The theoretical and empirical analysis on the compatibility of sustainable development strategies and poverty reduction policies at micro level

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June 2010

Abstract: This paper is devoted to analyze the poverty-environment nexus from micro perspective. The aim of this paper is to provide answers for the question of how to achieve the compatibility between sustainable development strategies and poverty reduction policies at micro level. A farm household consumption-production model is proposed to provide a broader understanding of the links between energy use, environment and poverty. I conclude that there are four channels through which poverty reduction can be compatible with environmental protection at household level.

Key words: poverty, environment, energy, health

1. Introduction

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Based on the assumption of vicious circle between poverty and environment, the most famous concept of sustainable development, which is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, was officially posed in Brundtland report. After that various aspects of sustainable development have gained increasing attention of the international development agencies and have been widely discussed in global conferences. However, the environmental sustainability is a key dimension of sustainable development (Jehan and Umana, 2003). In response to the sustainable development strategies a series of eight goals known as Millennium Development Goals (MDGs) were declared by UN member states in 2000. Ultimately, MDGs regard poverty reduction as its central goal. Both the sustainable development strategies and MDGs recognize that poverty reduction and environmental protection mutually reinforce and highlight that they are complementary goals. The environmental sustainability cannot be achieved without addressing poverty; similarly, the sustainable poverty reduction requires the environmental sustainability. In this sense, it is necessary to integrate the sustainable development strategies into poverty reduction policies.

Yet it remains a challenge as there is no consensus on the poverty-environment nexus. The relationships between poverty and the environment have been widely debated by researchers.

The dominant school of thought characterizes the linkages between poverty and environment as “downward spiral” or “vicious circle”. “Poor people are forced to overuse environmental resources to survive from day to day, and the impoverishment of their environment further impoverishes them, making their survival even more difficult and uncertain” (Brundtland report, 1987). On the one hand, the poor have high risk aversion. The later implies that the poor prefer to satisfy their needs (income or consumption) as soon as possible (Mink, 1993) as today’s survival is much more important than tomorrow’s for the poor. Thus the poor make tradeoff between present needs and future needs, and even have to meet the former at the expense of the latter (Osei-Hwedie, 1995). In this sense, poor people extract natural resources at a much more rapid rate regardless of conservation in natural resources and sustainable use of resources and subsequently this lead to the depletion of natural resources and the environmental degradation. On the other hand, the environmental degradation in turn adversely affects the poor from three aspects including livelihood, health and vulnerability. The environmental degradation lowers the productivity of natural resources upon which the livelihood of the poor depends directly. The ill health resulting from environmental pollution in turn lowers the labor productivity of the poor. Natural disasters and climatic change resulting from the environmental degradation make the poor to be more risk-adverse and vulnerable. Through all the three channels, the environmental degradation further reduces the income of the poor and subsequently forces the poor to extract natural resources. So, the “vicious circle” is formed. This “vicious circle” relationship between poverty and the environment implies that poverty is simultaneously a main reason and a result of the environmental degradation.
However, this simple direct causal relationship between poverty and the environment has been largely criticized by researchers from different angles. In general, the main arguments constitute the extensive debate are fourfold.

First, the view of poverty being the main direct reason of the environmental degradation is apparently untenable. Khan (2008) and Markandya (1998) argued that the viewpoint on environmental degradation resulting mainly from poverty has not been widely proved by empirical evidence. Some authors argued that the poor are willing to protect rather than destroy the environment upon which their livelihood closely depends (Moseley, 2001; Scherr, 2000; Duraiappah, 1998). Some authors pointed out that the rich have major responsibility to improve the environmental quality (Duraiappah, 1998; Myers, 1997).

Second, poverty and the environment are indirectly connected by a very complex web of macro-level factors and these factors interact with each other. These macro-level factors are main drivers of economic growth including pattern of economic growth, trade, population, technology and institution, as the environment is related to poverty through economic growth at macro level. The role of these factors, especially the role of pattern of growth, trade and population, in the poverty-environment nexus remains controversy. In addition, using one factor without combining with other factors to explicate the poverty-environment nexus will bias this nexus.

Concerning the poverty-environment nexus mediated by the pattern of economic growth, the debate focuses on whether the economic growth in the pattern of Environmental Kuznets Curve is sustainable? The so-called Environmental Kuznets Curve (EKC) hypothesis postulates that the long term relationship between environmental quality and economic growth is inverted-U shaped, and this means that the environmental quality worsens initially but improves later with economic growth after beyond a turning point. At the early stage of development, income is regarded as top-priority well-being and economic growth is considered as top-priority policy and subsequently economic growth and the environment are made tradeoff, in other words, economic growth is at the expense of environmental degradation. However, once economy grows to certain degree, the economic growth becomes compatible with the improvement of environmental quality as both supply and demand conditions that are main drivers for enhancing environmental protection are satisfied. In this sense, the economic growth in the pattern of Environmental Kuznets Curve is sustainable and therefore contributes to sustainable poverty reduction. Many scholars, however, have queried the capacity of the EKC to describe a sustainable growth path. The environmental degradation at the early stage of development may violate the ecological threshold and generate the irreversible damages (Arrow et al., 1995; Khan, 2008; Dinda, 2004), and therefore, undermine long-term economic growth and sustainable poverty reduction. Jalal (1993) argued that the development process without integrating environmental problem into economic growth cannot succeed in helping improvement of the environmental quality and poverty reduction. Torras and Boyce (1998) also supported the idea that the improvement of environmental quality cannot go on with the further economic growth in the rich countries.
With respect to the role of trade in the poverty-environment nexus, the debate is lively over the potential impact of trade on the environmental quality as it is theoretically ambiguous (Frankel and Rose, 2005). The environmental regulations as a source of comparative advantage play an important role in explicating the trade between developed and developing countries. The popular argument advocated by the trade supporters is that economic growth resulting from international trade will translate into a higher income level and this reinforces the consumers’ capability and increases their willing for paying cleaner environment (Kellenberg, 2008). Following this demand for environmental quality the government will implement the stricter environmental standard along with the increasing income. This is the so called income effect. Another argument is that the international trade can contribute to diffuse the environmentally friendly technologies from developed countries to developing countries (Common and Stagl, 2005) and subsequently is favorable for the environmental quality. In contrast, the trade opponents consider that the income effect is risky to occur as the long run income will decline in the case of depletion of natural capital caused by exportation of pollution-intensity goods or resource goods. In turn, these income losses will lead to further environmental degradation. Moreover, they consider that trade causes both pollution haven effect and pollution haven hypothesis (López and Toman, 2006; Liddle, 2001; Copeland and Taylor, 2004) as the developed countries with strong stringent environmental regulation specialize in clean sectors while the developing countries with weak stringent environmental regulation specialize in dirty sectors. In this sense, the sustainable economic growth in developed countries is at expense of the unsustainable economic growth in developing countries.

With regard to the poverty-environment nexus governed by population factor, the main issue contestable is whether population growth necessarily leads to the environmental degradation. Some authors support that population growth adversely affects the environmental quality because of unsustainable demand for natural resources and increased pollution (Rogers et al., 2008; Khan et al., 2009). In contrary, the other authors consider that population factor do not inevitably lead to the environmental degradation and even population growth is compatible with sustainable management of natural resources (Basili et al., 2006; Jehan and Umana, 2003).

Third, we cannot simply conclude and generalize one poverty-environment nexus for all the instances. That is because the analysis on the poverty-environment nexus should base on a certain specific natural resource (Duraiappah, 1996), what poverty is defined and the specific region context. Therefore, there are diverse patterns of the poverty-environment nexus. It implies that there are not common patterns of depending on natural resources and of being hurt by the environmental degradation for the poor in different regions (Bucknall et al., 2000). Duraiappah (1996) indicated that the poverty-environment nexus in one natural resource can generate feedback effects in another natural resource sector. Reardon and Vosti (1995) also argued that one should analyze the poverty-environment nexus through distinguishing different environmental problems. Reardon and Vosti (1995) defined poverty as “investment poverty” which is “the ability to make minimum investments in resource improvements to maintain or enhance the quantity and quality of the resource base, to
forestall or reverse resource degradation.”. In this case, the level of poverty, distinguished by welfare or investment poverty, and the type of poverty, differentiated according to the asset category, determine the productive activities and the investment decisions of a household and subsequently affect the relationship between poverty and environment as these activities and decisions affect the environment quality. Moreover, Reardon and Vosti (1995) pointed out that the poverty-environment nexus is conditioned by a set of micro-level factors, such as, markets, prices, local infrastructure, community wealth, as the behavior of the poor is affected by the later.

Finally, the conventional vicious circle ignores the dynamic perspective between poverty and the environment. Reardon and Vosti (1995) pointed out the linkages between poverty and the environment change over time and even the causal relationship between them may reverse. Bretschger and Smulders (2007) provided three reasons for explicating the dynamic perspective of the poverty-environment nexus. At first, certain natural resources have regeneration capability in a dynamic process. Then, the behavior of natural resource users also change over time under some conditions. In addition, the macroeconomic, which is the context that affects poverty-environment nexus, is dynamic.

From the grand debate above on the poverty-environment nexus, three lessons can be concluded. First, Comprehensive understanding the poverty-environment nexus has extremely important policy meanings in the purpose of win-win outcome. Without accurate and full information, implementing policies may generate contradictory effect (Agudelo et al., 2003). The traditional standpoint on a simple direct poverty-environment nexus will make policies to reduce poverty at the expense of environmental degradation or to protect the environment at the expense of impoverishment (Ambler, 1999). Yet there has not been a systematical analysis for this linkage (Agudelo et al., 2003; Reardon and Vosti, 1995). Second, there are a considerable number of studies have contributed to the debate on the poverty-environment nexus at macro level. The main macro-level factors mediating this nexus have been identified. In addition, it has been a consensus that in order to achieve the win-win outcome these mediating factors should be compatible with the environment, and subsequently, the economic growth can be sustainable which contributes to sustainable poverty reduction. Third, the current researches have paid insufficient attention to the poverty-environment nexus at micro level.

In this context, this paper is expected to contribute to fill the knowledge gap in the literature by devoting to analyze the poverty-environment nexus from micro perspective. The question addressed by this paper is what are the relationships between poverty and the environment at micro level? The aim of this paper is to provide answers for the questions of how to achieve the compatibility between sustainable development strategies and poverty reduction policies at micro level, or, how to integrate environmental policies into poverty reduction policies at household level so as to guarantee the poverty reduction and the environmental protection simultaneously. It is indispensable to take a micro view of the poverty-environment linkage. The analysis at micro level can reduce the gaps between common perception and reality and therefore help policy makers to take more appropriate policies. This
type of analysis addresses a specific environmental problem, takes into account a range of micro-level factors referring to both local circumstances and household characteristics that can affect the decisions poor people make and depends on the defined dimension of poverty.

Enhancing the livelihoods of the poor, improving the health of the poor and reducing the vulnerability of the poor to environmental shocks have been widely accepted as the solutions for achieving compatibility between poverty reduction and the environmental protection at household level. Livelihood, health and vulnerability as three important dimensions of poverty are strongly affected by the environment at household level. Poor people, especially those living in rural areas of developing countries, direct use of natural resources for their livelihoods including make a living from income and subsistence activities. Local water pollution, local indoor and outdoor air pollution are all major causes of ill health of the poor. Environmental shocks, such as, floods, climate change, may make the poor and even the non poor to be vulnerable to move into poverty in the future. The local environmental problem, in turn, is influenced by the decisions in production, consumption and investment made by poor household. The importance of the linkages between livelihood, health, vulnerability and the environment are apparent in the recent research on these topics (e.g. World Bank, 2002), yet a comprehensive review of diverse theoretical literatures has been lacking. So, another contribution of this paper is to provide a critical and brief review of theoretical literature that deals with interactions between household behaviours, the environment and the household’s well-being in terms of livelihood or health or vulnerability.

Another solution for realizing the compatibility of poverty reduction and the environmental protection is access to high quality of energy use that has been recently given considerable concerns. Although a growing attention has been paid towards the role of energy in poverty and environmental problems, only limited progress has been made in supporting this viewpoint by providing theoretical models. Depending heavily on biomass fuels for cooking, heating and lighting in rural households has raised considerable concerns over environmental consequences in literatures. One thread of this literature has largely debated the contribution of firewood collection to forest degradation (e.g. Bluffstone, 1995; Dayal, 2006; Heltberg et al., 2000; Chen et al., 2006). The other issue, indoor air pollution generated by burning dirty fuels, has also received increasing attention (e.g. Chaudhuri and Pfaff, 2002; Pfaff et al., 2004). Therefore, I seek to set up a model to provide a broader understanding of the links between energy use, environment and poverty.

Based on the model, the empirical analyses intend to further study how to make poverty reduction to be compatible with environmental protection through improving the health of the poor, reducing the vulnerability of the poor to environmental shocks and accessing to sustainable energy. I will choose rural households in the China Health and Nutrition Survey (CHNS) for two waves 2004 and 2006. It is still a challenge to capture the health outcome caused by the environmental pollution. It is crucial to understand the determinants of household’ energy switching for designing appropriate policies, yet it is relatively little known about these factors (Howells et al.,
The paper is organized as follows. Section 2 provides a review of important relevant theoretical literature. Empirical studies are discussed in section 3. The model is presented in section 4. Section 5 describes the data. Section 6 is devoted to empirical analyses. It finishes with dealing with some concluding remarks.

2. Review of theoretical literature

2.1 Literatures linking poverty, livelihood and the environment

In general, the literatures modelling the interactions between household behaviours, the environment and their livelihood can be classified into two types. One type of literature pays attention to soil degradation and models the decisions on land use made by rural households (Bulte and van Soest, 1999; 2001). These literatures seek to investigate policies aimed at encouraging households to invest in soil conservation. The other type of literature emphasizes deforestation resulting from rural household behaviours. However, the causes of deforestation have been largely debated. Zwane (2007) deals with deforestation caused by land clearing decisions made by rural household for the choice of more intensive agricultural production. Some authors argue that the deforestation is resulting from common access to forests for collecting common resources for production or grazing livestock or collecting fodder (Narain et al., 2008, Dayal, 2006; Bluffstone, 1995). Furthermore, the majority of literature has paid considerable attention to forest degradation generated by firewood collection (Bluffstone, 1995; Heltberg et al., 2000; Dayal, 2006). That is because the latter has been one of the most important energy sources for the poor household in developing countries. This type of literature tries to examine the factors that can contribute to deforestation reduction.

Most of literature has referred to and extended the agricultural household model initiated by Singh et al. (1986) to capture the impact of household behaviors of consumption and production on the environment (Bulte and van Soest, 1999, 2001; Zwane, 2007, Bluffstone, 1995; Dayal, 2006; Heltberg et al., 2000).

For the problem of soil degradation, Bulte and van Soest (1999, 2001) demonstrated that with perfect markets for inputs and outputs the higher price of agricultural production will unambiguously contribute to soil conservation, while with imperfect labor market the higher price of agricultural production has both positive and negative effect on soil degradation. In the case of deforestation, caused by deriving income from forest resources, Narain et al., (2008) demonstrated that the household activities in forest collection will decline with human capital. In the case of deforestation, caused by energy use of forest resources, the availability of off-farm opportunities, especially wages income, plays an important role in encouraging household behaviors in fuel substitution and stove technology adoption and therefore reducing pressure to forest resources.
2.2 Literatures linking poverty, health and the environment

To date, the literature modelling health outcome resulting from environmental pollution is extremely rare. Concerns over the health consequences of indoor air pollution generated by use of dirty fuel are increasing. Gupta and Ko’hlìn (2006) provided a model to describe the health outcome affected by household choice of fuel with polluting characteristics.

2.3 Literatures linking poverty, vulnerability and the environment

This sub-section is devoted to provide an overview of study on vulnerability to poverty. Recent review is provided by Guimarães (2007). In general, the mainstream methods on vulnerability to poverty can be classed into two approaches: monetary approach and capability approach. The monetary approach considers vulnerability as uncertain welfare mainly in terms of income or consumption. The capability approach regards vulnerability as lack of capability to cope with environmental shocks. The monetary approach quantitatively measure the vulnerability to poverty, in contrast, the capability approach does not provide a quantitative measure to identify the vulnerable household.

In the monetary approach, there are two main methods to assess vulnerability: vulnerability as expected poverty (VEP), vulnerability as low expected utility (VEU). The VEP method is mainly proposed and developed by Chaudhuri et al. (2002), Pritchett et al. (1999, 2000), Hoddinott and Quisumbing (2008). This method defines the vulnerability to poverty as the likelihood that the welfare of individual/household will fall below the benchmark in the future. It seeks to measure the welfare consequence resulting from the shock by estimating the expected value of the poverty measure. Therefore, the vulnerability is measured by all the possible level of consumption weighted by the probability of these consumption realizations. The VEU method is provided Ligon and Schechter (2003) employing the utilitarian approach. In this method, vulnerability is measured by the difference between the utility derived from a level of certainty-equivalent consumption (a benchmark) and the expected utility of consumption.

In the capability approach, both asset-based approach and sustainable livelihood approach provide frameworks to analyze vulnerability to poverty. They focus on analyzing the households’ characteristics and the social context where they live to define vulnerability. The asset-based approach considers that vulnerability is a function of both exposure to risk and capability to cope with the risk (Alwang et al., 2001; Guimarães, 2007; Moser, 1998; Rakodi, 1999). This approach concentrates on investigating the capability of the poor to respond to shock. More important, this approach emphasizes enhancing the household asset portfolio to cope with the shock.
However, this approach has not identified which assets are more efficient for managing certain type of risk than others. In other words, it has not identified which stocks of assets make the household less vulnerable. The vulnerability to poverty in sustainable livelihood approach is considered as the probability of realizing the livelihood stress (Alwang et al., 2001). This approach highlights managing the assets for coping with the shocks and requires identifying the combinations of assets for pursuit different livelihood strategies.

Although the VEP and VEU methods can quantitatively assess the vulnerability to poverty, they are still static measures that cannot satisfy the forward-looking requirement of vulnerability. Furthermore, these two methods neglect the capability of individual or household to cope with risks. Elbers and Gunning (2003a, b) have made efforts to overcome these limitations by developing a structural and dynamic model of Ramsey type. However, the model has some weaknesses indicated by Thorbecke (2004). In addition, the measure proposed by Calvo (2008) to assess the vulnerability to multidimensional poverty provides a direction to develop method to quantitatively measure vulnerability in the capability approach.

3. Review of empirical literature

3.1 Evidence of environmental impact on health

An emerging studies show adverse health effects of indoor, outdoor air pollution as well as unsafe water. The majority of literature focuses primarily on examining the impact of air pollution on health as air pollution is still a significant health hazard worldwide today (Chen and Kan, 2008).

For the problem of indoor air pollution, studies investigate the adverse impact of use of traditional fuels causing indoor air pollution on multiple health outcome measured by diverse health indicators. The smoke from burning traditional fuels, such as, coal, wood, produces a high level of pollutant emission, for example, particulate matter (PM), carbon monoxide (CO) and nitrogen dioxide (NO2), and consequently threatens health outcome, especially including respiratory disease and pulmonary illness. However, the empirical results are mixed. Many literatures find evidence that adverse health effects are associated with exposure to indoor air pollution. Smith et al. (2000) argued that indoor air pollution caused by biomass fuels increases a risk for infections of acute lower respiratory to children. After undertaking a Chinese household survey, Sinton et al. (2004) concluded that generally use of clean fuels is consistent with reported better health outcomes and especially use of clean stove is negatively associated with both reported asthma in children and respiratory disease in adult. Peabody et al. (2005) conducted linear and logistic regression models using survey data of rural Chinese households to examine association between short-term individual health outcome and fuel types as sources of indoor air pollution. The authors showed that a range of health outcomes, such as, self-reports of health status, disease history, are associated with diverse sources of indoor air pollution including
wood and coal fuels as well as crop residues. In particular, they found that compared with other polluting fuels the use of coal fuel can cause poorer health outcomes for both adults and children. Duflo et al. (2008) used a survey data drawn from rural area in Orissa and conducted a linear probability model to find a high incidence of short-term respiratory illness for both adults and children in case of using traditional stove. In contrary, Khalequzzaman et al. (2007, 2010) assessed the health effects of indoor air pollution on children under five years old from Bangladeshi households who are biomass or fossil fuel users and reported that there is no significant association between fuel use and respiratory disease in children under five years old. Among the available studies, few literatures further examine factors that can contribute to mitigate adverse health effects of indoor air pollution. Peabody et al. (2005) revealed that more kitchen windows can result in better ventilation and subsequently improve health outcome. Moreover, the amount of time spent in cooking near stove also affects individual health status (Duflo et al., 2008; Ezzati and Kammen, 2002).

Similarly, the available evidence on the adverse health effects of outdoor air pollution is mixed. In this type of studies, particulate matter (PM), sulfur dioxide (SO2), nitrogen dioxide (NO2) are considered as classical indicators measuring outdoor air pollutants (Chen and Kan, 2008). In addition, the indicators measuring health outcome resulting from outdoor air pollution are classified into two types: morbidity and mortality. Chen and Kan (2008) reported that a large body of evidence finds association between exposure to PM and morbidity as well as mortality. Neidell (2004) conducted panel studies and demonstrated that PM10 is generally associated with child hospitalizations for asthma. Qian et al. (2004) also revealed the evidence that long-term exposure to PM adversely affects children’s respiratory health in four Chinese cities. In contrast to above studies, Venners et al. (2003) did not find an association between PM2.5 and daily mortality in Chongqing of China. With respect to SO2, Chen and Kan (2008) concluded that a large body of literature has found the association between SO2 and daily mortality. This conclusion is consistent with the result found by Venners et al. (2003). There is a significantly positive relation between daily SO2 and cardiovascular and respiratory mortality in Chongqing of China. The adverse effect of NO2 on health is also found by Neidell (2004). NO2 is positively correlated with child hospitalizations for asthma. In particularly, it is significantly and positively correlated with asthma hospitalization in children for ages 6-12.

Numerous studies have investigated adverse effect of access to unsafe water on children health. A completed summary of literature is provided in World Bank (2007). A large of literature has reached an agreement that to improve access to safe water can reduce child mortality and morbidity. A more recent work is provided by Mangyo (2008). The author conducted a dynamic panel model with CHNS data to examine the effect of drinking water source on children health measured by height, weight and BMI. He found that access to clean water is positively but not statistically significant correlated with height, weight and BMI. However, if the mother of child is well educated, the access to clean water will be positively and statistically significant
correlated with height, weight and BMI.

From the literature review above, I can conclude three lessons. Firstly, we should pose a question about the robustness of the empirical findings in available studies on health outcome resulting from environmental pollution. That is because relatively few studies have used household survey data. Although the latter is used, its sample size is relatively small. Second, there is little consensus on the direction and magnitude of health outcome associated with exposure to environmental pollution. The inconsistently empirical findings can be explained by differences in terms of health indicators chosen, short-term or long-term health effect examined, econometrical techniques conducted and socio-economic factors considered. Finally, it is worthwhile that further efforts devote to assess the overall effect of air pollution on health outcome, as in real life we may simultaneously expose to diverse air pollution.

3.2 Evidence on choice of energy use

A growing body of empirical studies addresses investigating the responsible factors that affect the choice of domestic fuel. Most studies have largely focused on two categories of factors including household characteristics and price subsidy for fuels. The main household characteristics considered in literature consist of household income, sex and education of household head, household size and access to energy. Of these factors considered, it has reached a common view that income is the most important variable explaining fuel switching from dirty to clean. Campbell et al. (2003) found the energy transition away from wood towards electricity along with income increase. Gupta and Köhlin (2006) also report that the switch of fuel from fuelwood to liquified petroleum gas with increasing income. Education and access to energy are also important factors that positively associated with fuel switching. Gupta and Köhlin (2006) observed that the education level of household head is negatively associated with fuelwood use while it is positively associated with the choice of liquified petroleum gas. The same results are revealed by Ouedraogo (2006). Clearly, the availability of clean fuel is the key determinant of fuel switch. In contrast, the negative relationship between household size and the choice of clean fuel is demonstrated by some studies (e.g. Gundimeda and Köhlin, 2008; Ouedraogo, 2006). Regarding the role of price subsidy for fuels, the findings are mixed. Ouedraogo (2006) supported that the price subsidy for fuel is the dominant determinant of fuel switching as lowering the price of liquid petroleum gas significantly reduces the use of wood. It appears not consistent with the results of Gupta and Köhlin (2006) who reveals that the pricing policy that increases the price of dirty fuel while decreases the price of clean fuel cannot completely explain the choice of fuel, as other more important factors affecting fuel switching should be considered. Furthermore, beyond these basic determinants, another two important factors have been emphasized by some studies. One is fuel characteristics. Precisely, the complementarity or substitutability between fuels also explains the fuel choice (Gupta and Köhlin, 2006). The other is perceived health impact of indoor air pollution caused by dirty fuel.
(Masera et al., 2000). Although there is a growing recognition of this factor explaining fuel switching, no studies have provided evidence to support the role of this awareness in fuel switching to date. The reason explaining this finding in literature is that the adverse health effect of indoor air pollution caused by the use of dirty fuel is not given priority when choose fuel type, as the household and even the poor household have to make arbitrage between basic needs and fuel use (Gupta and Köhlin, 2006).

3.3 Evidence on vulnerability to poverty

To date, very few studies have provided evidence on vulnerability to poverty. One type of literature focuses on estimating the degree of vulnerability by quantifying vulnerability to poverty (e.g. Suryahadi and Sumarto, 2003; Günther and Harttgen, 2009). The other type concentrates on investigating the reasons for vulnerability by identifying the determinants of vulnerability (e.g. Glewwe and Hall, 1998; Angelica and Seiichi, 2006; Corbacho et al., 2007). To estimate the level of vulnerability, the latter is defined as the probability that an individual or a household become poor in the near future. Thus, the important mission of estimation is to estimate the mean and the variance of consumption or income. In turn, the consumption or income depends on a set of household and community characteristics. Subsequently, the probability of falling into poverty (i.e. vulnerability) can be estimated for each individual or household. In purpose of studying the reasons of vulnerability resulting from exposure to shocks, the authors estimate the determinants of the change of consumption or income in face of a certain shock (e.g. macroeconomic crises). They have emphasized the role of a set of household and community characteristics in affecting the consumption or income change over time. Regarding household characteristics, it has reached a consensus that low level of education, male household head, having more children, larger size of household and working in private sector are reasons forcing household to be more vulnerable. In contrast, with respect to community characteristics, only Angelica and Seiichi (2006) revealed that the regional different economic structure affects the vulnerability of household.

From the discussion above, I find that the most important difficulty for providing evidence on vulnerability is the lack of data. The limitation of data directly restricts the choice of econometrical method and further leads to an incomprehensive consideration of diverse risks.

4. The farm household consumption-production model

4.1 The role of energy use in the poverty-environment nexus

Why I pay more attention to energy? Energy fills a crucial role in achieving
sustainable development (Roosa, 2008; McDade, 2004; Abdalla, 2005). In other words, the energy is tightly related to the economic, social and environmental dimension of sustainable development. Energy connects the sustainable development at both micro (household) and macro (national) scales (Ezzati et al., 2004). However, the complex relationships between energy and sustainable development, especially, the poverty and the environmental implications of energy use have not been largely explored. The energy use plays a critical role in achieving all the goals of the Millennium Development Goals (Modi et al., 2005; Cabraal et al., 2005; McDade, 2004; Abdalla, 2005). The energy use closely links to various dimensions of welfare and affects environmental quality in various ways. To increase the quantity of energy use can affect many dimensions of welfare of the poor, while to improve the quality of energy use can positively affect both the environmental quality and welfare.

The most basic energy needs for the poor include cooking, heating, and lighting (World Bank, 2004). Cooked food and heat water are directly favourable for health. Access to improved lighting condition, such as electricity, have positive impact on education level (Kanagawa and Nakata, 2007; Heltberg, 2004). In particular, more attention has been paid on the direct and indirect income-generating productive use of energy in rural household activities (Cabraal et al., 2005; Omer, 2008) as energy is in the service of engine for mechanical equipments. The direct productive use of energy is required to improve productivity in various farm productions (e.g. land preparation, irrigation) as well as in household business activities. The indirect productive use of energy mainly consists of transporting agricultural inputs and products. Furthermore, the pattern of energy use will affect environmental quality and subsequently influence the health of the poor (Bojö and Reddy, 2003; Elliott, 2003; Haines et al., 2007). If the poor household depends on traditional pattern of energy for cooking, such as biomass, firewood, indoor air pollution will increase and this in turn will expose the household member to health risks (López and Toman, 2006; Wijayatunga and Attalage, 2002; Sagar, 2005; Jin et al., 2006). At the meantime, if the household chooses the polluting energy as the engine of mechanical equipments for production activities, the outdoor air quality will be degraded and then the health will also be threatened. Hereby, energy use plays an essential role in improving the health and therefore the productivity of the poor (López, 2006) through either increasing availability of energy or providing the environmentally-friendly energy. In this sense, to access sustainable energy which has minimal negative impacts on welfare and environmental quality (Omer, 2008) implies to integrate the sustainable development strategies into poverty reduction policies.

4.2 Main logic of the model

In what follows the model developed will describe rural household’s consumption and production behaviors. Not only the basic need of energy for cooking but also the productive use of energy is taken into account. The household can make a choice
between dirty and clean energy consumption. Both dirty and clean fuel use can generate indoor air pollution. However, consumption of dirty fuel for cooking generates more indoor air pollution than consumption of clean fuel. Similarly, to use dirty energy as the engine of mechanical equipments causes more outdoor air pollution than to use clean energy. Therefore, the health of the poor is threatened. In turn, the ill health affects labor productivity of the poor in production activities. On the whole, lack of access to clean energy will lead to a trap of poverty. That is because, the degradation of environmental quality leads to ill health and subsequently low labor productivity and finally low income.

I mainly refer to the papers of Singh et al., (1986), Pfaff et al. (2004), Chaudhuri and Pfaff (2002), Pitt and Rosenzweig (1984). Singh et al., (1986) set out a conventional rural household model to capture both production and consumption decisions made by the household. On the one hand, as a producer the household chooses allocation of labor in production activities, on the other hand, as a consumer the household allocates income in purchasing commodities. The model in the papers of Pfaff et al. (2004), Chaudhuri and Pfaff (2002) describes the impact of poor household’s consumption in dirty and clean energy on the environmental quality. Pitt and Rosenzweig (1984) supposed that the rural household’s production function depends on the effective labor since the health impact of environmental degradation affects the quality of the labor input used in agricultural function.

4.3 Basic structure of the model

The household utility (U) is considered as a function of both consumption of cooked food (C) and health (H).

\[ U = U(C, H) \]  

(1)

With \( \frac{\partial U}{\partial C} > 0, \frac{\partial U}{\partial H} > 0 \). The consumption of cooked food is a function of household produced \((C^h)\) and market purchased \((C^p)\) food.

\[ C = C(C^h, C^p) \]

(2)

With \( \frac{\partial C}{\partial C^h} > 0, \frac{\partial C}{\partial C^p} > 0 \). The status of health (H) is negatively influenced by both indoor (a) and outdoor (e) air pollution:

\[ H = H(a, e) \]

(3)

With \( \frac{\partial H}{\partial a} < 0, \frac{\partial H}{\partial e} < 0 \). Considering that the household can choose dirty \((q_d)\) (e.g. wood, coal), or clean \((q_c)\) (e.g. electricity, liquefied natural gas) for
cooking food. Then the consumption of both dirty and clean energy cause indoor air pollution. Thus, the level of indoor air pollution is:

$$a = a(q_d, q_c)$$ (4)

In addition, I assume that the dirty energy is more environmentally destructive, so \(\partial a / \partial q_d > \partial a / \partial q_c > 0\). The household also chooses mechanical equipments using dirty energy \((Q_d)\) (e.g. tractor, garden tractor) or clean energy \((Q_c)\) (e.g. electronic tractor). Similarly, the mechanical equipments which use dirty energy generate much more outdoor air pollution than the mechanical equipments which use clean energy.

Let \(A\) denote the initial outdoor air quality endowment. Thus, the level of outdoor air quality \((e)\) is:

$$e = e(Q_d, Q_c, A)$$ (5)

With \(\partial e / \partial Q_d > \partial e / \partial Q_c > 0\). In turn, the health impact of environmental degradation affects the quality of labour input used in agricultural function. Thus, the effective labour input \((L_e)\) in production results from both the health and the allocated time \((L')\) in production activities

$$L_e = L_e(H, L')$$ (6)

With \(\partial L_e / \partial H > 0, \partial L_e / \partial L' > 0\). The rural household mainly derives income from both agricultural and non agricultural production activities. I assume to neglect the imperfect in both agricultural goods and labour markets and subsequently the household can trade produced goods and labour in markets. Thus this model is a separated model which means that the consumption and production decisions can be taken separately. The agricultural production activities include gardening, farming, livestock and fishing, while the non agricultural production activities consist of small commercial business and working for wages. The farming and gardening productions depend on effective labor used of household \((L^i_e)\), mechanical equipments \((K)\) and other inputs \((N^i)\) (e.g. seedlings, hired labor).

$$Y = Y(L^i_e, K, N^i)$$ (7)
Where \( i = 1, 2 \) (1=farming, 2=gardening). The livestock production \( Y^3 \) is a function of both purchased feeding \( (M^p) \) and homemade animal feed \( (M^h) \).

\[
Y^3 = Y^3 (M^p, M^h)
\]  
(8)

The fishing production is a function of operating expenses \( (M) \) (e.g. gasoline, lines, fry).

\[
Y^4 = Y^4 (M)
\]  
(9)

The household commercial business \( Y^5 \) is a function of effective labour used \( (L^3_e) \) and commercial equipments \( (K^b) \)

\[
Y^5 = Y^5 (L^3_e, K^b)
\]  
(10)

The household wage income is a product of effective labour \( (L^4_e) \) and wage \( (w) \). The allocation of labour input in production activities is under the constraint of total household time endowment \( (T) \).

\[
L^1 + L^2 + L^3 + L^4 + L^5 = T
\]  
(11)

Where \( L^1, L^2, L^3, L^4 \) are allocation of labour in farming, gardening, commercial business and working activities. \( L^5 \) is leisure time. Thus, the household maximize the utility subject to income constraint and time constraint.

Max \( U(C, H) \)

Subject to

\[
\begin{align*}
C^p P_1 + C^h P_2 + q_d P_d + q_c P_c + Q_d P^0_d + \\
Q_c P^0_c + N^1 + N^2 + M^p + M^h + M + K^b P_3 + L^5 w = \\
Y^1 + Y^2 + Y^3 + Y^4 + Y^5 + L^4 w + I
\end{align*}
\]  
(12)

\[
L^1 + L^2 + L^3 + L^4 + L^5 = T
\]

Where \( P_1, P_2, \) and \( P_3 \) refer to the prices of market purchased food, household produced food, commercial equipments; \( P_d, P_c \) are prices of dirty and clean fuel,
\( P^d \), \( P^c \) are prices of mechanical equipments using dirty energy and mechanical equipments using clean energy, \( w \) represents wage and cost of leisure, \( I \) denotes other income, such as, fuel subsidy (e.g. electricity), and poverty funds.

The Lagrangian is:

\[
L = U (C (C^h, C^p), H (a (q_d, q_c), e (Q_d, Q_c, A))) - \lambda (\text{income constraint}) - \mu (\text{time constraint})
\]

(13)

This gives the following first order conditions:

\[
\frac{\partial L}{\partial C^h} = \frac{\partial U}{\partial C} \frac{\partial C}{\partial C^h} - \lambda P_2 = 0
\]

(14)

\[
\frac{\partial L}{\partial C^p} = \frac{\partial U}{\partial C} \frac{\partial C}{\partial C^p} - \lambda P_1 = 0
\]

(15)

\[
\frac{\partial L}{\partial q_c} = \frac{\partial U}{\partial H} \frac{\partial a}{\partial q_c} - \lambda (P_c - \frac{\partial Y}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial a}{\partial q_c} - \frac{\partial Y^2}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial a}{\partial q_c}) = 0
\]

(16)

\[
\frac{\partial L}{\partial q_d} = \frac{\partial U}{\partial H} \frac{\partial a}{\partial q_d} - \lambda (P_d - \frac{\partial Y}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial a}{\partial q_d} - \frac{\partial Y^2}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial a}{\partial q_d}) = 0
\]

(17)

\[
\frac{\partial L}{\partial Q_c} = \frac{\partial U}{\partial H} \frac{\partial e}{\partial Q_c} - \lambda (P^c - \frac{\partial Y}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial e}{\partial Q_c} - \frac{\partial Y^2}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial e}{\partial Q_c}) = 0
\]

(18)

\[
\frac{\partial L}{\partial Q_d} = \frac{\partial U}{\partial H} \frac{\partial e}{\partial Q_d} - \lambda (P^d - \frac{\partial Y}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial e}{\partial Q_d} - \frac{\partial Y^2}{\partial L^e} \frac{\partial L^e}{\partial H} \frac{\partial e}{\partial Q_d})
\]
Rearranging (14) - (15) of the first order conditions, it is found that:

\[
\frac{\partial U}{\partial C} \frac{\partial C}{\partial h} \bigg/ \frac{P_2}{P_1} = \frac{\partial U}{\partial C} \frac{\partial C}{\partial p}
\]  

(20)

Rearranging (16) - (17) of the first order conditions, it is found that:

\[
\frac{\partial U}{\partial H} \frac{\partial a}{\partial q_c} \bigg/ \left( P_c - \frac{\partial Y^1}{\partial L_c^1} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^2}{\partial L_c^2} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \right) \\
- \frac{\partial Y^5}{\partial L_c^3} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - w \frac{\partial L_c^4}{\partial H} \frac{\partial a}{\partial a} \frac{\partial a}{\partial q_c}
\]  

(21)

Rearranging (18) - (19) of the first order conditions, it is found that:

\[
\frac{\partial U}{\partial H} \frac{\partial e}{\partial q_c} \bigg/ \left( P^e_c - \frac{\partial Y^1}{\partial L_c^1} \frac{\partial H}{\partial e} \frac{\partial e}{\partial Q_c} - \frac{\partial Y^2}{\partial L_c^2} \frac{\partial H}{\partial e} \frac{\partial e}{\partial Q_c} \right) \\
- \frac{\partial Y^5}{\partial L_c^3} \frac{\partial H}{\partial e} \frac{\partial e}{\partial Q_c} - w \frac{\partial L_c^4}{\partial H} \frac{\partial e}{\partial e} \frac{\partial e}{\partial Q_c}
\]  

(22)

Equations (20), (21), (22) give the consumer theory result that the marginal rate of substitution equals the price ratio. The equation (21) implies that the utility that the household get from an additional unit of dirty fuel per monetary unit spent is equal to
the utility that get from an additional unit of clean fuel. So, the household will choose
clean fuel, when the utility get from an additional unit of clean fuel per monetary unit
spent is larger than the utility get from an additional unit of dirty fuel. This means
that:

\[
\frac{\partial U}{\partial H} \frac{\partial a}{\partial q_c} /\ (P_c - \frac{\partial Y^1}{\partial L_c^1} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^2}{\partial L_c^2} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^3}{\partial L_c^3} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - w \frac{\partial L_c^4}{\partial H} \frac{\partial a}{\partial q_c}) < d_p - P_c
\]

Equation (23) can be rewritten as:

\[
\frac{\partial H}{\partial a} \left( \frac{\partial a}{\partial q_d} - \frac{\partial a}{\partial q_c} \right) \left( \frac{\partial Y^1}{\partial L_c^1} \frac{\partial L_c^1}{\partial H} + \frac{\partial Y^2}{\partial L_c^2} \frac{\partial L_c^2}{\partial H} + \frac{\partial Y^3}{\partial L_c^3} \frac{\partial L_c^3}{\partial H} + w \frac{\partial L_c^4}{\partial H} \right) < P_d - P_c
\]

I confine the mathematical details to the appendix. Equation (24) indicates that the
choice of clean fuel depends on the prices of clean and dirty fuel, the effect of both
clean and dirty fuel on health (i.e. \( \frac{\partial H}{\partial a} \left( \frac{\partial a}{\partial q_d} - \frac{\partial a}{\partial q_c} \right) \)), and the overall effect of
health on both farm and off-farm income in farming, gardening, business and working
activities (i.e. \( \frac{\partial Y^1}{\partial L_c^1} \frac{\partial L_c^1}{\partial H} + \frac{\partial Y^2}{\partial L_c^2} \frac{\partial L_c^2}{\partial H} + \frac{\partial Y^3}{\partial L_c^3} \frac{\partial L_c^3}{\partial H} + w \frac{\partial L_c^4}{\partial H} \)).

Similarly, based on equation (22) the household will choose clean energy for
productive use when

\[
\frac{\partial U}{\partial H} \frac{\partial e}{\partial Q_c} /\ (P_{Q_c} - \frac{\partial Y^1}{\partial L_c^1} \frac{\partial H}{\partial e} \frac{\partial e}{\partial Q_c} - \frac{\partial Y^2}{\partial L_c^2} \frac{\partial H}{\partial e} \frac{\partial e}{\partial Q_c} - \frac{\partial Y^3}{\partial L_c^3} \frac{\partial H}{\partial e} \frac{\partial e}{\partial Q_c} - w \frac{\partial L_c^4}{\partial H} \frac{\partial e}{\partial Q_c})
\]
Equation (25) can be rewritten as:

$$\frac{\partial H}{\partial e} \left( \frac{\partial e}{\partial Q_d} \right) \left( \frac{\partial Y^1}{\partial L_c^1} \frac{\partial L_c^1}{\partial H} + \frac{\partial Y^2}{\partial L_c^2} \frac{\partial L_c^2}{\partial H} + \frac{\partial Y^3}{\partial L_c^3} \frac{\partial L_c^3}{\partial H} + w \frac{\partial L_c^4}{\partial H} \right) < P^C_d - P^C_e \quad (26)$$

Equation (26) indicates that the choice of clean energy for productive use depends on the prices of mechanical equipments using dirty energy and mechanical equipments using clean energy, the effect of both clean and dirty energy on health, and the overall effect of health on both farm and off-farm income.

The structural form of the model and the discussion above reveal two objectives for empirical analysis: studying the health outcome of the poor caused by both outdoor and indoor air pollution that results from initial air quality and energy consumption, and estimating the determinants of the choice of clean energy as fuel or for productive use made by the poor.

5. Data

The data used for the empirical analyse is from the China Health and Nutrition Survey (CHNS). CHNS, a collaborative effort involving the Chinese Academy of Preventive Medicine (CAPM) and the University of North Carolina’s Carolina Population Center (CPC), is an ongoing longitudinal household survey conducted in 9 provinces. These provinces include Guangxi, Guizhou, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Liaoning, and Shandong. Heilongjiang was added in 1997 when Liaoning was unable to participate. Liaoning subsequently returned to the project in 2000. These provinces are highly diversified in terms of economic development, geographic locations, natural resources, health indicators and demographics. Within each province, 4 counties were selected using a multistage, random cluster process. The provincial capital and a lower income city were selected when feasible. Villages and townships within the counties and urban and suburban neighborhoods within the cities were selected randomly.

Currently there are about 4,400 households in the overall survey of CHNS 2006, covering some 19,000 individuals. The CHNS 1991 was able to resurvey 95.3 percent of the households from the CHNS 1989. Among households interviewed in 1991, 93% were re-interviewed in 1993; among non-Liaoning households interviewed in 1993, 91% were re-interviewed in 1997. All individuals in each household were surveyed in 1991, 1993, 1997 and 2000 for all data; however in 1989, health and nutritional data were only collected from preschoolers and adults aged 20-45. CHNS 1989 surveyed 15,917 individuals. CHNS 1991 only surveyed individuals belonging to the original sample households which resulted in a total of 14,778 individuals. In CHNS 1993, all new households formed from sample households who resided in sample areas were added to this sample, resulting in a total of 13,893 individuals. In CHNS 1997, all newly-formed households who resided in sample areas and additional households to replace those no longer participating were added to the sample. New communities were also added to replace communities no longer participating, and Heilongjiang province replaced Liaoning province. A total of 14,426 individuals participated in 1997. In CHNS 2000, newly-formed households, replacement households, and replacement communities were again added, and Liaoning province returned to the study. A total of 15,648 individuals participated in 2000.

CHNS collects three sets of data in each round of the survey: household, community, and health and nutrition. In household surveys, home activities (e.g. physical activities, care provided to children and the elderly) and economic activities (e.g. fishing, farming, paid work) that each household member engaged during the previous year are documented in terms of time allocation and income. Household income variables are constructed including both earned (wages, farming, fishing and gardening income, and home business income), and unearned (income derived from assets), as well as subsidies and bonuses, such as welfare subsidies and ration coupons. It also collects information on physical conditions of the household dwelling and other characteristics of home environment, such as plumbing, water sources, and type of fuel for cooking. Besides home and economic activities, more detailed information on food consumption produced by household, health service consumption (e.g. immunization status), and demographics (e.g. birth date) was collected for household members. The community survey collects information on community infrastructure (e.g. transportation, energy access, and mass communications), a variety of community services (e.g. health insurance, medical institutions and shopping facilities), general population characteristics, and prevailing wages. It also collects detailed price data on food, cigarettes, alcohol and soft drinks in store and free market and the price data on fuel. For health and nutrition survey, detailed information on measures of health outcomes, such as height, weight, blood pressure, activities of daily living, self-reported health status, illness during previous month (e.g. respiratory disease), morbidity, physical function limitations, disease history and health-related behaviors (e.g., smoking, beverage consumption, medication, key chronic diseases) is collected. Nutrition data has also high quality. These data include dietary intake for three consecutive days.
6. Empirical analysis

In service of the objective of this paper, the empirical analysis is expected to contribute to further study how to make poverty reduction to be compatible with environmental protection at household level through improving the health of the poor, reducing the vulnerability to poverty in case of environmental shocks and accessing to sustainable energy.

However, the transition from a theoretical model to an empirical specification meets some difficulties. The choice of dependent and independent variables has to be simultaneously inspired by theoretical consideration and influenced by availability of data. When the variables in theoretical model are not measured in the sample of survey, I have to replace them by other variables or even treat them as unobservable.

6.1 health, energy use, environment

The objectives of this estimation are twofold: to capture the overall effect of environmental risk factors on health outcome; to identify factors which can play a role in mitigating the adverse impact of air pollution on health outcome. All the variables in regression are summarized in table 1.

6.1.1 Description of Variables

Dependent variables

I choose two types of indicator as health measure to capture the health outcome caused by the environmental pollution including self-reported current health status and body mass index (BMI). One of the most important reasons for choosing them is that the sample size of these two indicators is much larger than that of other indicators. So they are representative for rural adult health status. Self-reported current health status is a subjective measure of individual health, but it is highly correlated with mortality (Li and Zhu, 2006). It is measured in four categories in survey: poor, fair, good, and excellent. The dummy variable is equal 1 if excellent or good health status is reported and equals 0 if fair or poor health status is reported. BMI reflects short-term health status Duflo et al. (2008). In addition, BMI positively associated with both morbidity and mortality (Molini et al., 2010). BMI is defined as individual’s body weight (kg) divided by the square of his or her height (m). Based on the classification defined by the world health organization, a BMI of less than 18.5 is regarded as underweight. So I construct a binary variable for BMI, which is equals 1 if BMI< 18.5, and which is 0, otherwise.
Independent variables

Without direct measurement of indoor air pollution in survey data, fuel type is regarded as a proxy of pollution exposure in regression model. The dirty fuel types consist of coal, wood and straw, while the clean fuel types include liquified natural gas and natural gas. All these fuels are the dominant primary fuels used for daily cooking in this survey. Thus, four dummy variables are constructed as independent variable. They are defined based on the questionnaire responses: “What kind of fuel does your household normally use for cooking?”. To capture the impact of use of energy in mechanical equipments on health through outdoor air pollution, I define the independent variable based on the questionnaire responses: “Does your household own the farm machines listed?”. Dummy variable, equipment use, which is equal 1 if the household only owns mechanical equipments using dirty energy (e.g. tractor), 2 if the household owns both mechanical equipments using dirty and clean energy, 3 if the household only owns mechanical equipments using clean energy (e.g. power thresher), 4 if the household does not own mechanical equipments. In addition, the initial local outdoor air quality endowment is measured by three most common ambient air pollutants including Paticulate Matters (PM$_{10}$), Sulphur Dioxide (SO$_2$), Nitrogen Dioxide (NO$_2$). They are obtained from Chinese environmental statistical yearbook. Since the data on PM$_{10}$, SO$_2$, and NO$_2$ is very lacking and the community names in the household survey are not public, I use the data of three air pollutants for all the provincial capitals in CHNS.

Control variables

I control for individual-level and household-level variables. In the individual-level analysis, I control for variables including age and sex. At household-level, I control for variables consisting of per capita household income inflated to 2006 in terms of natural logarithms and source of drinking water.

Table 1: Description of variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-reported current health status</td>
<td>1 if health is excellent or good, 0 if fair or poor</td>
</tr>
<tr>
<td>Body mass index (BMI)</td>
<td>1 if BMI&lt; 18.5, 0 if BMI&gt;18.5</td>
</tr>
<tr>
<td>Coal</td>
<td>1 if it is used in household, 0 otherwise</td>
</tr>
<tr>
<td>Wood/straw</td>
<td>1 if it is used in household, 0 otherwise</td>
</tr>
<tr>
<td>Liquified natural gas</td>
<td>1 if it is used in household, 0 otherwise</td>
</tr>
<tr>
<td>Natural gas</td>
<td>1 if it is used in household, 0 otherwise</td>
</tr>
</tbody>
</table>
Equipment use  1 if the household only owns farm mechanical equipments using dirty energy 
2 if the household owns both farm mechanical equipments using dirty and clean energy 
3 if the household only owns farm mechanical equipments using clean energy 
4 if the household does not own farm mechanical equipments 

PM$_{10}$ milligram/m$^3$ 
SO$_2$ milligram/m$^3$ 
NO$_2$ milligram/m$^3$ 

Age 
Sex 1 if male and 2 if female 
Ground water 1 if yes, 0 if no 
Open well 1 if yes, 0 if no 
Creek, spring, river, lake 1 if yes, 0 if no 
Water plant 1 if yes, 0 if no 

Per capita household income inflated to 2006 (ln) 

6.1.2 Method of estimation 
I conduct cross-sectional studies for waves 2004 and 2006 by using logit regression models in STATA (version 11.0) to estimate the probability of becoming ill-health.

6.1.3 Results finding 
I find that in general the coal-fuel use is negatively associated with self-reported current health status in both 2004 and 2006 (in table 2). It is statistically significant for the year of 2004. The results show that the probability of being in excellent or good health decreases with coal-fuel use at a rate of 38.7 percentage point in 2004. In contrast, the use of coal is generally negatively correlated with underweight, and especially, it is significant negatively correlated with underweight in 2006. The use of coal reduces the probability of being underweight by 36.6 percentage point in 2006. Likewise, the use of biomass fuel in terms of wood or straw also negatively associated with self-reported current health status in both 2004 and 2006. In 2004 this relation is significant. The use of wood or straw decreases the probability of being in excellent or good health by 46.4 percentage point. Moreover, the use of wood or straw is in general positively but not significantly related to underweight. From the results of estimation, I conclude that the impact of coal-fuel on adult health outcome is mixed and depends on the measurement of health, while the use of wood or straw is
consistent positively related to adult illness. Furthermore, the results in 2004 suggest that the use of wood or straw is more significantly associated with worse health compared with coal fuel. It is opposite to the result found by Peabody et al. (2005).

In general, the use of natural gas has negative effect on self-reported current health status. In contrast, the effect of natural gas on BMI is not clear. Only in 2004 the use of liquified natural gas is significant negatively associated with self-reported current health status. The use of liquified natural gas decreases the probability of being in excellent or good health by 37.9 percentage point. This negative association is contrary to the conclusion made by the study of Sinton et al. (2004). However, the four coefficients for coal, wood or straw, liquified natural gas as well as natural gas in 2004 confirm the expectation that the negative effect of clean fuel is less than that of dirty fuel on health outcome.

Generally, the effects of farm mechanical equipments on health outcome are not significant. Two reasons may explain this result: the quality of data on this variable in survey is low because of large missing information; this variable is not a good proxy of outdoor air pollution. It is strange that \( \text{PM}_{10} \) is significant positively associated with both self-reported current health status and BMI in 2004 and 2006. However, I find that \( \text{SO}_2 \) is significant negatively correlated with BMI in both 2004 and 2006. In addition, \( \text{SO}_2 \) is also negatively related to self-reported current health status, while only in 2006 this relationship is statistically significant. The results on the health effect of \( \text{SO}_2 \) are consistent with the studies of Chen and Kan (2008) and Venners et al. (2003) who report the association between \( \text{SO}_2 \) and mortality, as both self-reported current health status and BMI are highly correlated with subsequent mortality. In addition, the significant negative association between \( \text{NO}_2 \) and health outcome is observed only for self-reported current health status in 2006.

Sex has a significant negative association with self-reported current health status in both 2004 and 2006. For example, in 2004 female has 46.5 percentage points higher probability of being in poor health than male. It is consistent with the paper of Li and Zhu (2006) who found that male has a higher probability of being in good health than female. Similarly, I also find that female has a higher probability of being underweight than male in both 2004 and 2006. This result is also observed by the study of (Molini et al., 2010). The significant positive relationship between age and worse health is also found. The results show that the probability of being in good health decreases with age at a rate of 4.4 percentage point. The negative relationship between age and self-reported current health status is also reported by Li and Zhu (2006). Likewise, the negative correlation between age and BMI found in this study is also reported by Molini et al. (2010). Consistent with the study of Li and Zhu (2006), I also find the significant positive association between income and health. Compared with the work of Li and Zhu (2006), the positive association between access to water plant and health outcome is found but it is not significant.

<table>
<thead>
<tr>
<th>Table 2: logit regression for estimating the probability of becoming ill-health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variable: Self-reported current health status</td>
</tr>
</tbody>
</table>
6.2 Choice of energy use

Since the data on mechanical equipments using dirty energy or clean energy and on prices of mechanical equipments are very limited, I examine merely the choice of household between dirty and clean fuel for cooking. The objective of this study is to identify the factors that increase the probability of choosing clean fuel.

6.2.1 Description of Variables

Dependent variable

To capture the behavior of household in fuel choice, the dependent variable is defined over a set of four alternative fuels used as the primary cooking energy in household including coal, electricity, liquified natural gas and wood or straw. They
are most used by household in survey.

**Independent variables**

It is a challenge to construct independent variables to represent the effect of both clean and dirty fuel on health and the overall effect of health on both farm and off-farm income upon which the choice of fuel depends. To capture the effect of fuel use on health, I will use the health indicator that can be significantly explained by fuel use, i.e. self-reported current health status. Thus, I construct a binary variable, i.e. SRCHH. If there is member in household reporting worse current health, then SRCHH is equal to 1, otherwise, it is 0. To capture the overall effect of health on both farm and off-farm income, I will define one independent variable to represent illness impact on absence of work based on the question: during the past 3 months have you had any difficulty carrying out your daily activities and work or studies due to illness? Other independent variables include the prices of both dirty and clean fuel. Thus I use the price of coal (honey-combed briquette) to represent the price of dirty fuel and the price of electricity to represent the price of clean fuel.

**Control variables**

I also control for a set of variables at household-level as well as location-specific effect. They are summarized in table 3.

<table>
<thead>
<tr>
<th>Table 3: Description of variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
</tr>
</tbody>
</table>
| Choice of fuel               | 1=coal  
                                      2=electricity  
                                      4= liquified natural gas  
                                      6= wood or straw |
| SRCHH                        | 1 if at least one member of household reporting worse current health, 0 otherwise |
| Have difficulty in work due to illness | 1 if at least one member of household have difficulty in work due to illness, and 0 otherwise |
| Coal price                   | Yuan |
| Electricity price            | Yuan |
| Sex (household head)         | 1 if male and 2 if female |
Highest level of education (household head)

1 = primary school
2 = lower middle school degree
3 = upper middle school degree
4 = technical or vocational degree
5 = university or college degree
6 = master’s degree or higher

Household size

Per capita household income inflated to 2006 (ln)

Coal subsidy
1 if household receive a coal subsidy last year, and 0 otherwise

Electricity subsidy
1 if household receive an electricity subsidy last year, and 0 otherwise

Liaoning
1=yes, 0=no
Heilongjiang
1=yes, 0=no
Jiangsu
1=yes, 0=no
Shandong
1=yes, 0=no
Henan
1=yes, 0=no
Hubei
1=yes, 0=no
Hunan
1=yes, 0=no
Guangxi
1=yes, 0=no

6.2.2 Method of estimation

Referring to the study of Ouedraogo (2006), I conduct a multinomial logit model to identify the determinants of fuel choice in household. The process of estimation consists of three steps. Firstly, I estimate the coefficient of this model (in table 4). Electricity is defined as the base category. Then some statistically tests are done in the purpose of rejecting the hypothesis null that all the estimated coefficients are equal to zero and measuring the fitness of model. Finally, I present the marginal effects to measure the impact of variation of exogenous variables as the coefficients estimated in the first step are difficult to interpret.

6.2.3 Results finding

The results of test allow rejecting the hypothesis null. In addition, the Mc Fadden pseudo-R² for the estimations in 2004 and 2006 are 0.270 and 0.234, respectively. Accordingly, 27% and 23.4% of the fuel choice of household can be explained by the exogenous variables in 2004 and 2006, respectively.
From the results of marginal effect in 2004, I find that in general the self-reported current health status of household members appears positively associated with the choice of dirty fuel while negatively associated with the use of clean fuel. The marginal effect of the variable “SRCHH” indicates that a change from no member being in worse health to at least one member reporting worse health decreases the average probability of electricity adoption by 0.02. It is contrary to the expected result that the more important the impact of dirty fuel use on health is, the higher the probability of choosing clean energy is. However, it is consistent with the available evidence studies. It implies that in reality health concerns resulting from indoor air pollution are not sufficient for promoting fuel switching as the health risks caused by the use of dirty fuel have not been well recognised. In the results of marginal effect in 2006, the marginal effect of the variable “Have difficulty in work due to illness” implicates that household member having difficulty in work due to illness involves an increase of 0.06 of the average electricity choice probability while the probability of liquified natural gas choice drops by 0.06. It is interesting to note that this empirical result is consistent with the expected result that the more important the impact of health on income is, the higher the probability of choosing clean energy is. Regarding the pricing subsidy factor, the coal price is significant negatively associated with the choice of coal in 2006. It is worthy to note that the coal price is significant positively associated with the use of liquified natural gas in both 2004 and 2006. The marginal effect of the variable “coal price” means that the increasing coal price increases the probability of choice in liquified natural gas by 0.01 and 0.09 in both 2004 and 2006, respectively. Accordingly, it provides an evidence to support that fuel price is an important factor explaining fuel switching. Furthermore, it is consistent with the
Table 4: estimation of multinomial logit model for choice of fuel

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
<td>Liquefied natural gas</td>
</tr>
<tr>
<td>Intercept</td>
<td>8.1137***</td>
<td>-1.6585</td>
</tr>
<tr>
<td>SRCHH</td>
<td>0.6376**</td>
<td>0.2798</td>
</tr>
<tr>
<td>Have difficulty in work due to illness</td>
<td>0.3550</td>
<td>0.3837</td>
</tr>
<tr>
<td>Coal price</td>
<td>0.0719</td>
<td>0.1597</td>
</tr>
<tr>
<td>Electricity price</td>
<td>0.4791</td>
<td>0.4417</td>
</tr>
<tr>
<td>Sex (household head)</td>
<td>-1.2667**</td>
<td>-0.0909</td>
</tr>
<tr>
<td>Highest level of education (household head)</td>
<td>0.0582</td>
<td>0.3084*</td>
</tr>
<tr>
<td>Household size</td>
<td>-0.1058</td>
<td>-0.0857</td>
</tr>
<tr>
<td>Per capita household income inflated to 2006 (ln)</td>
<td>-0.5022***</td>
<td>0.0324</td>
</tr>
<tr>
<td>Coal subsidy</td>
<td>-3.6596***</td>
<td>-4.5201***</td>
</tr>
<tr>
<td>Electricity subsidy</td>
<td>17.2626</td>
<td>15.9937</td>
</tr>
<tr>
<td>Liaoning</td>
<td>-3.4829***</td>
<td>0.6251</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>-2.7949***</td>
<td>-0.0460</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>-2.1631***</td>
<td>2.6941***</td>
</tr>
<tr>
<td>Shandong</td>
<td>-0.1455</td>
<td>3.9425***</td>
</tr>
<tr>
<td>Henan</td>
<td>15.146</td>
<td>16.6491</td>
</tr>
<tr>
<td>Hubei</td>
<td>-0.9391</td>
<td>1.3886</td>
</tr>
<tr>
<td>Hunan</td>
<td>0.0345</td>
<td>2.6058***</td>
</tr>
</tbody>
</table>
Guangxi  
-3.4680*** 1.9373** 2.2238*** -2.6990*** 2.1468*** 2.0913***

McFadden's $R^2 = 0.270$

Source: own calculation
Note: electricity is defined as basic category
* Significance levels of 10%
** Significance levels of 5%
*** Significance levels of 1%

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
<td>Electricity</td>
</tr>
<tr>
<td>SRCHH</td>
<td>0.0397</td>
<td>-0.0239*</td>
</tr>
<tr>
<td>Have difficulty in work due to illness</td>
<td>0.0082</td>
<td>-0.0169</td>
</tr>
<tr>
<td>Coal price</td>
<td>-0.0065</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Electricity price</td>
<td>0.0383*</td>
<td>-0.0164</td>
</tr>
<tr>
<td>Sex (household head)</td>
<td>-0.1027**</td>
<td>0.0414*</td>
</tr>
<tr>
<td>Highest level of education (household head)</td>
<td>0.0014</td>
<td>-0.0031</td>
</tr>
<tr>
<td>Household size</td>
<td>0.0072</td>
<td>0.0072</td>
</tr>
<tr>
<td>Per capita</td>
<td>-0.0284**</td>
<td>0.0191**</td>
</tr>
</tbody>
</table>

Table 5: Marginal effects of multinomial logit model for choice of fuel
household income
inflated to 2006
(ln)

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal subsidy</td>
<td>1.2543</td>
<td>0.4831</td>
<td>0.9704</td>
<td>-2.7078</td>
<td>-2.3651</td>
<td>0.8192</td>
<td>1.0365</td>
<td>0.5094</td>
</tr>
<tr>
<td>Electricity subsidy</td>
<td>0.5260</td>
<td>-0.7865</td>
<td>0.2250</td>
<td>0.0359</td>
<td>3.3140</td>
<td>-0.2699</td>
<td>-0.0127</td>
<td>-3.0313</td>
</tr>
<tr>
<td>Liaoning</td>
<td>-0.5720***</td>
<td>0.0458</td>
<td>0.2767**</td>
<td>0.2496**</td>
<td>-0.4812***</td>
<td>0.0301</td>
<td>0.2896***</td>
<td>0.1615*</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>-0.4546***</td>
<td>0.0385</td>
<td>0.1203</td>
<td>0.2958**</td>
<td>-0.2690***</td>
<td>0.0601</td>
<td>0.1323</td>
<td>0.0766</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>-0.7450***</td>
<td>-0.0647**</td>
<td>0.2643**</td>
<td>0.5454***</td>
<td>-0.7783***</td>
<td>-0.1108**</td>
<td>0.5110***</td>
<td>0.3781***</td>
</tr>
<tr>
<td>Shandong</td>
<td>-0.5569***</td>
<td>-0.1266***</td>
<td>0.2853***</td>
<td>0.3981***</td>
<td>-0.3095***</td>
<td>-0.3426***</td>
<td>0.3364***</td>
<td>0.3157***</td>
</tr>
<tr>
<td>Henan</td>
<td>-0.0136</td>
<td>-0.8034</td>
<td>0.2726</td>
<td>0.5444</td>
<td>-0.0455</td>
<td>-0.2773***</td>
<td>0.2547***</td>
<td>0.0682</td>
</tr>
<tr>
<td>Hubei</td>
<td>-0.4437***</td>
<td>-0.0561*</td>
<td>0.0482</td>
<td>0.4516***</td>
<td>-0.3389***</td>
<td>-0.2161***</td>
<td>0.2710***</td>
<td>0.2840***</td>
</tr>
<tr>
<td>Hunan</td>
<td>-0.1495**</td>
<td>-0.0400</td>
<td>0.3611***</td>
<td>-0.1716</td>
<td>-0.0776</td>
<td>-0.2708***</td>
<td>0.3571***</td>
<td>-0.0088</td>
</tr>
<tr>
<td>Guangxi</td>
<td>-0.8005***</td>
<td>-0.0096</td>
<td>0.3203***</td>
<td>0.4897***</td>
<td>-0.6503***</td>
<td>-0.0310</td>
<td>0.3397***</td>
<td>0.3416***</td>
</tr>
</tbody>
</table>

Source: own calculation

* Significance levels of 10%
** Significance levels of 5%
*** Significance levels of 1%
expected result indicated in equation (24), as the smaller the difference of price between dirty and clean fuels is, the higher the probability of choosing clean energy is. For the factors on household characteristics, as expected, the income is significant positively associated with fuel switching which is consistent with the finding in other studies. The results suggest that the level of education of household head is significant positively correlated with the choice of liquified natural gas while significant negatively related with the choice of wood. The results also reveal that the sex of household head is significant positively associated with the choice of clean fuel while negatively associated with the choice of dirty fuel. In other words, when the household head is female, the probability of clean fuel adoption increases while the probability of dirty fuel adoption decreases.

6.3 Assessing vulnerability to poverty

6.3.1 Method of estimation

I will refer to the work of Günther and Harttgen (2009) who integrates multilevel technique to assess vulnerability to poverty in face of shocks. The reasons for referring this study are threefold. Firstly, the method allows for a comprehensive consideration of various risks in spite of lacking information on a full range of shocks. Secondly, the method is suitable for both cross-sectional and short panel data. Finally, it is successful to quantify vulnerability and identify the sources of vulnerability simultaneously.

The method is briefly discussed as follow. In this method vulnerability to poverty is also defined as the probability that the welfare in terms of consumption fall below the benchmark. The principle of the method is to estimate the vulnerability parameters, i.e. the mean and variance of consumption.

The first step is to regress per capita household (log) consumption of household i in community j on a set of household characteristics of household i in community j, denote \( X_{ij} \) and various community characteristics \( Z_j \). That is:

\[
\ln C_{ij} = \varphi Z_j + \varphi X_{ij} + \varphi X_{ij} Z_j + e_{ij} + u_j \quad (27)
\]

The term \( X_{ij} Z_j \) represents the cross-level interactions. \( e_{ij} \) is error term at the household level; \( u_j \) is error term at the community level. \( e_{ij} \) and \( u_j \) are supposed to capture the effect of idiosyncratic shocks at household level and covariate shocks at community level on consumption. Furthermore, it is assumed that the effect of shocks on consumption depends on observable household and community characteristics. Therefore, the second step is to regress the squared residuals \( e_{ij}^2 \) and \( u_j^2 \) on a set of household \( X_{ij} \) and community \( Z_j \), characteristics in purpose of measuring the variance of consumption.

\[
e_{ij}^2 = \tau_1 Z_j + \tau_2 X_{ij} + \tau_3 X_{ij} Z_j \quad (28)
\]

\[
u_j^2 = \xi Z_j \quad (29)
\]

\[
(e_{ij} + u_j)^2 = \tau_1 Z_j + \tau_2 X_{ij} + \tau_3 X_{ij} Z_j \quad (30)
\]

The term \( e_{ij} + u_j \) represents the total shocks. Finally, the expected mean and the expected idiosyncratic, covariate and total variance of consumption can be estimated.
E (ln $C_{ij}$ | $X_{ij}, Z_j$) = $\phi Z_j + \sigma X_{ij} + \phi X_{ij} Z_j$ \hspace{1cm} (31)

$V (ln C_{ij} | X_{ij}, Z_j) = e_{ij}^2$ \hspace{1cm} (32)

$V (ln C_{ij} | X_{ij}, Z_j) = u_{ij}^2$ \hspace{1cm} (33)

$V (ln C_{ij} | X_{ij}, Z_j) = e_{ij}^2 + u_{ij}^2$ \hspace{1cm} (34)

After the estimation, in addition to assume that consumption follows a log-normally distribution, I can estimate the probability of falling into poverty in near future for each household using the equation in following:

$$v_{ij} = P (ln C_{ij} < ln z | X, Z) = \Phi\left(\frac{ln z - ln C_{ij}}{\sqrt{\sigma^2_{ij}}}\right)$$ \hspace{1cm} (35)

Where $\Phi$ is a cumulative density of standard normal distribution, $z$ is poverty line, $ln C_{ij}$ is the expected mean of per capita consumption in form of ln, and $\sigma^2_{ij}$ represents the estimated idiosyncratic variance, or the estimated covariate variance, or the estimated total variance of per capita consumption in form of ln.

In addition, the vulnerability threshold is defined as 50%. It means that if a household has 50% or higher probability to become poor in near future then the household is considered as vulnerable. In addition, I will choose the international standard poverty lines (PPP 2$) per day after adjusting for provincial inflation.

6.3.2 Description of Variables

Due to lacking of consumption data, I define welfare of household in terms of income. In addition, I choose a set of household-level and community-level variables as the determinants of income. All the variables are described and summarized in table 4.

<table>
<thead>
<tr>
<th>Name</th>
<th>definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per capita household income inflated to 2006 (ln)</td>
<td></td>
</tr>
<tr>
<td>Average of household age</td>
<td></td>
</tr>
<tr>
<td>Sex (household head)</td>
<td>1 if male and 2 if female</td>
</tr>
<tr>
<td>Highest level of education (household head)</td>
<td>1 = primary school 2 = lower middle school degree 3 = upper middle school degree 4 = technical or vocational degree 5 = university or college degree</td>
</tr>
</tbody>
</table>
6 = master’s degree or higher

Household size

Transportation assets 1 if household own transportation means and 0 otherwise

Farm machines 1 if household own farm machines and 0 otherwise

Commercial equipments 1 if household own commercial equipment and 0 otherwise

Welfare funds 1 if household receive welfare funds last year, and 0 otherwise

Source of water 1 if access to water plant, and 0 otherwise

Environmental sanitation around the dwelling place 1 if there are some or much excreta and 0 if there are no or very little excreta

Primary fuel use for cooking 1 if the household uses dirty fuel (coal, kerosene, wood/straw, charcoal) for cooking, 0 if the household uses clean fuel (electricity, liquefied natural gas, natural gas) for cooking

Number of free market

| PM_{10} | milligram/ m³ |
| SO₂    | milligram/ m³ |
| NO₂    | milligram/ m³ |

6.3.3 Results finding

The regression results of multilevel model are presented in table 7. Consistent with the findings in other studies, the level of education of household head, assets in terms of transportation means, farm machines and commercial equipments are significant positively correlated to income. In contrast, household size is significant negatively associated with income. Besides the basic factors as source of vulnerability considered by available studies, I also integrate other important variables representing the environmental risks on health at both household and community levels. As expected, at household level, both the environmental sanitation around the dwelling place and source of water can significantly explain the household income. At community level, both PM_{10} and SO₂ also negatively related to the household income. Moreover, the interaction between fuel use and PM_{10} is significant negatively associated with household income.

Table 7: regression results of multilevel model for per capita household income
<table>
<thead>
<tr>
<th>Household level variables</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age of household</td>
<td>-0.0010</td>
</tr>
<tr>
<td>Sex (household head)</td>
<td>0.0817</td>
</tr>
<tr>
<td>Highest level of education (household head)</td>
<td>0.1614***</td>
</tr>
<tr>
<td>Household size</td>
<td>-0.1700***</td>
</tr>
<tr>
<td>Transportation assets</td>
<td>0.1874***</td>
</tr>
<tr>
<td>Farm machines</td>
<td>0.1794***</td>
</tr>
<tr>
<td>Commercial equipments</td>
<td>0.2529***</td>
</tr>
<tr>
<td>Welfare funds</td>
<td>-0.1563</td>
</tr>
<tr>
<td>Source of water</td>
<td>0.2200***</td>
</tr>
<tr>
<td>Environmental sanitation around the dwelling place</td>
<td>-0.1347***</td>
</tr>
<tr>
<td>Primary fuel use for cooking</td>
<td>0.2176</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Community level variables</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of free market</td>
<td>-0.0096*</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>-1.4186</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>-1.8318</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>8.1323***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Community*household interaction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary fuel use for cooking* PM$_{10}$</td>
<td>-3.8912**</td>
</tr>
<tr>
<td>$\sigma^2_e$ (household level)</td>
<td>0.1020</td>
</tr>
<tr>
<td>Observation (household level)</td>
<td>2237</td>
</tr>
<tr>
<td>$\sigma^2_u$ (community level)</td>
<td>0.1192</td>
</tr>
<tr>
<td>Observation (community level)</td>
<td>144</td>
</tr>
</tbody>
</table>

Source: own calculations

Note: $\sigma^2_e$ denotes the unexplained variance at the household level and $\sigma^2_u$ refers to the unexplained variance at the community level.

* Significance levels of 10%
** Significance levels of 5%
*** Significance levels of 1%

After the estimation for the equations (27)-(34), the vulnerability based on the equation (35) can be estimated for each household. However, in order to that, I have to choose both poverty line and vulnerability threshold. Consistent with other studies, I will choose the common vulnerability threshold, 50%, i.e. the household who has a 50% or higher probability of falling into poverty in near future is considered as vulnerable. In addition, I will use the international standard poverty lines PPP 2$ per day by adjusting for the inflation in rural area as the Chinese national poverty line is too low.

Consequently, I estimate that 58.44% of households in rural area are vulnerable to poverty in 2004 (in Table 8). In other words, 58.44% of households have a 50% or higher probability to fall below the poverty line in near future. In contrast, 48.06% of households in rural area are vulnerable to poverty in 2006. It tells us that rural households are less vulnerable in 2006 than in 2004. The impact of both idiosyncratic and covariate shocks are more important in 2004 than in 2006. Moreover, the mean
vulnerability, which is the average probability of falling into poverty, is nearly equal to the poverty rate and subsequently the estimated vulnerability is feasible.

<table>
<thead>
<tr>
<th>Table 8: Vulnerability decomposition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Poverty rate</td>
</tr>
<tr>
<td>Mean vulnerability</td>
</tr>
<tr>
<td>Vulnerability rate</td>
</tr>
<tr>
<td>Idiosyncratic vulnerability</td>
</tr>
<tr>
<td>Covariate vulnerability</td>
</tr>
</tbody>
</table>

Source: own calculations

7. Conclusion

Four channels through which poverty reduction can be compatible with environmental protection at household level including enhancing the livelihoods of the poor (or sustainable management of natural resources), improving the health of the poor, reducing vulnerability of the poor to environmental shocks and accessing to sustainable energy have been emphasized in this paper. Furthermore, there are interactions between these channels, for example, sustainable management of natural resources can reduce vulnerability based on asset-based and sustainable livelihood approaches; access to sustainable energy is favorable with the health of the poor.

The existing theoretical literatures have made effort in supporting the first three solutions. Especially, from the discussion of review of literature, one may conclude that the availability of off-farm opportunities plays an important role in sustainable management of natural resource.

More important, I make my effort to support the fourth solution by setting up a farm household consumption-production model. Contributions expected of the model are twofold: to capture the health outcome caused by outdoor and indoor air pollution; to understand the determinants of households’ energy switching to high quality. From the discussion of first order, I have demonstrated that choice of clean fuel for cooking depends on the prices of clean and dirty fuel, the effect of both clean and dirty fuel on health and the overall effect of health on both farm and off-farm income. Similarly, the choice of clean energy for productive use depends on the prices of mechanical equipments using dirty energy and mechanical equipments using clean energy, the effect of both clean and dirty energy on health, and the overall effect of health on both farm and off-farm income.

For the empirical analyse of the impact of environmental risks on health outcome, I find that both clean and dirty fuels have adverse impact on health. However, the negative effect of clean fuel is less than the adverse impact of dirty fuel on health outcome. This result is consistent with the assumptions made in model. In addition, it is worthy to note that the results suggest that the use of wood or straw is more significantly associated with worse health compared with coal fuel. Besides, the negative association between initial outdoor air pollution in terms of NO\textsubscript{2} and SO\textsubscript{2} and health outcome in terms of self-reported current health and BMI further demonstrates the rationality of assumption made in the model. Furthermore, the results reveal that both female and older have higher probability of being in worse health. In contrast, both income and access to water plant decrease the probability of being illness.
With regard to the choice of fuel use, consistent with the finding in available
studies, some household characteristics can significantly explain the fuel switching
away from dirty fuel to clean fuel, such as, level of education and income. Likewise,
consistent with other evidence studies, it is unsuccessful to demonstrate that the health
effect resulting from indoor air pollution can sufficiently promote the fuel switching.
This result implies that the health risks caused by the use of dirty fuel have not been
well recognised. Subsequently, the adverse health effect of indoor air pollution is not
given priority when make choice in fuel type. It tells us that reinforcing the awareness
on the dangers of indoor air pollution is needed in purpose of affecting the
household’s behaviour in fuel choice. However, as expected, the empirical analyses
support the results derived from the model that the more important the impact of
health on income is, the higher the probability of choosing clean energy is, and the
smaller the difference of price between dirty and clean fuels is, the higher the
probability of choosing clean energy is.,

Finally, I provide evidence on quantifying the vulnerability to poverty. And the
results suggest that rural household in 2004 are more vulnerable to poverty than in
2006. Moreover, both idiosyncratic and covariate shocks have more important impact
in 2004 than in 2006, as the vulnerability to idiosyncratic shock and covariate shock
are much higher in 2004.

Although progress has been made in developing theoretical frameworks for
analyzing the poverty-environment nexus at micro level, it remains some directions
for further researches. First, modelling health outcome resulting from environmental
pollution, particularly caused by water pollution, needs further study. Second, more
efforts are called for in developing a structural and dynamic model to assess
vulnerability to poverty taking into account the forward-looking propriety of
vulnerability. The third direction is to examine the role of renewable energy in the
poverty-environment nexus at household level. Regarding empirical studies, it also
has much more things to do. In the area of environmental health, examining the
long-term health effect of environmental risks and quantifying the magnitude of the
health effect needs further study. For quantifying vulnerability, I will integrate more
variables representing household-level and community-level characteristics in order to
take a more comprehensive consideration of risk sources. In addition, further
investigation should focus on improving statistical method and using other household
survey with larger sample size to enforce the robustness of evidence.

Appendix

Demonstration equation (24):

From (23), we can have

\[
(P_c - \frac{\partial Y^1}{\partial L_c^1} \frac{\partial L_c^1}{\partial H} \frac{\partial a}{\partial q_c} - \frac{\partial Y^2}{\partial L_c^2} \frac{\partial L_c^2}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^3}{\partial L_c^3} \frac{\partial L_c^3}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial L_c^4}{\partial H} \frac{\partial a}{\partial q_c} - \frac{\partial a}{\partial q_c}) \bigg/ \frac{\partial a}{\partial q_c}
\]
\[
< \left( P_d - \frac{\partial Y^1}{\partial L_e^1} \frac{\partial L_e^1}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} - \frac{\partial Y^2}{\partial L_e^2} \frac{\partial L_e^2}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} - \frac{\partial Y^5}{\partial L_e^3} \frac{\partial L_e^3}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} \right) - \frac{\partial L_e^4}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} / \frac{\partial a}{\partial q_d}
\]

As $\frac{\partial a}{\partial q_c} > 0$ and $\frac{\partial a}{\partial q_d} > 0$, then

\[
\frac{\partial a}{\partial q_d} \left( P_c - \frac{\partial Y^1}{\partial L_e^1} \frac{\partial L_e^1}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^2}{\partial L_e^2} \frac{\partial L_e^2}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^5}{\partial L_e^3} \frac{\partial L_e^3}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \right) - w \frac{\partial L_e^4}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \frac{\partial a}{\partial q_d} < 0
\]

Then,

\[
P_c - \frac{\partial Y^1}{\partial L_e^1} \frac{\partial L_e^1}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^2}{\partial L_e^2} \frac{\partial L_e^2}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - \frac{\partial Y^5}{\partial L_e^3} \frac{\partial L_e^3}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} - w \frac{\partial L_e^4}{\partial H} \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \frac{\partial a}{\partial q_d}
\]

Then,

\[
\frac{\partial Y^1}{\partial L_e^1} \frac{\partial L_e^1}{\partial H} \left( \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} - \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \right) + \frac{\partial Y^2}{\partial L_e^2} \frac{\partial L_e^2}{\partial H} \left( \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} - \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \right) + \frac{\partial Y^5}{\partial L_e^3} \frac{\partial L_e^3}{\partial H} \left( \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_d} - \frac{\partial H}{\partial a} \frac{\partial a}{\partial q_c} \right) < P_d - P_c
\]

Finally,

\[
\frac{\partial H}{\partial a} \left( \frac{\partial a}{\partial q_d} - \frac{\partial a}{\partial q_c} \right) \left( \frac{\partial Y^1}{\partial L_e^1} \frac{\partial L_e^1}{\partial H} + \frac{\partial Y^2}{\partial L_e^2} \frac{\partial L_e^2}{\partial H} + \frac{\partial Y^5}{\partial L_e^3} \frac{\partial L_e^3}{\partial H} + w \frac{\partial L_e^4}{\partial H} \right) < P_d - P_c \tag{24}
\]

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