No special feature was ex-ante introduced to adapt the cooking device to the particular circumstances of these Andes' villages. For example, the design did not take into account that the firewood stove also performs as a heating device in high altitude areas where the temperature is much colder during winter months[12]. Also the stove combustion box was designed for the type of firewood that is common to coastal areas and did not take into account the specific varieties and qualities of firewood that are available in the different watersheds of Chalaco District. All these evidence suggest that there was plenty room for household experimentation with the new cooking device as well as for innovation and learning diffusion. It is important to note that household suited modifications to the stove initial design were not difficult to make as the combustion box and stove basement are made completely from handmade mud bricks, which can be easily manipulated. Some of the modifications observed included changes in the measures of the combustion box, the adaptation of the stove for the elaboration of local foods and the reallocation of the stove to improve its performance as a heating device. All these modifications are likely to have been diffused among villagers and the main point in this paper is to argue that the diffusion process was stronger in villages with stronger bonding links.

Finally, villagers are not only likely to communicate each other how to use or modify the stove but also the real benefits they obtained with the new device, the optimal way to process firewood inputs or the quality of the technology they received. A given household will be more likely to adopt the stove if others in the village experience effective savings in firewood consumption and/or reductions in indoor air pollution. Also, households may be more likely to delay adoption if negative news relate to the new device are relatively abundant in the village (i.e. stove material deformations).

[12] The minimum temperature during the winter season in coastal rural villages is close to 17 Celsius degrees, while at high altitudes villages in Chalaco District it can reach 0 Celsius degrees during the winter months.

4. Data

4.1 Household characteristics and Village Social Capital - 2003 Household Survey

From June to August 2003, data on household characteristics was collected in the all the 39 villages within the Chalaco District. Data collection was done by Universidad de Piura, a local university with a large experience in development projects in Piura Region. Neither stove distribution nor stove monitoring visits were done taking into account the survey data. The total random sample contains a total of 816 households; on average 21 households per village were randomly selected and interviewed. The data includes members, dwelling, and farm characteristics. More importantly, the survey contains a "social capital" questionnaire. During the interview, the household head (or the most informed household member) was asked the following questions:

a) **How much do you think you can trust in: village neighbours, local organizations, people from other villages, district authorities and strangers?** The scale of responses goes from 0 to 3 (0=nothing, 1=a little, 2=in a regular degree, 3=a lot).
b) **How do you personally evaluate the degree of: local communication and local cooperation in your village?** : In this case the scale of responses goes from 1 to 3 (1=none, 2=regular, 3=good). If the questions were not clear enough for the interviewed, the interviewer tried to provide examples related to the village life.

Using the household's responses to the social capital questionnaire, the village averages for these variables are obtained and used as measures/indicators of village social capital. In this study I refer to social capital as the nature and intensity of village social relationships, which have different dimensions (i.e. bonding vs. bridging social capital) and are dynamic in nature. Following Woolcock (1998) it is important to note that "…trust and norms of reciprocity, fairness, and cooperation are **"benefits"** that are nurtured in and by particular combinations of social relationships; they are undeniably important for facilitating and reinforcing efficient institutional performance, but they do not exist independently of social relationships"[13]. In his influential 1998 paper Woolcock

[13] It is also important to note that social capital is just one way to create trust. As Dasgupta (2001) notes, good local institutions, that clearly define rights and obligations can be also a source of communal trust.

also emphasizes that "…"consequences" may be one indicator of the types and combinations of social capital that are present, but they are not to be confused with social capital itself". Taking this into account, the empirical approach in this research will use village trust in local neighbours, village trust in local organizations, village communication, village cooperation and village trust in strangers as indicators for the "potential" degree of bonding and bridging social capital present in the villages of study.

How village social capital, defined as the nature and extent of village social relationships, influences technology adoption is the main question the present paper intends to address. The main hypothesis in this paper is that "bonding" social capital, defined as the nature and strength of the social relationships "within" the community (Woolcock, 1998), plays a central role facilitating the dissemination of information in the village. In those villages where the bonding links are strong, information will tend to circulate more intensively. However, it will be shown that the impact the bonding links *"per se"* will actually have on adoption decisions will depend on the concrete experience households in a given community are having with the new technology. A low rate of initial success may encourage the diffusion of negative information through the village network. Table I below resumes the 2003 survey information aggregated at the village level on sample size, proportion of occupied dwellings sampled and village social capital measures for the 26 villages in the sample that were also visited during the improved stove monitoring of 2004. Table II shows the degree of correlation among the different measures of social capital at the village level.

Table I – Village social capital indicators

Variable	Villages	Mean	S.D	Min	Max
Households per village	26	48.08	24.05	19	126
Sample size per village	26	21.28	8.99	8	43
Village proportion of households sampled	26	0.47	0.13	0.19	0.74
Trust in local neighbours index (**t1v**)	26	1.45	0.40	0.42	2.22
Trust in local organization index (**t2v**)	26	1.89	0.27	1.22	2.33
Trust in strangers index (**t3v**)	26	0.60	0.23	0.18	1.14
Village communication index (**comv**)	26	1.51	0.25	1.04	1.98
Village cooperation index (**coopv**)	26	1.42	0.29	0.88	1.88

The information in this table is presented at the aggregated village level

Table II – Linear correlations between the village social capital measures				
	t1v	**t2v**	**t3v**	**Comv**
Trust in local neighbours index (**t1v**)	1.00			
Trust in local organization index (**t2v**)	**0.77 *****	1.00		
Trust in strangers index (**t3v**)	-0.28	0.14	1.00	
Village communication index (**comv**)	**0.37 ***	**0.38***	-0.01	1.00
Village cooperation index (**coopv**)	0.14	0.18	-0.03	**0.61 *****

As it is standard ***, ** and * indicate statistical significance at the 1, 5% and 10% significance level.

As it was just mentioned, social capital is a concept that has multiple dimensions. At the village level two dimensions are identified in Woolcock's 1998 seminal paper: bonding and bridging social capital. The first one refers to the nature and intensity of the social relationships within the community; the second one is related to the nature and intensity of the links with agents outside the village. In my opinion the indexes for intra village trust, trust in local neighbours (t1v) and trust in local organizations (t2v), are more likely to be related to the first dimension of social capital. In the other hand, indicators such as the index for trust in strangers (t3v) are more likely to be related to the second dimension. The results in table II suggest that t1v and t2v tend to be highly and significantly correlated among them, but not with t3v. These results provide initial evidence on the fact that the two dimensions (bonding and bridging) do not necessarily move together. Also note that the village communication index is positively and significantly correlated with the first two trust indexes, which are linked to the bonding dimension of social links.

4.2 Improved Stove Adoption Patterns –The 2004 Stove Monitoring Survey

From April to August 2004, MIRHASPERU and Universidad de Piura monitored improved stoves performance in 26 beneficiary villages. During the visits, the interviewers had physical access to the kitchen area and were able to confirm the real situation of stove usage by the beneficiaries. Members of Universidad de Piura involved in the monitoring reported that visits to all the beneficiary villages were initially planned and that special emphasis was set in visiting villages in high altitude areas, where it was expected that the performance of the stove was relatively poor and adoption rates were also relatively low[14]. Mainly due to budget constraints and some security issues in certain

[14] Then, in any case the village monitoring sampling procedure should work against the social learning hypothesis in this paper.

areas relatively close to mining explorations, some villages were not visited, mainly in low altitude areas[15].

As table III shows, 82% of the total beneficiaries were visited per village. It is important to note that within villages there is not significant evidence on households refusing to be interviewed. In most of the cases household that were not interviewed were not at their dwelling place at the time of the interview; many of them were out for social visits at other villages and in some cases they were still at their farm plots or were out buying food items or tools in the main district town. It is also know that in some cases monitors ran out of time during the visits. Table III also shows that from the total number of visited beneficiaries, approximately 45% reported using the stove as the main way of preparing food. Stove users can be classified into two categories depending on the situation of stove usage by the time of the visits: a) those using the stove with some problem and b) those using the stove without any complications. The empirical estimations in this chapter use households in the second category, which are called "successful adopters", as a measure of village success in adoption. In my opinion these users are the ones that play a critical role diffusing positive information on stove usage and related benefits.

Table III – Village level adoption patterns

Variable	Villages	Mean	S.D.	Min	Max
Number of occupied dwellings per village	26	48.01	24.05	19	126
Total beneficiary households per village	26	40.71	17.05	15	88
Number of visited beneficiaries per village	26	33.23	14.71	10	76
Village proportion of visited beneficiaries during stove monitoring	26	0.82	0.13	.50	1
Village proportion of visited beneficiaries using the improved stove as the main way of preparing food	26	0.45	0.20	0.06	0.71
Village proportion of users that have some problems using the improved stove	26	0.28	0.25	0	1
Village proportion of users that do not present problems using the improved stove	26	0.72	0.25	0	1
Village proportion of visited beneficiaries that received the improved stove but do not use it or use it rarely.	26	0.55	0.19	0.29	0.94
Village proportion of non users that decided to uninstall the improved stove	26	0.32	0.21	0	0.73

The information in this table is presented at the aggregated village level

[15] During field visits in the summer of 2008 I was able to confirm that stoves success among beneficiaries was relative high in this low altitude villages, one reason for this is that the only function of the stove in this area is food preparation.

Table IV – Main problems encountered by stove beneficiaries (%)	
Users that report problems (N=93)	
Materials problems (iron frame deformed, chimney broken)	90.4
Stove uses more firewood	21.9
Non Users (N=454)	
Materials problems	15.6
Stove uses more firewood	34.1
It is not good for heating the house	5.6
It is hard to get use to it	10.5
It is dangerous	2.0
It is time consuming	8.1
None[16]	54.8

In table IV we can observe that the main inconvenient encountered by users with problems is related to stove materials issues, mainly deformations in the iron frame and chimney, which more likely were ex-ante non observable either to improved stove beneficiaries or to NGO members. Note also that a smaller proportion of users with problems reported that the stove used too much firewood. As the improved stove also has other expected benefits (i.e. reductions in indoor air pollution), it is possible that these households continued using the stove because the other benefits compensated for the higher levels of firewood consumption[17]. Among non users the major inconvenient reported was related to the higher consumption of firewood by the improved stove; some non users also reported stove materials problems but the proportion is in this case significantly lower than for the case of users with problems

Using the full set of observations in the 2004 monitoring report dataset, table V shows the linear correlations between the binary variable representing the household's decision to use the stove as the main cooking device (i.e. the adoption decision) and some village variables of interest. Table V shows that stove adoption as the main cooking device is positively and significantly correlated with the village proportion of users without problems and with three indexes measuring social capital: trust in local neighbours, trust in local organizations and village communication. The adoption decision is not

[16] Approx. 54% of non users that didn't reported problems received the new stove but did not install it.
[17] Note that a relative small proportion of non users also reported materials problems; as it is very likely that the nature of the material problems they were facing made it impossible for them to continue using the device, the main adoption regressions in this paper are also estimated excluding this group of non users, however we do not observe major differences in the results.

significantly correlated with the proportion of adopters with problems. Adoption is also significantly and negatively correlated with altitude and significantly and positively correlated with road accessibility. The correlation is negative and significant between the adoption variable and location in Mijal and Cerro Negro watersheds and positive and significant between adoption and location in Noma watershed[18].

Table V – Simple correlations between the household's adoption decision and village adoption patterns, social capital and geographic characteristics

Variable: Using the stove as a main way of cooking (No=0 Yes=1)	Correlation coeff.
Proportion of adopters/users using the stove without technical problems (w1p)	**0.28** ***
Proportion of adopters/users using the stove with technical problems (w2p)	0.04
Proportion of beneficiaries (benp)	**0.06** **
Trust in local neighbours index (t1v)	**0.08** ***
Trust in local organizations index (t2v)	**0.09** ***
Trust in strangers (t3v)	0.04
Village communication index (comv)	**0.06** **
Village Altitude	**-0.22** ***
Village is accessible by road (yes=1, no=0)	**0.15** **
Household's village is located in Mijal Watershed (M1=1)	**-0.22** ***
Household's village is located in Nogal Watershed (M2=1)	0.04
Household's village is located in Potros Watershed (M3=1)	0.04
Household's village is located in Noma Watershed (M4=1)	**0.22** ***
Household's village is located in Cerro Negro Watershed (M5=1)	**-0.14** ***

N= 878. ***,** and * indicate statistical significance at the 1%, 5% and 10% significance levels

Matching the socioeconomic survey and the stove monitoring data files, a total of 283 beneficiary household observations are available for estimation purposes. Average characteristics for stove users and non users are shown in table VI as well as the equality test p-value for the simple difference in means and average proportions for the variables included. As we can observe, the proportion of households with secondary education or higher is significantly higher for adopters than for not adopters. Note also that adopters are on average richer that not adopters (as measured by the value of their farm assets), but the unconditional difference in means is not statistically significant. In order to measure household's involvement in communal activities, entrepreneurship, experience with other technologies and preferences for environmental or women related outcomes, the following variables are considered: household's past participation in communal activities,

[18] Noma watershed is the most accessible watershed in terms of road access and quality. Mijal and Cerro Negro watershed villages are on average placed at higher altitudes and have also poor accessibility conditions, especially during the rainy season.

household's experience with fertilizers or elaborating processed products (i.e. alcoholic beverages, wheat flour, etc), and household's membership in environmental or women based local organizations.

We can see in table VI that adopters are significantly more involved in local activities; adopters and non adopters are equally likely to use fertilizer or elaborate processed products and non adopters have a significantly higher participation in environmental groups. Although this last result seems to go in the wrong direction, I must note that environmental groups are relatively abundant in high altitude villages, were the stove was less likely to meet all the needs households expected from the new device[19]. Also it may be the case that if the new stove was perceived as a bad technology in terms of firewood consumption for example, then households with higher forest preferences may be less likely to adopt it.

Table VI - Main household level characteristics for stove users and non users

	Users N=155	Non users N=128	Test of equality (p-value)
Household's head sex (male=1, female=0)	0.85	0.91	0.19
Household's head age	51 (14)	49 (13)	0.21
Household's number of Adults	2.72 (1.39)	2.95 (1.61)	0.20
Adult female in the household (yes-1, no=0)	0.88	0.89	0.73
Household head has secondary education or higher	**0.20**	**0.11**	**0.03**
Household head attended school and has at most primary education	0.74	0.78	0.35
Household head did not attended school	0.06	0.10	0.17
Household's farm size in has.	2.66 (2.72)	2.96 (3.18)	0.34
Household's value of farm assets (in Peruvian soles)	84 (13.4)	68 (5.6)	0.22
Household's processed products elaboration(yes=1, no=0)	0.55	0.57	0.69
Household's fertilizer usage (yes=1, no=0)	0.63	0.68	0.27
Household's participation in communal activities during the last 12 months (yes=1, no=0)	**0.50**	**0.34**	**0.01**
Household's membership in environmental group (yes=1, no=0)	**0.31**	**0.54**	**0.00**
Household's membership in mothers club (yes=1, no=0)	0.23	0.25	0.61

Standard deviations shown in parenthesis.

[19] These groups were created in this area during a government watershed management program in the 90's.

5. The Empirical Equation

A given household in a rural community will adopt a new technology as long as the expected economic gains "a_{ij}^{*}" it derives from its use are non negative. Assume that for the case of the new efficient firewood cooking device introduced in the villages in the Chalaco District, the expected economic gains are linear in a vector of household level characteristics "X_{ij}", a village level effect "W_j" and an individual error term "u_{ij}". The reduced form equation is given then by:

(1) $a_{ij}^{*} = \alpha_0 + \alpha_1 X_{ij} + W_j + u_{ij}$ (Where "i" refers to households and "j" to villages)

Let's allow the village effect in (1) to be function of non-stochastic village variables and a village error term. These variables include a village informational term given by "I_j", which measures the amount of information related to improved stove usage and performance available in the household's village of residence, and a vector of village level characteristics "Y_j", which includes the village proportion of beneficiaries, watershed location, altitude, road access and level of trust in strangers (as a measure of village bridging social capital). The effect of the village informational term "I_j" will be the central point of this analysis and this term is defined as a non linear function of the village level pattern of improved stove adoption "AP_j" and the village level of bonding social capital "$\mathrm{SC_j}$", that is $I_j = I_j(AP_j, SC_j)$. The village effect is then given by:

(2) $W_j = \beta_0 + I_j(AP_j, SC_j) + \beta_1 Y_j + e_j$

In this section of the paper I prefer not to define any specific functional form for the village informational term; in the next section different specifications will be allowed and estimated. In some cases the total proportion of stove adopters will be used to define the village pattern of adoption, while in others I will distinguish between adoption with and without problems. Taking (1) and (2) together, the following expression for the net household expected gains is obtained:

(3) $a_{i.j}^{*} = (\alpha_0 + \beta_0) + \alpha_1 X_{ij} + I_j(AP_j, SC_j) + \beta_1 Y_j + e_j + u_{ij}$

As household's "expected net gains" are unobservable to the econometrician, let's represent the adoption decision by the discrete choice variable "$a_{i.j}$", which will take the value of one if the household uses the improved firewood stove as the main way of preparing food and zero otherwise. The probability that household "i" in village "j" will use the new cooking technology as the main way of preparing food will then be given by:

(4) $P(a_{ij} = 1) = P\left(v_{ij} > -\{ \alpha_0 + \beta_0 + \alpha_1 X_{ij} + I_j(AP_j, SC_j)_j + \beta_1 Y_j \} \right)$, where $v_{ij} = e_j + u_{ij}$

Expression (4) clearly suggests a probit regression to estimate the household's likelihood of adoption; however it is known that the linear probability model is more amenable to the estimation of alternative functional forms for $I_j(.)$ and that the computation of higher order polynomials is more transparent when higher order polynomials are fitted onto $I_j(.)$[20]. Taking this into account, a linear probability model in the next form will be also estimated:

(5) $a_{i.j} = (\alpha_0 + \beta_0) + \alpha_1 X_{ij} + I_j(AP_j, SC_j) + \beta_1 Y_j + v_{ij}$

6. Baseline estimation results

This section only presents the results estimated using the linear probability regression with clustered standard errors at the village level. Probit regressions have also been used to estimate the main empirical specifications; the results are very similar to the ones in the linear regressions. All the specifications in this section control for household characteristics and include dummies for village watershed location. Table VII below presents the estimation results for the case where the informational term in (5) does not allow for an interaction term between bonding social capital and village adoption patterns. The odd columns in table VII control for village adoption patterns, village bonding social

[20] It is important to note that the adoption rate in the sample is 54% (fairly close to 50%) and that when we use the linear probability model with clustered standard errors, less than 2% of the predicted estimates lie outside the unit interval.

capital and also for the village proportion of beneficiaries. The even columns in table VII also include village road access, village altitude and the index for trust in strangers (as a measure for village bridging social capital) as village controls. In the specifications that correspond to columns 1 and 2 in table VII, the village informational term in equation (5) "$I_j(AP_j,SC_j)$" is defined as a function of the total proportion of stove adopters/users ("TP_j")[21], the square term for this proportion and the village indicator of bonding social capital ("SC_j"): village level of trust in local neighbours[22], that is:

(6) $I_j(AP_j,SC_j) = \lambda_1 TP_j + \lambda_2 TP_j^2 + \lambda_3 SC_j$

As it can be observed, the results in columns 1 and 2 show that the likelihood of adoption is decreasing in the total proportion of stove adopters; the linear and the quadratic term for the proportion of total adopters are respectively positive and negative and statistically significant. The results indicate that the marginal effect of the total proportion of adopters on the likelihood of adoption will be positive only if the proportion of total adopters in columns 1 and 2 is below 44% and 38% respectively. The results also indicate that the bonding social capital term is not significant in these regressions. The specification in columns 3 and 4 include the proportion of adopters without problems "PI_j" instead of the total proportion of adopters "PT_j" in the village informational term in equation (5). In my opinion, only this group of adopters plays a positive role influencing the decision to adopt the new technology. In other words, information on how to properly use the new technology or information on improved stove effective benefits is more likely to be disseminated by this group of improved stove users. The village informational effect in (5) is then defined as:

(7) $I_j(AP_j,SC_j) = \lambda_1 PI_j + \lambda_2 PI_j^2 + \lambda_3 SC_j$

[21] In this section all the proportions are estimated on the base of the total number of village stove beneficiaries.

[22] In all the specifications in this section, only the village level of trust in local neighbours is used as a measure for village bonding social capital. The results are very similar when the village level of trust in local organizations and the village communication index are used as measures of bonding links.

Table VII – Village level determinants of the household's likelihood of improved stove adoption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Village total proportion of adopters	**0.0243*** **	**0.0298 *** **						
	(0.0062)	(0.0071)						
Village total proportion of adopters^2	**-0.0003*** **	**-0.0004*** **						
	(0.0001)	(0.0001)						
Village proportion of adopters without problems			**0.0184*** **	**0.0179 *** **			**0.0199*** **	**0.0191*** **
			(0.0047)	(0.0051)			(0.0051)	(0.0059)
Village proportion of adopters without problems^2			**-0.0002*** **	**-0.0003*** **			**-0.0003*** **	**-0.0003*** **
			(0.0001)	(0.0001)			(0.0001)	(0.0001)
Village proportion of adopters with problems					0.0054	0.0113	-0.0011	0.0054
					(0.0105)	(0.0124)	(0.0101)	(0.0134)
Village proportion of adopters with problems^2					-0.0002	-0.0002	-0.0002	-0.0002
					(0.0003)	(0.0003)	(0.0003)	(0.0004)
Village level of trust in local neighbours (bonding social capital)	-0.0299	-0.0255	-0.0578	-0.0670	-0.0324	-0.0386	-0.0794	-0.0802
	(0.0809)	(0.0999)	(0.0824)	(0.0970)	(0.0842)	(0.0886)	(0.0913)	(0.1035)
Village proportion of beneficiaries	**0.0047*** **	**0.0059*** **	**0.0044** **	**0.0067*** **	0.0032	0.0023	**0.0054** **	**0.0077*** **
	(0.0016)	(0.0018)	(0.0019)	(0.0018)	(0.0020)	(0.0019)	(0.0020)	(0.0022)
Village level of trust in strangers (bridging social capital)		0.0426		0.0375		-0.1362		0.0660
		(0.2093)		(0.2079)		(0.1673)		(0.2059)
Village Altitude		**-0.0346** **		**-0.0473** **		**-0.0418** **		**-0.0502** **
		(0.0132)		(0.0203)		(0.0164)		(0.0224)
Village Road Access		**0.1459* **		**0.1358** **		**0.1116* **		0.1197
		(0.0729)		(0.0637)		(0.0577)		(0.0732)
N	283	283	283	283	283	283	283	283
Villages	24	24	24	24	24	24	24	24
R2	0.21	0.23	0.21	0.23	0.19	0.21	0.21	0.23

All regressions in this table control for watershed dummies and include as household level controls the household's head sex and age, household's head level of education, household's number of adults, presence of a female adult member in the household, household's wealth (measured by the value of farm assets), farm size, household's participation in women and environmental organizations, household's elaboration of processed products and usage of fertilizer and household's participation in local activities in the previous 12 months. As it is standard ***, ** and * indicate statistical significance at the 1%, 5% and 10% significance levels.

We can observe in columns 3 and 4 that the proportion of adopters without problems has a significant effect on the likelihood of adoption and that this effect is decreasing in this specific proportion, the linear term is positive and the quadratic term is negative. Compared to the results when the total proportion of adopters was included, we can see that the coefficients' size is lower in absolute value. In this case, the results indicate that the marginal effect of the proportion of adopters without problems on the likelihood to adopt the stove will be positive in columns 3 and 4 only if the proportion of adopters without problems is below 42% and 32% respectively. Note also that, as it was the case in columns 1 and 2, the coefficient for the social capital term appears as not significant. In order to confirm that only adopters without problems have a non linear significant impact on the household's adoption decisions, the specifications in columns 5 and 6 only include the proportion of adopters that reported problems using the new stove "$P2_j$". We can see in these columns that the effect of this proportion on the likelihood of adoption is not significant[23]. The specifications in columns 7 and 8 include the linear and quadratic terms for both, the proportion of adopters with and without problems. The village informational effect is then given by:

$$(8)\ I_j(AP_j, SC_j) = \lambda_1 P1_j + \lambda_2 P1_j^2 + \lambda_3 SC_j + \lambda_4 P2_j + \lambda_5 P2_j^2$$

The results in columns 7 and 8 corroborate that only users without problems have a significant non linear effect on the household's likelihood of adoption; while the impact of the proportion of adopters with problems is not significant[24]. Note also that the coefficients for the proportion of successful adopters in columns 7 and 8 are very similar to those in columns 3 and 4. As the monitoring visits were performed at early stages of adoption, it is very likely that the nonlinear effect of the proportion of adopters without problems on the individual adoption decisions, reflects the presence of strategic behaviour: the higher the proportion of beneficiary adopters without problems in the

[23] I have also estimated the specification in column III including the proportion of stove beneficiaries that report higher firewood consumption and also including the proportion of beneficiaries that report materials problems (without differencing between users and non users). The effect of beneficiaries that report higher consumption of firewood appears negative but not significant; the effect of beneficiaries with materials problems appears negative and also not significant.

[24] I have also estimated a regression where the effect of the total proportion of adopters with problems is considered to be only linear, the coefficient for the linear term in this case is also non significant.

village the more likely is the household to delay adoption and free ride on others experimentation. Note also that in all the specifications in table VII the term measuring bonding social capital appears as not significant. This particular result is in my opinion in line with this paper's main hypothesis: what type of effect social capital will have on the household's adoption decision should be closely linked to the village initial adoption patterns. Also, if information diffusion is the process behind the strong correlations we observe in table VII, we should expect these effects to be stronger in villages with stronger bonding links. In order to capture the heterogeneous effect of village adoption and village bonding social capital on the household's likelihood of adoption, it is then important to allow the marginal impact of social capital to depend on village patterns of adoption and vice versa. All the specifications in table VIII account for this and introduce for an interaction term between the village pattern of adoption and the village bonding social capital measure (the village level of trust in local neighbours). As it was the case for the specifications in table VII, the odd columns in table VIII control for the village pattern of adoption, bonding social capital and the proportion of beneficiaries; while the even columns also control for village altitude, road access and village trust in strangers. The specifications in columns 1 and 2 of table VIII define the informational effect in (5) as a function of the total proportion of adopters "TP_j" and include an interaction term between this proportion of adopters and the village bonding social capital indicator, that is:

$$(9)\quad I_j(AP_j, SC_j) = \lambda_1 TP_j + \lambda_2 TP_j^2 + \lambda_3 TP_j * SC_j + \lambda_4 SC_j$$

As it can be observed in columns 1 and 2 of table VIII, as expected the coefficient for the interaction term between the total proportion of adopters and the social capital indicator is positive but not significant; moreover the coefficient for the linear bonding social capital term appears also as not significant in both specifications. As discussed before, not all stove adopters are likely to influence individual adoption decisions in the same manner; and the type of information that different adopters transmit will flow through the network in different ways. As the specifications in columns 1 and 2 do not distinguish between adopters with or without problems, it should not be a surprise that the interaction term and the linear social capital term appear as not significant in these regressions.

Table VIII – Village level determinants of the household's likelihood of improved stove adoption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Village total proportion of adopters	**0.0203*** **	**0.0225 *** **						
	(0.0069)	(0.0078)						
Village total proportion of adopters^2	**-0.0003*** **	**-0.0005*** **						
	(0.0001)	(0.0002)						
Village total proportion of adopters * Village level of trust in neighbours	0.0045	0.0092						
	(0.0044)	(0.0057)						
Village proportion of adopters without problems			**0.0121***	0.0062			**0.0191*** **	**0.0145***
			(0.0062)	(0.0081)			(0.0065)	(0.0078)
Village proportion of adopters without problems^2			**-0.0002*** **	**-0.0004*** **			**-0.0004*** **	**-0.0005*** **
			(0.0001)	(0.0001)			(0.0001)	(0.0002)
Village proportion of adopters without problems * Village level of trust in neighbours			**0.0056** **	**0.0102*** **			0.0025	0.0053
			(0.0026)	(0.0034)			(0.0035)	(0.0038)
Village proportion of adopters with problems					**0.0215** **	**0.0284*** **	0.0098	0.0177
					(0.0086)	(0.0090)	(0.0113)	(0.0145)
Village proportion of adopters with problems^2					0.0002	**0.0005***	0.0004	**0.0006***
					(0.0004)	(0.0003)	(0.0003)	(0.0003)
Village proportion of adopters with problems *Village level of trust in neighbours					**-0.0220** **	**-0.0277*** **	**-0.0238** **	**-0.0330*** **
					(0.0078)	(0.0069)	(0.0094)	(0.0126)
Village level of trust in local neighbours (bonding social capital)	-0.2561	-0.4867	**-0.2867** **	**-0.4882** **	**0.1989** **	**0.2550** **	0.0438	0.0188
	(0.2134)	(0.3094)	(0.1285)	(0.1997)	(0.0950)	(0.1024)	(0.2136)	(0.2566)
Village proportion of beneficiaries	**0.0052*** **	**0.0064*** **	**0.0048** **	**0.0082*** **	0.0019	0.0002	**0.0056** **	**0.0087** **
	(0.0016)	(0.0021)	(0.0019)	(0.0019)	(0.0022)	(0.0021)	(0.0024)	(0.0033)
Village level of trust in strangers (bridging social capital)		0.0669		0.0556		-0.1695		0.0823
		(0.2148)		(0.1518)		(0.1304)		(0.1637)
Village Altitude		**-0.0378** **		**-0.0613*** **		**-0.0396** **		**-0.0645** **
		(0.0142)		(0.0219)		(0.0164)		(0.0305)
Village Road Access		**0.1775** **		**0.1801** **		**0.1613*** **		**0.2231** **
		(0.0811)		(0.0701)		(0.0418)		(0.0878)
N	283	283	283	283	283	283	283	283
Villages	24	24	24	24	24	24	24	24
R2	0.21	0.24	0.21	0.24	0.20	0.23	0.23	0.26

All regressions in this table control for watershed dummies and include as household level controls the household's head sex and age, household's head level of education, household's number of adults, presence of a female adult member in the household, household's wealth (measured by the value of farm assets), farm size, household's participation in women and environmental organizations, household elaboration of processed products and usage of fertilizer and household participation in local activities in the previous 12 months. As it is standard ***, ** and * indicate statistical significance at the 1%, 5% and 10% significance levels.

The specifications in columns 3 and 4 of table VIII only include in the village informational term the proportion of "successful" adopters instead of the total proportion of adopters in the village, and also add an interaction term between this proportion and the bonding social capital indicator. The village information term in equation (5) is then defined as:

$$(10)\quad I_j(AP_j, SC_j) = \lambda_1 P1_j + \lambda_2 P1_j^2 + \lambda_3 P1_j * SC_j + \lambda_4 SC_j$$

The results in these columns show that the interaction term between the proportion of adopters without problems and the bonding social capital indicator is positive as expected and more importantly that it is statistically significant at the 5% and 1% significance level respectively. These results confirm the important role the proportion of village successful adopters has played in influencing household's adoption decisions and suggest that the marginal impact of this type of adopters will be higher in villages with strong bonding links, probably because the type of information this adopters provide will be diffused with more intensity in this type of rural communities. For example, the results in column 3 evaluated at the sample means imply that the marginal effect of the proportion of adopters without problems on the likelihood of adoption is close to 0.2%; while if we evaluate this effect at the observed maximum level of bonding social capital it will be equal to 0.6%. Note also that the results in columns 3 and 4 show that the coefficient for the linear bonding social capital term is negative and significant. This last result together with the positive sign for the interaction term implies that the marginal effect of bonding links is increasing in village initial success in adoption; however this marginal effect will be positive only if the village proportion of adopters without problems is above 51%.

To confirm that only "successful" adopters positively influence the household's adoption decision through its interaction term with the bonding social capital variable, the specifications in columns 5 and 6 only include the village proportion of adopters with problems as well as an interaction term between this variable and the social capital indicator. As we observed in table VII, the proportion of adopters with problems did not have a significant impact on the household's adoption decision; interestingly, the results in table VIII now indicate that the interaction term between the proportion of adopters

with problems and the bonding social capital indicator is negative and statistically significant. The results in columns 5 and 6 suggest that the proportion of users with problems is more likely to negatively influence the decisions to adopt the stove in those villages with strong bonding links. Note also that in this specification the coefficient for the linear bonding social capital term is positive, which together with the negative sign for the interaction term suggests that the marginal impact of bonding social capital on the likelihood of adoption is decreasing in the proportion of adopters with problems. For this specific case, if the proportion of adopters with problems is approximately higher than 10%, the marginal impact of bonding social capital on the household's adoption decision is more likely to be negative.

So far the results in table VIII provide a strong support for the information diffusion/social learning hypothesis[25], social effects are increasing in the strength of bonding links and more interestingly, the network appears to diffuse the adoption information in the right direction: adoption without problems encourages adoption decisions through its network effect (the interaction term between this type of adoption and bonding social capital) and adoption with problems appears to do exactly the opposite[26]. Finally, as we also did in table VII, in columns 7 and 8 of table VIII both proportions are included as well their respective interaction terms with the bonding social capital variable. The informational term is then defined as:

$$(11)\quad I_j(AP_j, SC_j) = \lambda_1 P1_j + \lambda_2 P1_j^2 + \lambda_3 P1_j * SC_j + \lambda_4 P2_j + \lambda_5 P2_j^2 + \lambda_6 P2_j * SC + \lambda_7 SC_j$$

The results in columns 7 and 8 confirm that only the proportion of adopters without problems positively influences the household's likelihood of adoption through its network effect; however the interaction term between this proportion and the bonding

[25] I have also estimated the regressions in table VIII using the village trust in local based organizations and the village index of communication as indicators of bonding social capital, the results are very similar.

[26] I have also allowed for an interaction term between the bridging social capital indicator (trust in strangers) and the village improved stove adoption patterns. The coefficient for the interaction between the bridging social capital indicator and the proportion of successful adopters has a negative sign, indicating that village social effects are weaker in villages with stronger bridging links; however, the coefficient is not significant once we control for the interaction term between the bonding social capital indicator and the proportion of adopters without problems.

social capital measure although still positive, appears as not significant. In the other hand, columns 7 and 8 show that proportion of adopters with problems appears to negatively and significantly affect individual adoption mainly through its interaction with bonding social capital. Note that when both interaction terms are added in the regression, the bonding social capital term "*per se*" appears as not significant and very small in absolute size. This specific result supports the hypothesis that the effect bonding social capital has on individual adoption is closely linked to initial village stove performance[27]. It is important to mention as well that the results in table VIII indicate that the absolute size of the coefficient for the interaction term is much higher for the case of the proportion of adopters with problems. This specific result suggests that bad news about a new technology tend to have a higher network impact on adoption decisions than good news, especially in villages with strong bonding links.

In my opinion, the results in this section strongly support the social learning hypothesis and the significant role social capital has played in the diffusion of information related to stove usage and performance. Although I have not yet commented on the main identification issues that may be present in this study, the fact that social effects are heterogeneous in social capital and that the marginal effect of this variable is closely linked to village adoption patterns, provides important evidence towards social learning as the relevant process behind the observed data patterns. Also the fact that social capital was measured before the intervention implies that the social capital indicators are not influenced by the improved stove adoption process; then, our estimates should be free from endogeneity problems due to reverse causality between social capital and households' adoption decisions. In order to provide stronger support for the social learning hypothesis, section 6 will show that the information diffusion hypothesis also applies to the decision to uninstall the stove among beneficiary non users. Before doing that, in the next section I will briefly comment the results on the main household factors that influence the household's likelihood of adoption.

[27] Interestingly, if I exclude the linear social capital term from the regressions in columns 7 and 8, we will observe that both interaction terms have the expected signs and are statistically significant at the 5% significance level.

6.1. Household level determinants of adoption

This section focuses on the household level determinants of adoption that have been included as controls in the estimations in section 5; these are: the household's head sex and age, the household's head level of education, the household's number of adults, presence of a female adult member in the household, the household's wealth (measured by the value of farm assets), the household's farm size, the household's participation in women and environmental organizations, the household's elaboration of processed products and usage of fertilizer and the household's participation in communal activities in the previous 12 months. Table IX presents the household level coefficients that correspond to the specifications in the even columns in table VIII, where in addition to village adoption patterns and social capital, also the village proportion of beneficiaries, watershed location, altitude, road access and the level of trust in strangers were controlled for. As we can observe in table IX, the coefficients for the household level variables are relatively stable in terms of size, sign and significance level across the four specifications.

The results in table IX indicate that the household's composition has a significant impact on the likelihood of adoption. In first place, the household's number of adults has a non linear significant effect on adoption; this effect is always negative for the observed sample values and it is decreasing in absolute value in the total number of adults. A higher number of adults in the household implies that labor for firewood collection is relatively abundant, which decreases the cost of collecting firewood and then has a negative impact on adoption. A higher number of adults may also imply that a higher amount of firewood is required, which may have a positive effect on household's adoption. The results suggest that the first effect dominates the second one and also that the first effect appears to be stronger when the number of adults is relatively low, which may indicate decreasing returns to labor in firewood collection activities. Columns 2, 3 and 4 show that the number of adult members is not the only household composition factor that significantly influences the likelihood of technology adoption; as we can see, households in which at least one adult woman is present are 15% to 18% more likely to adopt the new stove. These results are in line with the fact that women are the main expected beneficiaries of the new stove, as in many cases they are the ones in charge of

firewood collection, food preparation and usually spend a higher amount of time inside the dwelling place, benefiting significantly from reductions in indoor pollution. Another plausible explanation for this result is that women may assign a higher weight on children and elderly members health outcomes; then they may be more likely to use the stove as a way to reduce the incidence of respiratory illnesses in these groups of family members.

TABLE IX - Household level factors affecting the household's likelihood of improved stove adoption

	(2)	(4)	(6)	(8)
Household's head sex	-0.062	-0.021	-0.039	-0.027
	(0.074)	(0.071)	(0.077)	(0.074)
Household's head age	0.002	0.002	0.002	0.002
	(0.002)	(0.002)	(0.002)	(0.002)
Household's number of adults	**-0.132****	**-0.119****	**-0.111***	**-0.127****
	(0.056)	**(0.056)**	**(0.057)**	**(0.056)**
Household's number of adults^2	**0.013****	**0.013****	**0.012***	**0.012****
	(0.006)	**(0.006)**	**(0.006)**	**(0.005)**
Adult female member present in the household (yes=1)	0.127	**0.153***	**0.182***	**0.169***
	(0.078)	**(0.085)**	**(0.092)**	**(0.086)**
Household's head has formal education at the maximum level of primary school (yes=1)	0.003	0.039	0.070	-0.013
	(0.122)	(0.122)	(0.115)	(0.128)
Household's head has formal education at the level of secondary school or higher (yes=1)	0.069	0.094	0.120	0.074
	(0.139)	(0.141)	(0.129)	(0.159)
Household's members participated as organizers or supporters in local activities in the past 12 months (yes=1)	**0.138****	**0.131****	**0.147****	**0.135****
	(0.055)	**(0.049)**	**(0.052)**	**(0.051)**
Household's value of farm assets in Peruvian Soles	**0.006*****	**0.006*****	**0.006*****	**0.005*****
	(0.002)	**(0.002)**	**(0.002)**	**(0.002)**
Household belongs to a local environmental group (yes=1)	-0.011	-0.033	-0.045	-0.034
	(0.081)	(0.076)	(0.069)	(0.077)
Household belongs to a local women based organization (yes=1)	-0.018	-0.022	-0.005	0.033
	(0.066)	(0.065)	(0.064)	(0.071)
Household uses fertilizer (yes=1)	-0.038	-0.057	-0.058	-0.053
	(0.062)	(0.062)	(0.061)	(0.061)
Household elaborates processed products (yes=1)	0.051	0.025	0.042	0.058
	(0.062)	(0.058)	(0.057)	(0.059)
Household's farm size	0.010	0.006	0.008	0.010
	(0.011)	(0.011)	(0.011)	(0.012)
N	283	283	283	283
Villages	24	24	24	24
R2	0.24	0.24	0.23	0.26

As it is standard ***, ** and * indicate statistical significance at the 1%, 5% and 10% significance levels.

The results in table IX also indicate that wealthier households are significantly more likely to adopt the improved stove; a wealth increase of 10.00 "nuevos soles" (approx. CAN$ 4.00) increases the likelihood of adoption by approximately 0.6%. This result may indicate that richer households are more likely to bear the costs of technology adoption. For example they are more likely to afford the higher amounts of firewood consumption that may be incurred during initial trials with the new technology. The results also indicate that households that reported being involved in local activities in the 12 months previous to the survey (either as organizers or supporters) are approximately 15% more likely to adopt the improved stove than household that did not participate. Probably this group of households has been more likely to participate in development projects in the past and by so are more proactive and open to new technologies. It can also be the case that, as these households are more likely to participate in the communal social live, they are also more likely to be exposed to information regarding the use of the new device. The results in table XI indicate that household's previous experience in fertilizer usage or in the elaboration of processed products does not have a significant impact on the likelihood of adoption. Also note that the coefficient sign for the dummy variable that takes the value of one if the household has secondary education or higher is positive in all columns but it is not statistically significant. Finally whether the household belongs or not to an environmental organization or to a women club does not seem not to significantly influence the likelihood of adoption.

7. The Decision to uninstall the improved stove among beneficiary non users

In section 5 it was shown that the proportion of beneficiary households that adopted the improved stove without problems has a positive effect on the household's likelihood of adoption through its interaction with village bonding social capital; while the opposite was true for households facing problems with the new efficient firewood technology. In order to provide stronger empirical evidence towards the information diffusion hypothesis, this section focuses just on non users beneficiaries (beneficiary households that by the time of the monitoring visits reported not using the stove), and analyzes among this specific group, how village patterns of adoption and bonding social capital affect the decision to uninstall the new cooking device; which can be interpreted as a

decision to abandon any present or future attempt to adopt the new technology. If the village proportion of adopters without problems is relatively high and bonding social links are strong, non users may reasonably expect to be able to adopt the stove at some point in time (e.g. they may expect to be able to learn from others), which decreases the likelihood of uninstalling the new device. On the other hand if good information on stove usage does not diffuse in the village due to weak bonding links or if the proportion of adopters with problems is high and this information expands through a strong social network, then it is very likely that a non user will decide to abandon the new technology. In the light of the findings in the previous sections, it is then expected for a higher proportion of adopters without problems to have a negative impact on the decision to uninstall the stove and for a higher proportion of adopters with problems to encourage the uninstalling decision. We also expect that these effects will be increasing in village bonding social capital.

The specifications in table X use the linear probability model with clustered standard errors at the village level to estimate the likelihood of uninstalling the improved stove among beneficiary non users[28]. The regressions in table X include in the village informational term a linear term for village adoption patterns and an interaction term between village adoption patterns and the village bonding social capital indicator (as before trust in local neighbours)[29]. The estimations in table X also control for the same household characteristics included in table IX, the village proportion of beneficiaries and dummy variables for village watershed location. The specification that corresponds to the first column of table X defines the informational effect as a function of the total proportion of stove users, bonding social capital and the interaction term between these variables. As we can see in column 1, the effect of the total proportion of adopters on the uninstalling decision is statistically not significant. Neither the total proportion of adopters' linear term nor its interaction with bonding social capital appears to significantly influence the non user's uninstalling decision. These results should not

[28] Only beneficiary non users that installed their improved stove are considered in the estimations.

[29] As it was the case in table VII, I initially estimate the regressions in table X without considering an interaction term between social capital and village adoption in the village informational term. In either case, when I only considered a linear term for village adoption or when a quadratic term for village adoption was also estimated, the coefficients for village adoption appeared as not significant.

surprise us; as we discussed before, not all adopters influence household decisions in the same way.

Table X – Village factors affecting the household's likelihood of uninstalling the improved stove

	(1)	(2)	(3)
Village total proportion of adopters	0.0856		
	(0.0126)		
Village total proportion of adopters * Village level of trust in local neighbours	-0.0091		
	(0.0085)		
Village proportion of adopters without problems		0.0143	
		(0.0095)	
Village proportion of adopters without problems * Village level of trust in local neighbours		**-0.0134****	
		(0.0061)	
Village proportion of adopters with problems			**-0.0403***
			(0.0196)
Village proportion of adopters with problems *Village level of trust in local neighbours			**0.0331****
			(0.0128)
Level of trust in local neighbours (bonding social capital)	0.4001	0.4367	**-0.3880***
	(0.4488)	(0.3120)	(0.1999)
N	102	102	102
Villages	23	23	23
R2	0.29	0.32	0.32

Only beneficiary non users that installed their improved stove are considered in the estimations. All columns in table X control for the same household level controls as tables VII and VIII, watershed location as well as for the proportion of village beneficiaries. ***, ** and * indicate statistical significance at the 1%, 5% and 10% significance levels.

In column 2 the estimated regression includes the proportion of adopters without problems instead of the total proportion of adopters. As we can observe, the coefficient for the interaction term between the proportion of adopters without problems and village social capital is negative and significant at the 5% significance level. Note that in this case, the linear term for the proportion of adopters without problems appears as not significant. This result tells us that in the case of total absence of bonding links, the proportion of successful adopters will not have any impact on the household's decision to uninstall the new technology. In order to confirm that only adopters without problems have a negative significant impact on the decision to uninstall the improved stove through its interaction with village bonding links, the specification in column 3 only includes in the regression the proportion of adopters with problems. As expected, in this case the interaction term is positive and significant; the proportion of adopters with problems is more likely to encourage the uninstalling decision in villages with strong levels of bonding social capital. Also note that in column 3 the coefficient for the social capital

linear term is negative and significant at the 10% significance level. This means that the marginal impact of social capital on the decision to uninstall the stove will be positive (encourage the uninstalling decision) only if the proportion of adopters with problems is relatively high[30] (above 12%).

The results for the impact of adoption patterns and bonding social capital on the non user's decision to uninstall the improved stove are in line with what our information diffusion/social learning hypothesis proposes. Beneficiary non users are less likely to uninstall their stoves (abandon the technology) in villages where success in adoption is relatively high; the network effect, as before, has a multiplier effect on the impact of other decisions on the household's likelihood of uninstalling the new stove technology.

8. Relevant Identification Issues

In empirical studies that focus on the effects of social capital, the problem of reverse causality between the variable of interest and the social capital variable is very likely to be present. For example, in studies that try to relate economic performance to social capital at the village level, it is not only the case that social capital affects economic performance, but also that good economic performance may allow building better social capital (Narayan et al. 1998). In the context of technology adoption in rural communities, it can be the case that households that decide to adopt a new technology are more likely to invest in their social relationships, affecting in this way the level of village links. However, in my opinion the estimated regressions in this paper are not likely to suffer from this problem, as the household survey measuring social capital was carried prior to stove distribution and almost one year before the monitoring survey. In other words, the estimated measures of social capital are not likely to have been drastically influenced by this specific program intervention or by the nature of the adoption process in each village.

[30] The results in table X also hold when we separately introduce as additional controls village altitude, village road accessibility and village trust in strangers. When these three controls are introduced at the same time, significance is lost for the interaction term between social capital and the village proportion of adopters without problems in column 2. This lost in significance may be related to the fact that the village proportion of users without problems is strongly correlated with village road access and altitude; then in my opinion 102 observations may not be a big enough sample to identify the effects of these variables when included simultaneously in the uninstalling decision regression.

In the context of the present study, serious identification issues will also arise if villages with higher proportions of stove adopters were more likely to be visited by NGO members during the monitoring process and if within villages households using the improved stove were more likely to be interviewed (or probably those not using the improved stove may have systematically refused to be interviewed). As it was commented in section 3.2, visits to all the beneficiary villages were initially planned and the order of visits was not done as a function of the expected number of working stoves. In fact, strong emphasis was set in visiting villages in high altitudes, where one should expect rates of adoption to be significantly lower. Note that on average 82% of the beneficiaries per village were visited and that from information provided by MIRHASPERU and Universidad de Piura members it is known that the improved stove monitoring team did not report any situation where beneficiary households refused to be interviewed[31].

In studies on social interactions, one of the main issues in terms of identifying the effect of group level decisions on individual decisions (also called endogenous effects) has to do with the presence of the reflection problem (Manski 1993). As it was originally defined, the reflection problem is an issue of collinearity. In Manski seminal paper, endogenous effects are not identified because they are a linear combination of exogenous and correlated effects. However, as Brock and Durlauf (2000) clearly explain, non identification in social effects models is intrinsically linked to linearity; for the case of non linear social effects (as it is the case in the present paper), and under correct model specification, social effects are generally identified[32].

As it was mentioned earlier in the introduction to this paper, the presence of village unobservables is probably the most important issue in terms of identifying the presence of social learning during the process of improved stove adoption in the villages of Chalaco

[31] During summer 2008, I carried fieldwork in the area of intervention in order to study the current situation of improved stove usage, from 433 households visited only one household refused to be interviewed.

[32] For a detailed explanation on this issue please refer to Durlauf, Steven and Brock, William (2000). "Interaction Based Models", Handbook of Econometrics 5, James H. Heckman and Edward Leamer, eds., pages 44 to 45.

District. Households' stove adoption decisions within the village may be correlated not because a social learning process is present but because villagers share common unobservable characteristics or are subject to the same type of village shocks and environments. Although it may not be possible to address all possible alternative hypothesis, in my opinion the present paper provides solid evidence in order to support the information hypothesis as the generating process behind the strong observed correlation between household adoption and village adoption. In first place it was shown that not all adopters influence adoption decisions in the same manner and most importantly it was also shown that social effects are heterogeneous in village bonding social capital. This last result is in line with what we should expect from a social learning process: it must be stronger in villages with stronger bonding links. Interestingly when only the total proportion of adopters was included in the village informational effect, no multiplier effect for social capital was found (the interaction term appeared as not significant); the multiplier effect of social capital was only significant when we distinguished between adoption with and without problems. As expected the interaction term for the proportion of successful adopters and bonding social capital has a positive significant impact on adoption while the interaction term for the proportion of adopters with problems and bonding social capital has a negative impact.

Another important result that in my opinion supports the social learning hypothesis as the driving process in the data is that the bonding social capital's marginal impact on individual adoption was shown to be closely linked to village initial adoption performance; bonding social capital only appears to have a positive impact on adoption if village success in adoption is relatively high. This finding suggests that the role of social capital in the context of this study is precisely to diffuse information: if adoption success in the village is relatively low, the network may diffuse the information that the new technology is not a good one, which negatively affects adoption of the technology. The results obtained in section 5 are robust to different measures of bonding social capital and remained significant when key geographical factors influencing stove performance and NGO effort such as village altitude or village road accessibility were controlled for.

As a final step in the direction to show that the observed results are not likely to be caused by some confounding village factor potentially correlated to household adoption, village adoption and the bonding social capital variable, this paper also extended the social learning hypothesis to other type of decisions by the beneficiary households. More precisely in section 6 it was shown that social capital has also a multiplier effect on the decision to uninstall the improved stove among beneficiary non users. The results in that section indicated that the interaction term between social capital and successful adoption (adoption without problems) has a negative effect on the uninstalling decision while the reverse is true for adoption with problems. Up to this point in the present research, I think than no other village process or alternative story is likely to generate the type of complex patterns we have consistently identified in the improved stove adoption data[33].

9. Concluding Remarks

This paper studied how the household's decision to adopt a new firewood stove technology is influenced by others households' adoption in the village and by the strength of bonding communal links. The main result in this study shows that the impact of others decisions on the individual household's decision to adopt tends to be higher in villages with stronger bonding links. It is also shown that only village adopters without problems have a positive effect on the household's likelihood of adoption through its interaction with village bonding social capital, while the reverse is true for adopters with problems. Note that when we considered the total proportion of adopters as an indicator of village adoption patterns, the network effect captured by the interaction between social capital and this variable, appeared as not significant. Moreover, our results also suggest that the marginal impact of bonding social capital on the likelihood of adoption is linked to village initial performance in stove usage: if the village's proportion of adopters without problems is relatively low or if the proportion of adopters with problems is relatively high, the marginal impact of the bonding social capital variable is more likely to be negative. In

[33] I have also estimated the main regressions including the proportion of village households participating in environmental organizations and women based organizations, no change in the main results was observed. The main regressions were also estimated including a dummy variable taking the value of one if the household "self reported" most influential village member was using the stove without any problem, the coefficient for this variable was not significant in the regressions and not significant change in the results was observed.

other words, if the new technology on average does not performs well, the network is more likely to transmit "negative" (and probably the right) information on the new cooking device. In order to argue that unobservable factors are not likely to drive the observed data patterns, this paper pushed the information hypothesis harder and related village adoption and bonding social capital to the decision to uninstall the improved stove among beneficiary non users. The results pointed in the expected direction: adoption without problems has a negative impact on the likelihood to uninstall the stove mainly through its interaction with social capital, while village adoption with problems encourages it. These results constitute strong evidence towards the information diffusion hypothesis. Also, the fact that the social capital measures employed in the main regressions were obtained prior to the improved stove intervention guarantees that the reverse causality problem between adoption decisions and social capital is not present in our estimations.

The main findings in this study suggest that the nature and extent of communal social relationships play an important role determining the impact of peer effects on rural households' technology adoption decisions. The results in the present research have important policy implications for development programs related to the introduction of new technologies in rural areas of developing countries. The first important implication that can be derived from this paper is that technology diffusion programs that rely on informational spillovers during early adoption stages must first obtain a clear understanding of the nature of communal social relationships; we should not expect to see a strong multiplier effect of village adoption on individual household adoption if village bonding links are extremely weak. Having said this, it is also important to note that "creating" social capital is not an easy task; neither is to decide the optimal levels of bonding and bridging links that are appropriate to promote economic development.

The second relevant implication in this paper is related to the fact that in the context of development programs introducing new technologies in rural communities it is crucial to properly and constantly monitor the adoption process by beneficiaries. A low initial level of success in adoption or a poor initial performance of the technology may lead to the

complete rejection of the technology by the beneficiaries. This process of technology abandonment may be stronger if bonding social capital in the community is relatively high; in such circumstances the social network is likely to intensively disseminate negative information regarding the new technology. Interestingly, our results also suggest that rural households tend to react to bad news more drastically than they react to good news about a new technology.

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Figure 1: improved firewood stove original design

source: MIRHASPERU

Figure 2: traditional firewood cooking technology

Source MIRHAPSERU

Figure 3: improved firewood stove observed in the summer 2008