Exposure to firewood: Consequences in health and labor force participation for Mexican households

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1. Introduction

Fuel provision is an important resource for devepelopment of activities that are necessary in the households such as cooking and heating. But, the consumption of household fuels in developed countries and urban areas are differents respect to rural areas in developing countries. In developed countries and urban areas in developing countries is more generalized the use of Liquefied petroleum gas (LPG) and electricity. Advantages related with consumption of these fuels are efficiency in cooking and cleaning, moreover, its consumption is not related to health problems such as cough, acute respiratory infections and chronic obstructive pulmonary disease (Smith et al., 2005). However, for its implementation is required that localities have resources of accessibility such as infrastructure, and households must pay start-up cost (installation within dwelling, cost of stove). When households are poor and have not access to credit market is complicated to have the services and this problem is accentuated if household is located in municipalities with high marginality degree. In developing countries, specifically in its rural areas, is more accessible the use of firewood due the closeness to natural resources such as forest, which is an input for firewood and it can be collected by the household members. World Health Organization (WHO) (2002) observes that three billions people in the world use solid biomass fuel (firewood, dung, charcoal, and crop residues) for cooking and heating. Respect to these households, 90% are rural households located mainly in developing countries, such is indicated by Boy et al.(2000).

The use of solid biomass fuel, specifically firewood is that these fuels are low efficient for generating energy: respect to other fuels such as LPG or electricity, there exists shrinkage in its combustion, it implies to use more quantity than other fuels. Also, burning solid fuels produces extremely high levels of Indoor Air Pollution (IAP): typical 24-hour levels of Particles until ten micro-meters (PM10) in biomass-using households in Africa, Asia or Latin America range from 300 to 3000 micrograms per cubic metre (WHO, 2006). As well, the consumption of firewood and others biomass implies that these there are incomplete combustion. Incomplete combustion is that the fuel not consume totally, for this reason there are particles suspended in the air that contain toxic substance as Monoxide of carbon, that is harmful and that can cause respiratory problems in exposed people (WHO, 2006).

IAP is associated to 1.6 millions of deaths (WHO,2002). There exist studies that found association between exposure to contaminants produced by firewood with health problems: Balakrishnan et al. (2004), Dasgupta et al. (2004a and 2004b), McCracken and Smith (1998), Naeher et al. (2001), inter alia. These studies are related to exposure of firewood in household use with incidence of acute respiratory infections (Ezzati et al. 2002), low birth weight for children with exposed mother (Boy et al., 2002), infant mortality (Hughes, et al. 2000) and cataracts in mature women that live a near border between Nepal and India (Pokhrel et al., 2005). Health of people is affected by diseases related with exposure to contaminants derived of firewood consumption, implying that this people have difficulties for to carry out activities such as studying, domestic tasks and participate in labor market, which in turn generate economic losses, specifically, lost wage and medical expenses to improve their health. According to 2010 Population Census, in Mexico there are 4.1 million of household using biomass fuels (almost all is firewood), so, these household could be at risk to suffer respiratory problems. In this paper the main question that we want to response is: Which are economic losses generated by the use of firewood in Mexican households?

Respiratory problems for exposition to IAP rise disease burden among population of countries and this fact can affects the operation of health systems, which need more economic resources and medical personal to face the problem. Additionally, when a person has health problems (in this case, respiratory problems) it affects in negative form her capacity to work, limiting her probability to participate in labor market, or can reduce her worked hours and this way, reduce her labor income. According to Grossman (1972), each indiviual born with health endowment but his health depreciates across time but, he can produce health with inputs such as good alimentation, exercise and preventive care. The health, according to Currie and Madrian (1999) and Grossman (1999), can cosiders as part of human capital and has a positively relationship to ability of work, due the individual can work, sacrificating leisure, gain earnings and to buy health inputs in the market and this way improve his health status.

So, you can observe that there exist links among fuel choice, exposure to contaminants and presence of health problems and health problems and labor force participation. Is important to explore which is the mechanism that constitute these links and if we want to establish a causal relationships. However, in the literature there are not studies that propose the issues jointly. For example, in literature about of health problems related to exposure to biomass solid fuels, the addressing the issue is to consider the exposure as exogenous variable; is this case the studies cited above.We cannot consider these studies as causal studies.If we neglect the role of gender, ethnicity and bargaining among household members, which generate a bias in the estimates, pointed out by Pitt et al. (2006). These authors studied the effect of IAP on the incidence of respiratory disease in Bangladeshi households. In contrast with previous studies, their estimation strategy considered the endogeneity problems respect to cooking. They propose a household model that considers the division of labor within household, sharing this among women. Another study examining the effect in Los Angeles, California, Coffey (2003) shows that richer households choose to live in areas with low atmospheric pollution. Other possible resource of endogeneity is to assume exposure to fuel such as if household does not choose fuel or fuels that use. For example, could there be cultural reasons for use a determined fuel into household. Is possible to resolve the endogenity problem modeling the household fuel choice process and then, to model the exposure to firewood and its effects in health. If additionally we want modeling the relationship between health status and labor force participation could exist other endogeneity problem. If the health status is determined previously for the effect of exposure to firewood the relationship between health and labor force participation must be corrected, otherwise the estimates can be biased.

In Mexico, there are not causal studies about IAP and prevalence of respiratory diseases and there are not studies about of economic losses generated (lost wages, medical expenses, reduction in worked hours) by IAP. The first study about economic losses related with pollution is Margulis (1992) but in this study only consider gross estimation in aspects such as pollution in water, soil erosion, outdoor air pollution (not IAP). Most recently, Hoejer, et al. (2005) developed a similar work of Margulis and considered IAP. They estimated that IAP is related with approximately 3,000 deaths in Mexico. These studies are descriptive, have many limitations, however, are useful as starting point for studies more refined but, these studies only offer associations among variables but not causal relationships that determine which effects in respiratory problems are caused by exposure to contaminants derived to firewood.

There are not studies about the choice of household fuel in Mexico. This issue is important because if the patterns for use of household fuels are known is possible to design public policies that improve the access to people for fuels more clean and without harmful effects in their health and too, is possible the mitigation of damage to environment such as outdoor air pollution, soil erosion and deforestation (Heltberg, 2005). For Mexico, Fernandez and Islas (2005) developed a research about of patterns of use household fuels in the Mexican households. Their research contributes as the first investigation about important issue but this paper does not have a theoretical framework; however, *put the ball on the field* for others continue the study about of household fuel choice. Household fuel choice and relationship between IAP an respiratory diseases are important issues of study, but we do not know any paper that linking both issues, i.e., a study relates the choice of household fuels with exposure to fuels for cooking and health problems in people exposed. Many authors (Amacher et al., 1996; Heltberg et al., 2000; Gupta and Colin, 2006) propose an theoretical model where relate choice of use household fuel and environmental degradation but do not model the effects in the health of people. The literature about relationship between health status (or health problems) and labor force participation for Mexico is very few. There are two articles related with this topic. First, Parker (1999) studied the effect of health and salaries in the labor market for elderly people using the 1994 National Aging Survey. She found that people with bad health reduce their hourly earnings. Second, van Gameren (2008) used 2001 Mexican Health and Aging Study. He found a positive probability to participate in labor market for elderly people with good health status. The purpose in this paper is to response the main quiestion about which are economic losses generated by the use of firewood in Mexican households. Derived from this question arise specific questions such as: is there any mechanism within the household that defines which types of fuel use?; use of firewood causes helath problems in exposed people?, firewood is more harmful for health of people than LPG?; and, respiratory problems caused by firewood-based indoor pollution generates reductions in probability of participate in labor market?. We are interesting in to contrast the hyphotesis that people determine which types of fuel for cooking based-on their demographic, educational, cultural characteristics and available services in dwelling. Additionally, the use of firewood causes respiratory problems in exposed individual; firewood is more harmful to health than LPG. People with respiratory problems due exposure to firewood reduces his participation in labor market respect to use LPG.

Because potential problems of endogeneity described above, we propose an integrated model, for each individual, that determines the household fuel choice, the effect of chosen fuel in presence of respiratory problems and the effect of the latter in labor force participation. After, this model is econometrically implemented, using a national representative survey for Mexican people.

This research contributes in two ways. We model the process of household fuel choice and its effects in health of household members and, the effect of health in the labor force participation. After, we estimate an econometric model and to contrast the hypotheses. Firstly, a theoretical economic model is proposed: An individual is assumed to maximize utility across the choice at least one fuel for cooking[1], consumption of a composite good(related to food and other necessary goods) his health status (it is produced for each individual using health inputs purchased in the market and time for health), and time dedicated to produce health and for leisure; this utility function is subject to time (individual total time) and financial constraints, constituted for the total income generated for all members (labor and non-labor income) and non-negative constrains in fuels; additionally, for each individual there exists a labor supply function that depends to wage rate and health status. When the utility is maximized, the optimum levels of fuels, composite good, time dedicated to work, to produce health and lesisure and input to produce health. From the model, we can say that if a fuel is harmful for health, the individual will purchase less quantity than other fuel that is harmless for health. Our

[1] firewood or LPG

framework is better than other because we develop a theoretical model that permits to integrate the relationships because exposure to firewood with health status and labor force participation, a topic no developed in the literature about of important issue non developed in Mexico neither other countries.

Secondly, we propose an econometric model, specifically, a trivariate recursive probit, which model, an integrate way, the relationships among household fuel choice, health status and labor force participation. Although is not necessary to include exclusion restrictions in a recursive model (Heckman, 1978), we include a framework that is similar with Instrumental Variables (IV) framework. This model is estimated in similar way to three-step least squares, but, we use Maximum Simulated Likelihood because dependent variables are dichotomous. Respect to dataset,we use Mexican Family Life Survey (MxFLS) that is a representative survey of Mexican Population with multi-thematic information. After estimation model, we calculate conditional and join predicted probabilities and treatment effects of firewood in health problems and treatment effects of health problems in labor force participation, based-on Zhang, et al. (2009). Our empirical model estimate causal relationships due the econometric implementation making difference respect to previous studies such as Margulis (1992) and Hoejer et al.(2005). Finally, our research is a contribution to literature in fuel choice used in household, health status and labor force participation in Mexico.

The section 2 include the literature review; in section 3 is developed a theoretical model, section 4 contains econometric strategy, section 5 contains data and results and finally section 6 shows the discussion and conclusions.

2. Literature Review

On each of the research question there is an abundant literature: this is available, but there is a lack of integration; something we want to overcome in this paper. Nevertheless, we briefly describe the main findings for each one of the questions.

2.1 Determinants of fuel choice

Households use fuels for basic activities such as cooking and heating and these activities are important for the welfare of each household member. Heltberg et al. (2000) and Chen et al. (2006) explain that fuels are elements of utility function in households because these are necessary to generate energy that used in transformation of crude food in cooked food and energy necessary for heating too. Depending of its context, each family use one or more fuels, including biomass fuels (as firewood, coal, charcoal, crop residues and, dry dung of cattle) and modern fuels as LPG, biogas or electricity. There is a discussion on how households (or household members) choose fuels for cooking and heating. First, there are differences between biomass and modern fuels: the biomass fuels are cheaper than clean fuels (such as LPG or electricity) and its use not need special conditions but, biomass fuels are harmful to health of household members. WHO (2002) reports that approximately the middle of world population use biomass fuel; this population live in developing countries. There are countries as Bangladesh and India whose proportion that consumes is upper to 70%; Balakrishnan et al. (2004), Dasgupta et al.,(2004). WHO (2006) related the contamination for biomass (or Indoor Air Pollution) with problems as the poverty.

For choice of fuels that is used on households is involved many factors: accessibility to many fuels Heltberg (2005), for example LPG requires a net of high roads for to guarantee the provision of resource; also require the existence of cook stove in households. On the other hand, firewood not require special cook stove, in many places its access is free or cheaper. Other factors are the cultural characteristics of region or country. There are two approaches for explain how is the choice process but first must to explain how to relate, based on economic theory, the choice of fuels could be modeling as an adoption technology process, using of framework of the model of random utility proposed in McFadden (1974) and Manski and McFadden (1981), which methodology is common used in the literature about of this issue. The first work that proposes this framework is Amacher et al. (1996); they investigated the relationship between consumption of firewood and deforestation in Nepal; their results say there is a positive relationship between consumption of firewood and deforestation because the poverty of people: poverty people is incentivated clearing forest and typically practice subsistance agriculture. Heltberg et al. (2000) relate the choice of household fuel and forest degradation in India; their results say households choose of fuels based on the stock of forest; when stock is reduced, so they replace firewood or other fuels as coal.

Jumbe and Angelsen (2011) find that in Malawi the determinants of use of firewood as fuel is related to aspects such as distance for the resources and the existence for plantation managed in harmony with environment. Heltberg (2005) finds, for Guatemalan households, the household fuel choice is determined for family income, opportunity costs of firewood and that is possible observe the use of multiple fuels and the use of LPG is realized in household with members more educated. Gupta and Kohlin (2006), for their study of household fuel in Kolkata in India, showed that education of household head is positively related with consumption of kerosene and LPG and negatively related with firewood and coal. Chen et al. (2006) found that education is negatively related with the use of firewood but is insignificant in the consumption of coal in Jiangxi, China. Israel (2002) shows that there are barriers for the choice of LPG in Bolivian households and the access for major economic opportunities for women reduce the consumption of firewood. Pundo and Fraser (2003) show the education of spouses and dwelling characteristics are important determinants for cooking fuel choice in Kenya. Ouedraogo (2006) finds, for households in Burkina Faso, the switching of biomass fuels to LPG and kerosene is strongly related with factors as poverty, specifically the possession of electricity in the household. All those studies model the choice of household fuel for cooking but others use of fuel in the household is for heating: Braun (2010) finds that the choice of fuel for heating in German households is determined for dwelling characteristics. Couture et al. (2012) modeling the choice household fuel for heating in French households; their results are counter-intuitive: they say that people more educated use more firewood and less LPG because people more educated is more susceptible to global warming and they recommends to subsidize the consumption of firewood: there are too much evidence that the excessive use of firewood is related with deforestation, soil erosion [2] and generate health problems WHO (2002).

What tell the experts about of the process for choice fuel? There are two approaches that are opposed; the first approach is the energy ladder model and the other is multiple fuels model: Leach (1992), Masera, et al. (2000). Based in literature review, neither energy ladder model nor multiple fuels can explain all processes of adoption in all areas; however, these theories could be a base for to research the theme.

The energy ladder model propose as main idea that the people switching from biomass fuels to modern fuels; this switching is related to improve of household income and the modernization process of cities because to economic development in developing countries. Analyzing data of many developing countries, Leach (1992) proposed that is occurring an energy transition in them; poor household begin using firewood but, according its income grow, household acquire fuels less damage as charcoal and, finally will use clean fuels as LPG or electricity. The option for switching is available in urban areas moreover the access to clean fuels improves the welfare of members of households, as noted by Smith et al. (2005). For this approach Davis (1998) assessed the effect of electricity in the transition energy. His results do not showed strong evidence that energy ladder model is fulfilled in South Africa because the people do not remove completely consumption of biomass fuel.

The multiple fuels model postulates that households use several fuels, i.e., fuels are complementary and not sustitutes. Masera et al. (2000) developed a study in rural Mexican municipality with access to biomass and modern fuels with the finality to assess if energy ladder model apply in Mexico. They have demonstrated that this model not applied in Mexico. Instead, they found that the people use multiple fuels. They explain that the energy ladder fails in Mexico due that there are not unidirectional switching, i.e., not necessarily remove biomass fuel. Households have preferences for cook determined food with determined fuels, example tortillas with firewood in *comal* . Finally, they concluded that economic development does not correlate with pollution reduction. Heltberg (2005) concludes that in Guatemalan households is possible to find many that consume multiple fuels but is only in urban areas. After of review both approaches, is difficult to generalize one or another model for explain other contexts in other societies. Is difficult

[2]Heltberg et al. (2000), Chen et al. (2006) and Amacher (1996) explain that the use of firewood is associated with deforestation, soil degradation and other environmental problems

to establish with clarity about that is endogenous degree in adoption fuels matters, is because we decided to model choice of household fuel.

2.2 Firewood and respiratory illnesses

The literature about health problems related with exposure to contaminants of biomass (firewood, charcoal, and others). World Bank, WHO, Universities and Centers of Research had developed studies about of theme, principally in rural areas in developing countries. The principal issues in health are related with respiratory problems, is because the most papers are related to epidemiological aspects. According to The World Health Report 2002 of WHO, there is evidence that biomass fuels are associated with health problems, specifically, respiratory diseases.There are many studies that associate the exposure to contaminants produced by firewood with health problems: Balakrishnan et al. (2004), Dasgupta et al. (2004a and 2004b). In these articles is used measures as concentration of contaminants in specific areas in dwelling, such as bedrooms or cooking room and it is considered as potential risk for health. The results show that there is positive association between high concentrations of contaminants and prevalence of respiratory problems. However, Dasgupta et al. (2004b) show importance of ventilation factors in dwellings in the mitigation of health risks. These factors are cooking room located in open areas, roofs and walls with permeable material, which disperse the smoke and particles derived of firewood consumption.

Other side, there exist studies that use measures of particles realized on people or use questionnaires about symptoms related to health problems. These studies related exposure to firewood in household with incidence of acute respiratory infections (Ezzati et al. 2002), low birth weight children of expose mother (Boy et al., 2002), infant mortality (Hughes, et al. 2000) and cataracts in mature women a border between Nepal and India (Pokhrel et al., 2005). Naeher et al. (2001) find for study in Guatemala, that households exposure to carbon monoxide due consumption of firewood have more health problems that household with less exposure.

The problem with the consumption of firewood and others biomass is that these there are incomplete burning [3]. Incomplete burning is that the fuel not consume totally, for this reason there are particles suspended in the air that contain toxic substance as Monoxide of carbon, that is harmful and that can cause respiratory problems in exposed people. This problem may worsen if households do not have ventilation resource such as cooking room located in open areas, roofs and walls with permeable material that permits dissipate the pollution but it non dissapear. In mentionated studies the principal drawback is that consider as exogenous the levels of exposure to contaminants in exposed people, but is possible that there exist tasks established in households for each member according his gender or place occupied in hierarchical structure within house-

[3] "Fuel for life", WHO (2006)

hold. Pitt et al. (2006) include in their analysis the time of exposure, which is positive association with probability of suffer respiratory problems. Moreover, they consider exposure as endogenous, specifically, that it depends the type of relationship that woman has with household head. The mother of household head designs who women cook and who dedicate to work in farm. When we correct for endogeneity of exposure time, the effect in exposure time in presence of respiratory problems is higher than estimates without correct the bias. Finally, we demostrate that the presence of ventilation factors is irrelevant in mitigation of presence of respiratory problems.

2.3 Health problems, firewood vs. LPG

As detailed above, the exposure to contaminants derived of consumption of firewood is associated with health problems. Smith, et al. (2005) and many studies carry out by Energy Sector Management Assistance Program(ESMAP) detail the advantages of LPG versus firewood. Specially, LPG is not related to health problems and it is more efficient than biomass fuels. Smith, et al. (2005) developed a replicable experiment cooking rice with different combinations of fuels and kind of stoves to determine efficiency and contaminants liberated in burning. In the figure 1 you can observe that LPG burn up totally but biomass fuels have incomplete combustion, therefore make sense to study the damage of health for consumption of all fuels and to compare the effects for each fuel. Fuel is less inefficient than LPG and more contaminant. Moreover, the Mexican Census Population 2010 shows that approximately 15% household in Mexico use firewood for cooking. Because there is not literature about this cause-consequence question, our paper will contribute to respond this question.

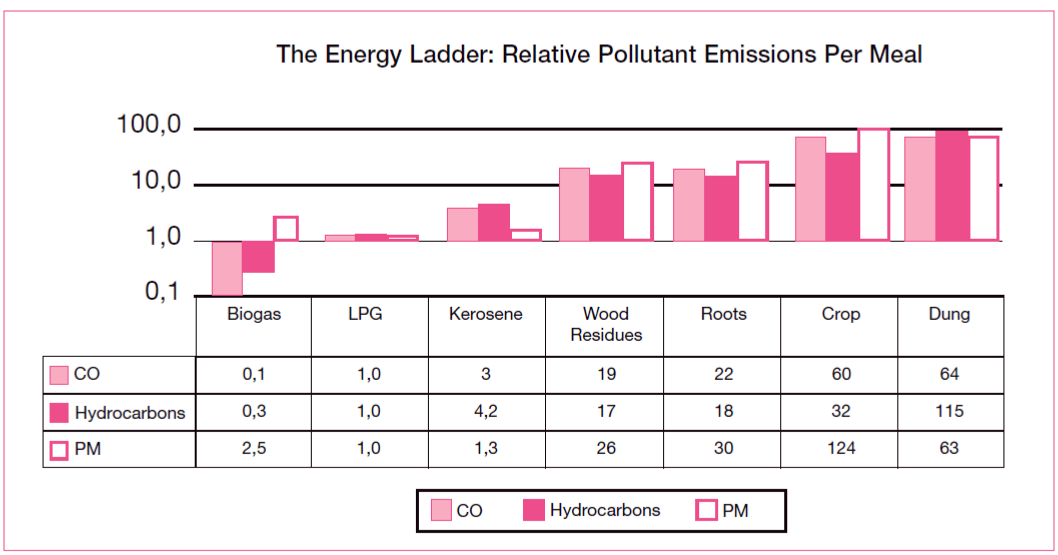

Figure 1.

Source: Extracted of Smith, et al.(2005). Logarithmic scale. The values are shown as grams per megajoule of energy delivered to the cooking pot (g/MJ-d)

2.4 Indoor air pollution and labor force participation, firewood vs. LPG

Many diseases related to firewood consumption imply economic losses, specifically, lost productivity (for example, lost worked hoursand) and medical expenses, which limits participation in household activities, labor market, schooling, all which can adversely household development. The relation between illness caused by firewood-based indoor pollution and economic losses has been not studied. In respect of medical expenses,in a study realized in India, Hughes and Dunleavy (2000), found a positive relation between use of firewood and infant mortality[4] for respiratory causes, using a survival curves an DALYs [5] measure. After, they calculate monetary values for avoided deaths to reduce IAP, but in this case to talk about causality is not possible because the estimates are based-on relative risks and attributable factors obtain of other studies and these results are used for descriptive purposes, as starting point for studies (generally, case-control studies with few observations, with longitudinal more technical. In Mexico, a study with this kind is Hoejer et al. (2005). They calculated that the IAP generated economic losses in morbidity in 6.1 millions of U.S. dollars.

About relationship between illness caused by firewood-based indoor pollution, the problem there are not studies with causal framework. Duflo et al. (2007) argument that the problems of IAP can generate lost productivity, specifically, in reduction in labor force participation and lost worked hours. Kishore and Spears (2012) find that the use of improved kitchen improves the well-being of people respect to people that do not use it. Although do not developed causal studies on the effects exposure to firewood and labor variables, there exist studies related to health status (or health problems) and its effects on labor aspects such as labor force participation, worked hours and labor earns. An issue is the difficulty to measure correctly the health status on the people due endogeneity problems and difficulty to measurement problems [6]. Sickness should make people less productive, but is difficult measure his health status, point out Schultz and Tansel (1997). These authors studied wage and labor supply effects of illness in two African countries: Ghana and Ivory Coast. The problem is the measurement error when you measure the health with self-report of individual. Its implications are endogeneity, so the estimates are incorrect. Using disabled days as health measure and corrected the endogenity by to use relative food prices and local health infrastructure, they found the disability days reduce wage by at least 10% and hours by 3% or more, although they did not estimate impacts in probability of labor force participation, something that we will make.

Tsafack and Zamo (2010) studied the effect to fertility on health status and this in la-

[4]Infant mortality is refereed on child under five years

[5]DALY is Disability-adjusted life year

[6]Is complicated find a good measure that reflect to health status. Self-perception health may introduce another source of endogeneity resulting from the possibility that people out of the labor force report poor health to justify their non-participation, Cai (2010)

bor force participation in female workers in Cameroon. Using a simultaneous-equations model and 2SLS[7], they found a negative effects of fertility in health status (self-reported) and turn in labor force participation. Kidd et al. (2000) assess if there are differences among able-bodied and disabled men in United Kingdom. Correcting by selectivity, they found that there is a discrimination component in differential of wage among able-bodied and disabled men. Cai (2010), evaluated the relationship between health and labor force participation for male and female Australian workers. Correcting endogenity in three ways (presents by measurement error, simultaneity and unobserved heterogeneity) he uses panel data simultaneous equation model, dividing in estimates for men a women and he found positive effect of health in labor fore participation and rejects exogeneity of health measurements.

In other cases, other health measure is used: the presence of chronic disease and its relationship with labor force participation. Zhang et al. (2009) the impact of several chronic diseases (diabetes, cardiovascular diseases, mental diseases and others) in labor force participation in Australia. All diseases are measured for responses by individual with exception mental state (which is measured with a test). Using a cuadrivariate endogenous probit, they found negative impact of prevalence of chronic diseases in labor force participation, which differ by gender. The authors showed is right to correct by endogeneity. Brown III et al. (2005) researched the impact of diabetes on employment in American people that live near to border with Mexico. Using genetic factors (familiar history of diabetes) as instrumental variables, they using a bivariate endogenous probit for to correct endogeneity. Their results show that exist negative relationship between diabetes and labor force participation, but is significant only for men. Chatterji et al. (2011) estimate effects of recent psychiatric disorders on employment, hours worked and wages. They use the National Comorbidity Survey-Replication of United States, and diagnostics are determined by questionnaire. They using a bivariate endogenous probit and 2SLS models and they find negative effects of presence in psychiatric diseases in labor force participation, wages and hours worked.

For Mexico, there is two studies related with health status and labor force participation (LFP) and both research in elderly people. First, Parker (1999) studied the effect of health and salaries in the labor market for elderly people using the 1994 National Aging Survey. She found that people with bad health reduce their hourly earnings. Second, van Gameren (2008) used 2001 Mexican Health and Aging Study. He found a positive probability of LFP with good health status. Both studies using IV method for to correct measurement error due health status is measured by self-report health.

[7] 2SLS is Two-stage least squares

3. Theoretical Model

The consumption of fuels is an important resource for developing activities such as cooking and heating, and this fact generate utility of each individual that use them. The purpose of this section is to propose a theoretical model that links the process that each individual make to choose fuel (or fuels) for cooking and heating within household and presence of health problems (specifically, respiratory problems)and its effects in labor force participation.

For our model, we based on papers about choice of household fuel or amount of household fuel: Amacher et al. (1996), Heltberg et al. (2000), Gupta and Colin (2006), Chen et al. (2006) and Chaudhuri and Pfaff (2003). In these papers, the authors propose an economic model in a framework to maximization constrained problem. They assume households that maximize their utility through to choose a fuel for cooking or heating, subject to constraints such as expenditure, production functions of rural goods, collection function of firewood. In their solutions, the household finds the optimum quantities of produced goods. The first models that explain this are Amacher et al. (1996) and, Heltberg et al. (2000). For our purposes, these models only are useful for the first part, i.e., to model of fuel choice but we need to model of second part that is the relationship between exposure to fuel and health problems.

For the second part, there are many papers that model maximization of utility of the household in relation with characteristics related with health: Nutrition and health as Strauss and Thomas (1998), Pitt et al. (1990a). Others as Pitt et al. (1990b) propose the effects of illness in child under five years in the time for dedicated for school in siblings woman; the difference with others papers is that in that model the household maximizes a health production function. We base-on Pitt et al. (2006) because they propose a function related to exposure to fuel (in that case, firewood) and health problems; however, there is not a process for to choose fuels, all households cook only firewood.

We assume that an individual A obtain utility consuming fuels for cooking, a composite good such as food, when he has good health status, that is produce by himself; he obtains too utility dedicating time for produce health and for leisure. This fact is represented by his utility function, that is based-on his personal characteristics:

$$U = U\left(F_1, ..., F_J, C, H, T^H, T^L; \mathbf{X^P}\right) \tag{1}$$

C is a composite good (Hicksian good with price normalized to one),

F_i is the amount of household fuel i, i=1,...,J,

T^H Time dedicated to produce health

T^L Time dedicated to leisure

X^H is a vector of personal characteristics,

Inidivual A can use one or more fuels for cooking, provided that these fuels generate utility for individual. For example, any people prefer to use LPG not firewood, so that utility generated by firewood is zero in this case. Based-on literature review, we can propose the signs of derivatives on utility functions.

$$\frac{\partial U}{\partial F_i} \geq 0 \quad \text{For every fuel i=1,...,J} \tag{2}$$

$$\frac{\partial U}{\partial C} > 0, \quad \frac{\partial U}{\partial H} > 0, \quad \frac{\partial U}{\partial T^H} > 0, \quad \frac{\partial U}{\partial T^L} > 0 \tag{3}$$

According to economic theory [8] the consumption of food and leisure increase utility of people, therefore the signs of partial derivatives of utility function respect these arguments is positive. Based-on Grossman (1972), health status is considered as part of human capital and is postively related with utility. Moreover, if individual dedicates time to produce health, this fact improve health, according to Grossman (1999). Individual A needs to maximize his utility choosing at least fuel used for cooking, quantities of compisted good, time for dedicated produce to health and leisure and optimum level of health, and this latter is produced by individual A, and this faces a maximization problems subject to an expenditure and time constraints, and his health production, which is produced using technology function:

$$H = H\left(F_1, ..., F_J, S, T^H, C; \mathbf{X^P}\right) \tag{4}$$

Individual health is produced based-on types of fuels used for cooking, which can affect negatively or non-affect the health[9] such as firewood, coal or dung, according to Smith et al. (2005). Health is produced when individual uses inputs S that are bought in the market; these inputs are medicines, vitamins, pay for gym, and others. Input's price is denoted P_S. Consumption of composite good increase the individual health. Time for dedicated to produce health is important because it can increase health; this time is related with activities such as practicing sports. The signs of derivative of health production function are:

$$\frac{\partial H}{\partial F_i} \leq 0 \quad \text{For every fuel i=1,...,J} \quad \text{(to prove)} \tag{5}$$

[8] Deaton and Muellbauer (1980)

[9] we will prove this fact through to resolve of model

$\frac{\partial H}{\partial S} > 0$ (Grossman, 1999)

$\frac{\partial H}{\partial C} > 0,$ (to prove)

$\frac{\partial H}{\partial T^H} > 0$ (Grossman, 1999)

Individuals choose at least one fuel for cooking and their choice is made based-on personal characteristics such as age, education, and others. There are papers that relate the exposure to biomass fuel (firewood, charcoal and coal) with the prevalence of respiratory diseases but they assume that the choice of fuel is exogenous; however, if the choice household fuel is not exogenous, the exposure to fuel for household member cooking is not exogenous and the relationship proved empirically by the literature, such as Ezzati et al.(2002), Boy et al. (2002), Hughes, et al. (2000), Pokhrel et al. (2005) and Pitt et al. (2006) have problems of endogeneity; is the reason for our model is important because will permit to answer this question. Individual has a total allocation of time, which is share among three activities: work, leisure and production of health.

$$\overline{T} = T^W + T^H + T^L \tag{6}$$

$\overline{T}$ is the total allocation time,

T^W is time to work,

T^H represents time to produce health,

T^L is the time for leisure

The expenditure constraint is used to buy composite good, inputs for health and fuels for cooking and it is funded with labor and non-labor income and w is a wage rate.

$$C + \sum_{j=1}^{J} P_j F_j + P_S S = \overline{Y} + w(? \tag{7}$$

$\overline{y}$ is non-labor income. Substituting equation (6) in (7):

$$C + \sum_{j=1}^{J} P_j F_j + P_S S = \overline{Y} + w(\overline{\mathbf{T}} - \mathbf{T^H} - \mathbf{T^L}) \tag{8}$$

Reordering (8), we obtain equation 9.

$$C+\sum_{j=1}^{J}P_jF_j+P_SS+w(T^H+T^L)=\overline{Y}+w\overline{T} \tag{9}$$

Equation 9 is called **Full-income constraint**. This equation represents the purchasing power of individual A, which can be spent in composite good, fuels for cooking, inputs for health and time to produce health and time for leisure. Equation's name apppears in Deaton and Muellbauer (1980). We assume that fuel are used in non-negative quantities and at least one fuel is used. All prices of fuels are strictly positive.

$$F_j \geq 0 \quad \text{For each j=1,...,J} \tag{10}$$

With respect to utility function, we assume that $u \in C^2$ respect to all variables. The Problem of Maximum Constrained is showed in equation (11):

$$\max_{F_1,...,F_J,C,S,T^H,T^L} U=U\left(F_1,...,F_J,C,H,T^H,T^L;\mathbf{X^P}\right) \tag{11}$$

subject to:

$$C+\sum_{j=1}^{J}P_jF_j+P_SS+w(T^H+T^L)=\overline{Y}+w\overline{T}$$

$$F_j \geq 0 \quad \text{For each j=1,...,J}$$

Link between health problems and labor force participation is through the labor suplly function. Individual A offers his labor based-on wage rate paid in the market and his health status. Zhang et al. (2009) and Brown III et al. (2005) showed there is negative relationship among health problems[10] and labor force participation. Economic theory shows that there is positive relatioship between wage rate and labor force participation.

$$L^w=L^w\left(w,H\right) \tag{12}$$

And its derivatives:

$$\frac{\partial L^w}{\partial w}>0, \quad \frac{\partial L^w}{\partial H}>0 \tag{13}$$

[10]or positive between good health and labor force participation

From equation (13) we can explain the effect of fuel that is harmful for health in labor force participation. Replacing (4) in (12), we obtain:

$$L^w = L^w\left(w, \mathbf{H}\left(\mathbf{F_1}, ..., \mathbf{F_J}, \mathbf{S}, \mathbf{T^H}, \mathbf{C}\right)\right) \tag{14}$$

Applying chain rule to (14) we obtain the change in labor force participation respect to fuel i:

$$\frac{\partial L^w}{\partial F_i} = \left(\frac{\partial L^w}{\partial H}\right)\left(\frac{\partial H}{\partial F_i}\right) \tag{15}$$

The sign in (15) is non-positive because first term in right side is positive but sign of second term can be zero or negative, depending if fuel i is harmful for health or not. Returning to maximization problem of individual A, the Lagrangian function for this problem is showed in the following equation

$$\begin{aligned} \mathcal{L} &= U\left(F_1, \ldots, F_J, C, H\left(F_1, \ldots, F_J, C, S, L^H\right), T^H, T^L\right) \\ & \lambda\left(\overline{Y} + w\overline{T} - C - \sum_{j=1}^{J} P_j F_j - P_S S - w\left(T^H + T^L\right)\right) + \gamma_1 F_1 + \ldots + \gamma_J F_J \end{aligned}$$

Kuhn-Tucker conditions:

$$\frac{\partial \mathcal{L}}{\partial F_i} = \frac{\partial U}{\partial F_i} + \frac{\partial U}{\partial H}\frac{\partial H}{\partial F_i} - \lambda P_i + \gamma_i = 0 \quad \text{for each fuel i=1,\ldots,J} \tag{16}$$

$$\frac{\partial \mathcal{L}}{\partial C} = \frac{\partial U}{\partial C} + \frac{\partial U}{\partial H}\frac{\partial H}{\partial C} - \lambda = 0 \tag{17}$$

$$\frac{\partial \mathcal{L}}{\partial S} = \frac{\partial U}{\partial H}\frac{\partial H}{\partial S} - \lambda P_S = 0 \tag{18}$$

$$\frac{\partial \mathcal{L}}{\partial T^H} = \frac{\partial U}{\partial T^H} + \frac{\partial U}{\partial H}\frac{\partial H}{\partial T^H} - \lambda w = 0 \tag{19}$$

$$\frac{\partial \mathcal{L}}{\partial T^L} = \frac{\partial U}{\partial T^L} - \lambda w = 0 \tag{20}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = \left(\overline{Y} + w\overline{T} - C - \sum_{j=1}^{J} P_j F_j - P_S S - w\left(T^H + T^L\right) \right) = 0 \tag{21}$$

And slacknesses complementary constraint:

$$\gamma_i \geq 0, \quad F_i \geq 0, \quad \gamma_i F_i = 0 \quad \text{for each fuel i=1,...,J} \tag{22}$$

In (22) we must prove if constraints are active (i.e., if gamma is zero) or inactive (if gamma is positive). If γ_i is zero means that individual A uses Fuel i. Because there are J fuels, so there exist 2^J cases respect to values of gammas[11]. For our purposes, we are interesting in one case, when all gammas are zero, i.e., when all slacknesses constraint are actives, it fact implies interior solution[12]

From Kuhn-Tucker conditions, we can find relationship for the analysis of model. Reordering (20) we can obtain the sign of λ:

$$\lambda = \frac{\frac{\partial U}{\partial T^L}}{w} > 0 \tag{23}$$

In (23), λ is positive because marginal utility of leisure is positive and wage rate too. In this case, λ represents of marginal utility of full income. Replacing (23) in (18) we obtain marginal productivity in health respect to health inputs:

$$\frac{\partial H}{\partial S} = \left(\frac{\frac{\partial U}{\partial T^L}}{\frac{\partial U}{\partial H}} \right) \left(\frac{P_S}{w} \right) > 0 \tag{24}$$

In (24) is showed that the marginal productivity in health of inputs health is positive and increase when inputs price is bigger than wage rate. The expression is positive because the ratio of marginal utilities od leisure and health are positive. This expression is postulate by Grossman's Model. Similarly, replacing (23) in (19) we obtain marginal productivity in health of time to produce health:

$$\frac{\partial H}{\partial T^H} = \frac{\frac{\partial U}{\partial T^L} - \frac{\partial U}{\partial T^H}}{\frac{\partial U}{\partial H}} \tag{25}$$

Based-on Grossman's model, we assumes that marginal productive in health respect time dedicated to health is positive; for this is necessary that marginal utility for leisure

[11] For a good reference about issue, you can revise Sundaram (1996)

[12] Sundaram, op. cit.

let bigger than marginal utility of time for health. Marginal productivity of health due to composite good is obtained replacing (23) in (17):

$$\frac{\partial H}{\partial C} = \frac{\frac{1}{w}\frac{\partial U}{\partial T^L} - \frac{\partial U}{\partial C}}{\frac{\partial U}{\partial H}} \tag{26}$$

In (26),for marginal productivity let positive is necessary that marginal utility of leisure, weighted by wage rate, let bigger than marginal utility of composite good. Finally, we need to prove the effect of use of fuel in health status of individual A, for this, replacing (23) in (16):

$$\frac{\partial H}{\partial F_i} = \frac{\frac{P_i}{w}\frac{\partial U}{\partial T^L} - \frac{\partial U}{\partial F_i}}{\frac{\partial U}{\partial H}} \quad \text{for each fuel i=1,. . . ,J} \tag{27}$$

In (27) all elements are positives. Conditions to obtain that derivative of health respect to fuel i is non-positive is that marginal utility of fuel i is at least equal to marginal utility of leisure multilpied by price of fuel and divided to wage rate. If fuel k is harmful for health, it means that second term in numerator is bigger than first term, so derivative is negative, it is, if individual A consumes fuel k obtains utility but this fuels increase his risk to have respiratory problems but fuel is consumed due this fuel satisfy a basical necessity in short term, cooking and respiatory problems can be caused after exposure to fuel. Moreover, if price of fuel i is cheap, even smaller than wage rate, first term in (27) is more little than second, resulting in a negative expression. If any fuel k is harmless for health, partial derivative of health respect to fuel k is zero.

Which are effects in labor supply due to fuels, health inputs, composite good and time dedicated to produce health? From (14) we can derive respect to mentioned elements. (27) can be replaced in (15):

$$\frac{\partial L^w}{\partial F_i} = \left(\frac{\partial L^w}{\partial H}\right)\left(\frac{\frac{\mathbf{P_i}}{\mathbf{w}}\frac{\partial \mathbf{U}}{\partial \mathbf{T^L}} - \frac{\partial \mathbf{U}}{\partial \mathbf{F_i}}}{\frac{\partial \mathbf{U}}{\partial \mathbf{H}}}\right) \leq 0 \tag{28}$$

(28) implies that if any fuel is harmful for health, i.e., generates respiratory problems, inidividual A will be sick and this fact will reduce his participation in labor market, so the effect of fuel in labor force participation is negative. Therefore, we propose that the effect of fuel in labor force participation is across health status, the latter has an effect in labor force participation. If fuel is harmless to health, the effect in labor force participation is zero. Deriving (14) respect to health inputs, we can obtain the effects in labor force participation when individual i to invert in health inputs:

$$\frac{\partial L^w}{\partial S} = \left(\frac{\partial L^w}{\partial H}\right)\left(\frac{\partial H}{\partial S}\right) \tag{29}$$

Replacing $\dfrac{\partial H}{\partial S}$ in (29) by (24) obtain:

$$\frac{\partial L^w}{\partial S} = \left(\frac{\partial L^w}{\partial H}\right)\left(\frac{\dfrac{\partial \mathbf{U}}{\partial \mathbf{T^L}}\dfrac{\mathbf{P_S}}{\mathbf{w}}}{\dfrac{\partial \mathbf{U}}{\partial \mathbf{H}}}\right) \tag{30}$$

$$\frac{\partial L^w}{\partial T^H} = \left(\frac{\partial L^w}{\partial H}\right)\left(\frac{\dfrac{\partial \mathbf{U}}{\partial \mathbf{T^L}} - \dfrac{\partial \mathbf{U}}{\partial \mathbf{T^H}}}{\dfrac{\partial \mathbf{U}}{\partial \mathbf{H}}}\right) \tag{31}$$

In (30) we can observe that both terms in right side are positive, it implies that if individual A inverts in health inputs, it fact increase his health and this increase to probability of participate in labor market. Analogously, we can obtain the derivative of labor supply respect of time to produce health[13].

The effect of health time in labor supply is positive but is lower than effect of health inputs: if individual A dedicates more time to produce health, the latter increases and this fact can increase labor force participation, but if individual dedicates more time for health it reduce net time disposable for work, then the effect in labor force participation is positive but lower than if relationship between $\dfrac{P_S}{w}$ is equal or less than one.

Finally, the effect of consumption of composite good in labor supply is positive because if individual A increase his consumption of C[14] this fact implies that good alimentation improve health and this implies to improve probability to participate in labor market. Based-on results about theoretical model, we estimate an econometric model to contrast, empirically, if these results have a right signs and partial derivatives, and this fact can give validity the model.

$$\frac{\partial L^w}{\partial C} = \left(\frac{\partial L^w}{\partial H}\right)\left(\frac{\dfrac{\mathbf{1}}{\mathbf{w}}\dfrac{\partial \mathbf{U}}{\partial \mathbf{T^L}} - \dfrac{\partial \mathbf{U}}{\partial \mathbf{C}}}{\dfrac{\partial \mathbf{U}}{\partial \mathbf{H}}}\right) \tag{32}$$

[13]Deriving (14) respect to T^H and replace $\dfrac{\partial H}{\partial T^H}$

[14]We assume increase C in levels that is harmless of individual A

If we assumes a Cobb-Douglas specification for utility function with J fuels, health production function and labor supply [15], is more clear to understand the effects obtained in theoretical model. Then, the next equations are three fucntions:

$$U = F_1^{\alpha_1} \dots F_J^{\alpha_J} C^{\alpha_{J+1}} H^{\alpha_{J+2}} \left(T^H\right)^{\alpha_{J+3}} \left(T^L\right)^{\alpha_{J+4}} \quad \text{Utility function} \tag{33}$$

$$H = F_1^{-\beta_1} \dots F_J^{-\beta_J} C^{\beta_{J+1}} S^{\beta_{J+2}} \left(T^H\right)^{\beta_{J+3}} \quad \text{Health production function} \tag{34}$$

In (33) and (34), all coeficients (alphas and betas) are positive and sum one. In (34) coeficients in fuels are negative because we assume that all fuels are harmful for health and you derive health production function respect any fuel, the result is negative. Labor supply is:

$$L^w(w, H) = w^\gamma H^{1-\gamma} \quad \text{Labor supply function} \tag{35}$$

Replacing health production function in utility function and considering constraints explained above, we solve the maximization problem and find solution for fuels bought, composite good, health inputs and time dedicated to produce health and leisure.The only factible solution[16] is when all slacknesses complementary constraints are active (i.e., are multipliers are zero). The solution is:

$$F_j^* \left(\overline{Y} + w\overline{T}, P_1, \dots, P_J, P_S\right) = \left(\frac{\alpha_j - \beta_j \alpha_{J+2}}{P_j}\right) \left(\overline{Y} + w\overline{T}\right) \quad \text{for each j=1,...,J} \tag{36}$$

$$C^* \left(\overline{Y} + w\overline{T}, P_1, \dots, P_J, P_S\right) = \left(\alpha_{J+1} - \beta_{J+1}\alpha_{J+2}\right) \left(\overline{Y} + w\overline{T}\right) \tag{37}$$

$$S^* \left(\overline{Y} + w\overline{T}, P_1, \dots, P_J, P_S\right) = \left(\frac{\alpha_{J+2}\beta_{J+2}}{P_S}\right) \left(\overline{Y} + w\overline{T}\right) \tag{38}$$

$$T^{H*} \left(\overline{Y} + w\overline{T}, P_1, \dots, P_J, P_S\right) = \left(\frac{\alpha_{J+3} + \beta_{J+3}\alpha_{J+2}}{w}\right) \left(\overline{Y} + w\overline{T}\right) \tag{39}$$

$$T^{L*} \left(\overline{Y} + w\overline{T}, P_1, \dots, P_J, P_S\right) = \left(\frac{\alpha_{J+4}}{w}\right) \left(\overline{Y} + w\overline{T}\right) \tag{40}$$

[15] In appendix section we explain, in detailed way, the solution of maximization problem
[16] It will develop in appendix section

In (36) yoy can observe that demanded quantity of any fuel j is a proportion of total income and price of this fuel. Negative term (that is, the product β_j and α_{J+2}) expresses that fuel i is harmful for health, so individual A demands less quantity respect to other fuel k that is identical i (i.e., same price) but that is harmless for health. So, we conclude that any individual will demand more quantity of any fuel when is harmless for health respect a fuel with same price but that is harmful for health.

$$H^* (.) = \prod_{j=1}^{J} \left(\frac{\alpha_j - \beta_j \alpha_{J+2}}{P_j} \right)^{-\beta_j} (\alpha_{J+1} + \beta_{J+1} \alpha_{J+2})^{\beta_{J+1}} \left(\frac{\alpha_{J+2} \beta_{J+2}}{P_S} \right)^{\beta_{J+2}} \left(\frac{\alpha_{J+3} + \beta_{J+3} \alpha_{J+2}}{w} \right)^{\beta_{J+3}} \left(\overline{Y} + w\overline{T} \right) \tag{41}$$

$$L^{w*} (.) = w^{\gamma} \left(\prod_{j=1}^{J} \left(\frac{\alpha_j - \beta_j \alpha_{J+2}}{P_j} \right)^{-\beta_j} (\alpha_{J+1} + \beta_{J+1} \alpha_{J+2})^{\beta_{J+1}} \left(\frac{\alpha_{J+2} \beta_{J+2}}{P_S} \right)^{\beta_{J+2}} \left(\frac{\alpha_{J+3} + \beta_{J+3} \alpha_{J+2}}{w} \right)^{\beta_{J+3}} \left(\overline{Y} + w\overline{T} \right) \right)^{1-\gamma} \tag{42}$$

In (41) and (42) you can observe effect direct the consumption of fuel i on health status and labor force participation. Coefficients from β_1 to β_J represents degree of damage of fuel i in health status. If fuel i is harmless to health, so health status is higher than if fuel i is harmful for health. In same way, labor force participation is higher when fuel i is harmless for health. This fact shows that if any fuel is harmful for health, it reduces health status and reduces labor force participation and this latter can reduce worked hours and labor income too.

4. Econometric Strategy

From theoretical model, we conclude that individual faces the decision about which fuels and that there exist two effects to consider due use of fuels for cooking: the effect of exposure to fuel on health status, specifically, effect in prevalence of respiratory problems. The second effects is respiratory problems on labor force participation. In literature about these issues, each one was studied in separate way, i.e., there are studies about determinants of fuel choice used for cooking and heating; there are studies too about relationship between IAP and prevalence of respiratory diseases and finally, sutdies about health problems (or health status) and labor force participation.

In literature about IAP and its effects in respiratory problems is typical to consider exposure to IAP as an exogenous such as studies cited in literature review section above. This fact is main drawback: the expousre can be endogenous because there exist factors that affect the decision about what household member is assigned to cooking. (Pitt et al., 2006) found, in Bangladeshi households, the distribution activities as cooking and farming work for women is assigned by household head's mother, in this obeys to status of women respect to household head, for example spouse youngest of houseghold head[17]

[17] In Bangladesh, as cooountry almost muslim, a man can married with four spouses

or women with children less five years is assigned to cooking, so these women are more exposed that other women in household, so that exposure to IAP is clearly endogenous. In this studie all households cooking with firewood. In countries as México, specially in rural areas, many tasks realized in household have clearly division for gender, for example cooking is defined as a task realized for women, therefore exposure to IAP cannot be exogenous in this context.

Respect to fuel used for cooking can exist other resource that become exposure to IAP in endogenous. If we take exposure to firewood or LPG as exogenous is possible that we obtain biased estimates if we run an econometric model. There exists widespread literature (described above in literature section) about of determinants of use fuels for cooking and heating. Variables as education, hoisehold income and live in urban area is related to use clean fuels such as LPG, electricity and Bio-Gas. Aditionally, Therefore, it necessary to consider this source and problems of accessibility, i.e., in many places there are not accessibility to all fuels or those require suitable infrastructure such as LPG. In other cases, the cultural habits determine the use of determined fuel or the use is related with economic factors, for example Fernández and Islas (2005) found that indigenous people is more propensity to use firewood than LPG in México.

Finally, in studies about relationship health status and labor force participation, the literature in this issue shows existence of endogenous problems due measurement errors in health status and simultaneity between health status and labor force participation. Cai (2010) shows that self-perception in health may introduce another source of endogeneity resulting from the possibility that people out of the labor force report poor health to justify their non-participation, Cai (2010). Sickness should make people less productive, but is difficult measure his health status, point out Schultz and Tansel (1997). In our case, endogeneity in health problems due that health problems is caused by exposure to firewood. Therefore, it necessary to correct these resource of endogeneity in exposure to fuels for cooking and prevalence of respiratory problems. For this reason we propose a multi-equation recursive model. In our case, there exist two fuels for cooking available in Mexico, other fuels, such as electricity, kerosene or charcoal are few used. Our dependent variables are dichotomous: use of fuel has two options: firewood and LPG. Respect to respiratory problems has two options: presence or ausence of respiratory problems, specifically, cough. Last variable is participate in labor market. In terms of Heckman (1978) we have a system of endogenous dummy variable. The character of this model is recursive: first, we estimates choice fuel for cooking, after probability of respiratory problem, including as explanatory variable fuel used for cooking. The last estimate probability of participing in labor market, including variable of respiratory problems as explanatory. We do not include variable of fuel in third equation because there are not theoretical and empirical reasons for including this variable in third equation[18]. This econometric implementation is appropriate to approach in complete way the

[18]Theoretical is referred our economic model and empirical means that we did not find in literature a model that include this variable

issues include in our study.

4.1 Trivariate Probit Model

We propose a multivariate recursive probit. This model is a generalization of bivariate recursive probit proposed in Maddala and Lee (1976) and Maddala (1983). The goal is to estimate of determinants of fuel used for cooking after, to estimate the effects on health of exposure to IAP, and finally the effect of health problems on labor force participation in Mexico. Let W^* a latent variable of labor force participation of each individual, which is determined by his health status H and other covariates. But the health status is assumed as determined for the exposure of fuels F and the latter for personal characteristics. So, the equation of labor force participation is:

$$W^* = X_W^{'}\beta_W + \zeta_H H + \varepsilon_W \tag{43}$$

From equation (43) you can observe that W^* depends to exogenous covariates $X_W^{'}$ and health status H. However, W^* is unobserved; we observe W that is determined for:

$$W = \begin{cases} 1 & if \;\; W^* > 0 \\ 0 & if \;\; W^* \leq 0 \end{cases}$$

W with value one is referred when the person participates in labor market and zero when does not. Respect to health problems is assumed as endogenous:

$$H^* = X_H^{'}\beta_H + \theta_F F + \varepsilon_H \tag{44}$$

In (44), is observed that health status depends to exogenous covariates $X_H^{'}$ and dummy about type of fuel, F, which has a value of one for firewood and zero for LPG. H^* is unobserved; we observe H that is obtained for:

$$H = \begin{cases} 1 & if \;\; H^* > 0 \\ 0 & if \;\; H^* \leq 0 \end{cases}$$

$$F^* = X_F^{'}\beta_F + \varepsilon_F \tag{45}$$

In (45) is observed that type of fuel depends to exogenous covariates $X_F^{'}$. But, F^* is unobserved; we observe F that is obtained for:

$$F = \begin{cases} 1 & if \quad F^* > 0 \\ 0 & if \quad F^* \leq 0 \end{cases}$$

F with value one indicates that individual use firewood and zero that use LPG. We can observe that is a trivariate recursive probit model due that two variables that operate as endogenous in each equation be explanatory in other. This kind of system are known as triangular endogenous structure[19] (Wooldridge, 2010 in chapter 9). In this system is observed that F is dependent variable in first equation but is explanatory in the second equation. Also, H is dependent in second equation but is explanatory in third equation. In many cases the dependent variable in first equation is explanatory in third equation too. The three equations are interrelated through the error terms. Assume that errors term are independent and identically distributed in all observations, following a trivariate normal distribution: $N \sim (\mathbf{0}, \mathbf{\Sigma}_3)$ [20]. For purpose of identification, each variance is assumed to be one. The covariance-matrix is:

$$\Sigma = \begin{pmatrix} 1 & \rho_{WH} & \rho_{WF} \\ \rho_{WH} & 1 & \rho_{HF} \\ \rho_{WF} & \rho_{HF} & 1 \end{pmatrix}$$

With this model, we can estimates jointly the three equations that relates to household choice fuel, health problems and labor force participation. Is not necessary that exogenous covariates to be differents for the identification of model. The only problem that all covariates are the same in three equations is too small variation in the data. Wilde (2000) explains in a Lemma: *The existence of one varying exogenous regressor in each equation is sufficient to avoid small variation identification problems in multiple equation probit models with endogenous dummy regressors*.However, we prefer include covariates of third equation in second equation and both covariates in first equation in similar way instrumental variables framework. In other side, the relationship between each pair of equations is showed for coefficient of correlation. Greene (2008) explains that these correlations are called *tetrachoric correlations* when we compare pairs of equations.

The probabilities related to three variables of interest are given by:

$$Prob(W = w, H = h, F = f) = \Phi_3 \left(q_w(\zeta_H H + X'_W \beta_W), q_h(\theta_F F + X'_H \beta_H), q_f X'_F \beta_F, \widehat{\Sigma} \right)$$

Where $q_w = 2w - 1$, $q_h = 2h - 1$ and $q_f = 2f - 1$. In each case q_m
m=w,h,f is 1 if w, h or f is 1 or -1 if w,h or f is 0, and $\widehat{\Sigma}$ as was defined above. The log-likelihood function is:

[19] A similar structure is used by Zhang et al. (2009)

[20] General case is detailed in Greene (2008)

$$logL = \sum_{i=1}^{N} log\Phi_3 \left[q_{iw}(\zeta_h H + X_{iw}^{'}\beta_w), q_{ih}(\theta_f F + X_{ih}^{'}), q_{if} X_{if}^{'}\beta_f | \widehat{\Sigma} \right] \tag{46}$$

The problem with equation (13) is that it requires to evaluate of multiple integral, triple integrals for this trivariate probit model. When is necessary to estimate models that use normal distribution is not possible to obtain closed-form solution, maximum likelihood estimation is very complicated method for obtain good and quick results, it is detailed in Greene (2008). Although there are many methods for to evaluate trivariate integration, the most adequate is GHK[21] simulator or Maximum Simulated Likelihood (MSL). The GHK simulator take advantage that a multivariate normal distribution function can be expressed as the product of conditioned univariate normal distribution functions, which can be evaluated in easy way.This transformation uses the probability conditional theorem [22]. In Cappellari and Jenkins (2003) is explained in detail the process of GHK simulator; the probabilities are obtained by simulation recursive process from inverse cumulative normal distribution R times. The simulated probability is then plugged into the likelihood function, and standard maximization techniques are used. The MSL estimator is unbiased, consistent when the number of draws and the number of draws tends to infinity. If the ratio of the number of draws to the square root of sample size is sufficiently large, so the simulation bias is reduced to zero [23]. Finally, the solution is obtained only when the convergence is obtained of course.

4.2 Calculation of conditional probabilities and treatment effects

A useful tool that can be obtained from this trivariate probit is predicted probabilities and treatment effects[24]. These measures is a source of information that can be used for understand the research problem in a better way. For example we can estimate what is probability of respiratory problems due to firewood and LPG or probability to participate in labor market conditional person is sick or not. When we deduct two conditional probabilities with same final result but different previous condition. For example treatment effect of firewood in prevalence of respiratory problem is probability of person is sick conditional to use firewood minus probability of person is sick conditional to use LPG. Based-on Smith et al. (2005) we expect this effect as positive. Zhang et al. (2009) explain that these probabilities imply ratios due are composite events. Treatment effect of firewood in respiratory problems is calculate in this way:

[21] GHK is called due Geweke, Hajivassiliou and Keane. A detailed survey about it can be revised Gourieroux and Monfort, (1996)

[22] $P(A|B) = \frac{P(A \cup B}{P(B)}$ Bayes' theorem

[23] Cameron and Trivedi (2005)

[24] We based-on this part in Zhang et al. (2009)

$$\widehat{P}\left(Disease=1|Firewood=1,X\right)=\frac{\Sigma_{w=0,1}\widehat{P}\left(LFP=w,Disease=1|Firewood=1\right)}{\Sigma_{w,d=0,1}\widehat{P}\left(LFP=w,Disease=d|Firewood=1\right)} \quad (47)$$

$$\widehat{P}\left(Disease=1|Firewood=0,X\right)=\frac{\Sigma_{w=0,1}\widehat{P}\left(LFP=w,Disease=1|Firewood=0\right)}{\Sigma_{w,d=0,1}\widehat{P}\left(LFP=w,Disease=d|Firewood=0\right)} \quad (48)$$

$$TE_{Firewood}=\widehat{P}\left(Disease=1|Firewood=1,X\right)-\widehat{P}\left(Disease=1|Firewood=0,X\right) \quad (49)$$

Analogously, we can calculate treatment effect of disease in labor force participation.

$$\widehat{P}\left(LFP=1|Disease=1,X\right)=\frac{\Sigma_{f=0,1}\widehat{P}\left(LFP=1,Disease=1|Firewood=f\right)}{\Sigma_{w,f=0,1}\widehat{P}\left(LFP=w,Disease=1|Firewood=f\right)} \quad (50)$$

$$\widehat{P}\left(LFP=1|Disease=0,X\right)=\frac{\Sigma_{f=0,1}\widehat{P}\left(LFP=1,Disease=0|Firewood=f\right)}{\Sigma_{w,f=0,1}\widehat{P}\left(LFP=w,Disease=0|Firewood=f\right)} \quad (51)$$

$$TE_{Disease}=\widehat{P}\left(LFP=1|Disease=1,X\right)-\widehat{P}\left(LFP=1|Disease=0,X\right) \quad (52)$$

Due that is the trivariate probit, we can observe eight posible results $2^3=8$, conditional probabilities are formed by these marginal probabilities.

5. Data

The data come from the Mexican Family Life Survey (MxFLS); this is a multi-thematic survey because it presents information about themes such as expenditure in consumption of household, socio-demographic characteristics, health and anthropometrics measure, violence, and dwelling characteristics (type of roof, walls, use of fuel in the households). MxFLS is a longitudinal survey with data representative for national and rural-urban level. There are two waves for this survey: 2002 and 2005. We use subsample of first wave only people aged 15-65 years, men and women. The reason for use this subsample is focus in people that potentially can participate in labor market, can be exposure to IAP and can choose fuels for cooking with finality to model of the process for choose fuel for cooking, the effect of latter in prevalence of respiratory problems and its effects in labor force participation.Is for this reason that we use variables that are related to this process. Aditionally, we estimate separated model by gender, because, structurally, labor force participation is different by gender, female participation, especially in married women, includes information about husband as salary and if they have childre. Mroz (1987) models female wage, specifiying labor force participating as endogenous. In total sample first wave there are 8,44o households and 35,677 people (17,154 men and 18,523 women). Our subsample consists 8,310 men and 10,483 women aged 15-65 and these observations have information in all variables used for analysis. In tables 1 and 2 are showed summarize statistical for men and women. List of variables are almost equal, the difference is in one variable: for men is include a dummy with value of one if person is household head and zero otherwise; for women is include a dummy with value of one if person has children under five years and zero otherwise. Three dicotomic variables denote respectively if person use firewood (one if use firewood, zero if use LPG). Variable of respiratory problem is cough, it has value of one if person has cough and zero is not. Labor force participation is wide sense of work: value of one denotes that person actually work , searched work or person worked without salary (in family business) and zero otherwise. Use of firewood is low, with proportions in women and men less to 0.4, but use is high in rural areas (up to 0.6) respect to urban areas (less to 0.2), but use is few different in women respect to men.

Table 1: **Summary statistics for men**

Variable	Mean	Std. Dev.	Min.	Max.	N
Household use firewood	0.355	0.479	0	1	8310
Person coughs	0.167	0.373	0	1	8310
Labor force participation	0.793	0.405	0	1	8310
Household have electricity	0.985	0.122	0	1	8310
Total expenditure of household	4,668.3	2,4852.2	0	1,453,310.2	8310
N. of members	4.884	2.21	1	17	8310
Person is indigenous	0.131	0.337	0	1	8310
% Households use LPG in municipality	0.799	0.239	0.01	0.99	8310
H. with cooking room	0.923	0.266	0	1	8310
Solid floor	0.875	0.331	0	1	8310
At least high school	0.163	0.369	0	1	8310
Age of person	37.976	17.681	15	94	8310
Person lives in urban zone	0.557	0.497	0	1	8310
Household head	0.613	0.487	0	1	8310

Prevalence of cough is lower in women and men but is slighty higher in women.

Due in rural areas more firewood is used, prevalence of cough is higher in rural areas than urban areas, this fact can be indicative of relationship exposure to firewood and prevalence of cough. Labor force participation is very high in men that women (0.79 versus 0.34) this fact confirms difference in participation by gender. Moreover, women in urban areas participate more respect to rural areas; respect to men, there are not significative differences of participation in labor market, for this, is irrelevant include this variable in equation of LFP[25].

Table 2: **Summary statistics for women**

Variable	Mean	Std. Dev.	Min.	Max.	N
Household use firewood	0.343	0.475	0	1	10483
Person coughs	0.207	0.405	0	1	10483
Labor force participation	0.342	0.474	0	1	10483
Household have electricity	0.986	0.116	0	1	10483
Total expenditure of household	4,571.9	22,505.9	0	1,453,310.2	10483
N. of members	4.896	2.207	1	17	10483
Person is indigenous	0.122	0.328	0	1	10483
% Households use LPG in municipality	0.796	0.244	0.01	0.99	10483
H. with cooking room	0.923	0.266	0	1	10483
Solid floor	0.875	0.331	0	1	10483
At least high school	0.128	0.334	0	1	10483
Age of person	37.464	16.775	15	98	10483
Person lives in urban zone	0.570	0.495	0	1	10483
Woman with children under 5	0.257	0.437	0	1	10483

Many characteristics of house are used for approximate well-being of people and its influence in decision of fuel for cooking to use; Ouedraogo (2006) found that poverty is positively associate to use biomass fuels as firewood and charcoal. Dummies about services as electricity (one is person has access), cooking room and solid floor (one if possess). Total expenditure of household is measured in pesos, number of members live in household; a big number of members can be relate to poverty. The accessibility to LPG is not same in all municipalities; is because that we use a source of variation that is percentage of households that use LPG in the municipality; this variable was obtained from 2000 Mexican Census. If person lives in municipality with acces to LPG, so is possible that person can be choose between both fuels, i.e., firewood and LPG. There exists a variable denotes cultural factor: person is indigenous or not. Fernández and Islas (2004) found that indigenous people use more firewood than non-indigenous people. Education of person (one is person studied at least high school completed) is positively asociated to use clean fuels such as LPG and electricity, according to Gupta and Kohlin (2006) and Grossman (1999) explain that people with education is more efficient in to

[25]We made statistical test of mean difference and could not reject of nule hyphotesis of mean equality. P-value is 0.8076

produce health, finally, education is positively related to participate in labor market. Age of person is important in determining choice fuel for cooking and labor force participation in women[26]. Respect to household head, you can observe that more half of men are household head and this fact can be positively related to LFP. Person with children under five years old can be negatively related to LFP in women.

Respect to which variables are included in each equations, in system for men and women, we propose in next two equations:

For men:

$$F = G\left(El,\ TEx,\ NMe.,\ Ind.,\ \%LPGmu\ Cookr,\ Sflo,\ HSch,\ Age,\ Urb,\ HH\right)$$

$$Cough = H\left(Firewood,\ Hsch,\ Age,\ Urb,\ HH\right)$$

$$LFP = G\left(Cough,\ Hsch,\ HH\right)$$

For women:

$$F = G\left(El,\ TEx,\ NMe.,\ Ind.,\ \%LPGmu\ Cookr,\ Sflo,\ HSch,\ Age,\ Urb,\ HH\right)$$

$$Cough = H\left(Firewood,\ Hsch,\ Age,\ Urb,\ Children < 5\right)$$

$$LFP = G\left(Cough,\ Age,\ Hsch,\ Urban,\ Children < 5\right)$$

Respect to equation of fuel choice (for men and women) is evident that instruments in this equation are electricity, solid fuel, percentage household in municipality that use LPG, cook room, total expenditure household, number of members and person is indigenous; these variables are used in other studies (in literature section you can see references) and determine which fuels is chosen for person in cooking activities; therefore, these variable only to be in this equation. Education variable, urban, age and household head appear too in this equation, and although determine too the choice fuel, these variables are part of other two equations and appear with identification purposes. In equation of cough, appears variable of fuel used for cooking, this fact justifies recursive feature of system; appear too education variable, age of person, urban variable and household head variable. Finally in LFP equation in men, appear cough variable, education and household head; the latter is only variable that is related with LFP equation and appear in other two equation with identification purposes. Analogously, in LFP equation for women children less five years is associated to LFP, in negative way.

[26]In men is not included in labor force participation equation becuase simple correlation between LFP and age is -0.0052; this fact can be related to men work due role to assigned in society and our subsample contemplates people with possibilities of participate in labor market (15 to 65 years old)

6. Results

In tables A and B are the results of trivariate recursive probit models for men and women and in both systems we run one hundred iterations with seed 123456789 in Stata Program. On choice fuel equation for men and women is observed that percentage of households that use LPG in municipality is useful as source of variation and other described variables. The probability of choice firewood is reduced when the percentage of households that use LPG in municipality rises, that is similar a accessibility to LPG. In households with total expenditure low is more possible that use firewood; this result is similar with results in Heltberg (2005) for Guatemala. The number of members is positively related with use of firewood both men and women. When man or woman is indigenous, increase the probability of use firewood; this fact is related to cultural factors. People that live in urban areas use more LPG and less firewood. In households have cooking room the use of firewood is lower. When people had completed at least high school, the use of firewood is less possible; this results is similar to Gupta and Kohlin (2006). From these variables, we can conclude that use of firewood is more associated with people live in rural areas, indigenous and lower education, variables related to context of poverty. Age of people is positively related to use firewood. Respect to household head, this variable is negatively related to use firewood and women, variable of children less 5 is negatively related to use of firewood.

Respect to prevalence of cough equation, we observe a positive effect of exposure of IAP in prevalence of cough it sign is within of benchmark in literature about health problems associated to IAP, such as Pitt et al. (2006) and the other studies described above, but our result is causal because we control of endogeneity by to instrument use of fuel; this result is similar in men and women equations. Complete at least high school is negatively related to presence of cough, this result is consistent with Grossman (1999) respect to educated people is more efficient for produce health. Age of person is positively related to presence of cough; this fact is consistent with exposed in Grossman (1972), respect to health is depreciated with age. Men and women that live in urban areas are not statistically different in suffer of cough respect to people that live in rural areas. Women have children less 5 are more propensity to suffer cough; men that are household head tend to suffer less cough that men non household head.

For labor force participation equation is observed that cough reduces labor force participation in men and women.This fact is marked in literature: Zhang et al. (2009), Brown III et al. (2005) and Chatterji et al. (2011). But, our results are different because we use respiratory problem in this study and that we correct endogeneity of cough and fuel choice. For men, education is positively related to LFP; if a man is household head, his probability of participate in labor market increase, presumably it is due that he can be the principal contributor to family income therefore he need work. If we link signs of household head variable in three equations can observe something: negatively related to use of firewood, positively related to LFP and negatively related to probability of cough.

We can supose that: when a man is household head work more, so he is less time in household, dedicate less cooking and therefore is less exposed to fuel. For women, LFP declines with age and when woman has children less 5. Women live in urban areas her participation increases. Women have children less 5 reduce their LFP and increase their home time and therefore are more exposed to IAP. Finally, men or women more educated increase their LFP, reduce their home time and therefore reduce exposure to IAP and they use LPG because are more educated and more efficient for produce health.

Likelihood ratio for determine if to model trivariate probit is correct; statistic is a chi-squared with k degree freedom, k is number of equations, in this case three. For men and women is correct to model trivariate probit. The tetrachoric correlations are showed in columns 4, 5 and 6 in tables A and B. The rho between fuel use and cough equation is negative and significant for men and women. This fact reflects that both equations have a negative relation but it can due to unobservable variables that imply opposite sign in correlation. Maybe many variables unobserved such as health status in other diseases can tend to reduce use of firewood but this person has health endowment and can are more sensitive to IAP. The rho between fuel use and LFP equations is significant with sign negative in women and positive in men. The relationship between cough and LFP equations 2 and 3 are positively related in both genders but it can due to unobservable variables that imply same sign in correlation. Maybe there exist many variables that affect prevalence of cough and LFP in simultaneous way; if a person is indebted and sick, she need work more for pay her indebt.

Table A: Cough, use of firewood and labor force participation in men

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	firewood	cough	employing	atrho21	atrho31	atrho32
Household have electricity	-0.616***					
	(0.166)					
Total expenditure of household	-5.54e-06***					
	(1.99e-06)					
N. of members	0.0785***					
	(0.00831)					
Person is indigenous	0.365***					
	(0.0585)					
% Households use LPG in municipality	-2.567***					
	(0.0989)					
H. with cooking room	-0.363***					
	(0.0632)					
Solid floor	-0.877***					
	(0.0566)					
At least high school	-0.477***	-0.150***	0.119***			
	(0.0576)	(0.0496)	(0.0446)			
Age of person	0.00928***	0.00959***				
	(0.00125)	(0.00126)				
Person lives in urban zone	-0.952***	0.0145				
	(0.0364)	(0.0450)				
Household head	-0.318***	-0.149***	0.641***			
	(0.0458)	(0.0416)	(0.0326)			
Household use firewood		0.254***				
		(0.0734)				
Person coughs			-1.246***			
			(0.164)			
Constant	3.336***	-1.322***	0.583***	-0.117**	0.0788***	0.706***
	(0.202)	(0.0594)	(0.0279)	(0.0474)	(0.0245)	(0.132)
Observations	8,310	8,310	8,310	8,310	8,310	8,310

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi2(3) = 47.5366 Prob > chi2 = 0.0000

Table B: Cough, use of firewood and labor force participation in women

VARIABLES	(1) firewood	(2) cough	(3) employing	(4) atrho21	(5) atrho31	(6) atrho32
Household have electricity	-0.477***					
	(0.152)					
Total expenditure of household	-7.70e-06***					
	(2.06e-06)					
N. of members	0.0862***					
	(0.00738)					
Person is indigenous	0.457***					
	(0.0558)					
% Households use LPG in municipality	-2.682***					
	(0.0891)					
H. with cooking room	-0.420***					
	(0.0568)					
Solid floor	-0.846***					
	(0.0513)					
At least high school	-0.533***	-0.0915**	0.378***			
	(0.0596)	(0.0461)	(0.0429)			
Age of person	0.00314***	0.00398***	-0.00439***			
	(0.00101)	(0.000873)	(0.000920)			
Woman with children under 5	-0.163***	0.0786**	-0.159***			
	(0.0383)	(0.0331)	(0.0316)			
Person lives in urban zone	-0.892***	0.0157	0.276***			
	(0.0328)	(0.0390)	(0.0349)			
Household use firewood		0.427***				
		(0.0582)				
Person coughs			-0.860***			
			(0.188)			
Constant	3.294***	-1.139***	-0.222***	-0.155***	-0.0378*	0.535***
	(0.185)	(0.0556)	(0.0604)	(0.0394)	(0.0214)	(0.152)
Observations	10,483	10,483	10,483	10,483	10,483	10,483

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi2(3) = 36.5991 Prob > chi2 = 0.0000

6.1 Predicted probabilities and treatment effects

From econometric model we obtains predicted probabilities. We obtain eight probabilities that are obtained of different combinations of values dependent variables. First value in name of variable is refered use of fuel, second is referred presence of cough and last if person participate or not in labor market. Tables 3 to 5 show predicted probabilities and treatment effect for men, and 6 to 8 for women. In table 3, first probability is referred when person uses firewood and has cough and works, this value is low; second probabilities is same case that first but when person not work, this values is near to zero. Last probability is case when man uses LPG, is healthy and works. In table 4 for we observe predicted probability of cough conditional use of fuel. Man that use firewood has higher probability of has cough respect to man that use LPG therefore treatment effect of firewood in cough is positive: man uses firewood has more probability suffer cough than man uses LPG: man use firewood has nine times more probability of suffer cough that a man use LPG. In table 5 is showed the effect of cough in LFP. Man suffer cough has less probability of LFP than man not suffer cough.

Table 3: **Predicted Probabilities for men**

Variable	Mean	Std. Dev.
Pred. Prob. 111	0.059	0.068
Pred. Prob. 110	0.004	0.014
Pred. Prob. 101	0.206	0.187
Pred. Prob. 011	0.101	0.051
Pred. Prob. 100	0.084	0.116
Pred. Prob. 010	0.006	0.012
Pred. Prob. 001	0.392	0.247
Pred. Prob. 000	0.148	0.132
N	8310	

Table 4: **Treatment effect of firewood in cough for men**

Variable	Mean	Std. Dev.
Predicted probability of Cough cond. firewood	0.224	0.089
Predicted probability of Cough cond. LPG	0.025	0.03
Treatment effect of firewood in cough	0.199	0.062
N	8310	

In table 7 for we observe predicted probability of cough conditional use of fuel. Woman that use firewood has higher probability of has cough respect to woman that use LPG therefore treatment effect of firewood in cough is positive: woman uses firewood has more probability suffer cough than woman uses LPG: woman use firewood has three times more probability of suffer cough that a woman use LPG. However, woman suffer

Table 5: **Treatment effect of cough in LFP for men**

Variable	Mean	Std. Dev.
Predict probability of LFP cond. cough	0.316	0.316
Predict probability of LFP cond. not cough	0.362	0.321
Treatment effect of cough in LFP	-0.045	0.026
N	8310	

cough has less probability of LFP that woman not suffer cough; this effect is higher in women than man, this maybe due to differences in determination of LFP by gender.

In both cases, men and women, is evident problems generated by IAP generated to exposure firewood in prevalence of respiratory problem, in this case cough, and presence of cough in LFP. Therefore, is important attend these problems have generate harmful in health and reduce of labor force participation. People more sick reduce their participation in labor market and will have less income and this can reduce their household expenditure and increase impoverishment risk. Adecquated policy can be give improved stoves that use firewood for reduce exposure risk or to establish credit for LPG stoves.

Table 6: **Predicted probabilities for women**

Variable	Mean	Std. Dev.
Pred. Prob. 111	0.038	0.047
Pred. Prob. 110	0.038	0.056
Pred. Prob. 101	0.062	0.058
Pred. Prob. 011	0.084	0.045
Pred. Prob. 100	0.203	0.189
Pred. Prob. 010	0.05	0.036
Pred. Prob. 001	0.175	0.138
Pred. Prob. 000	0.35	0.179
N	10483	

Table 7: **Treatment effect of firewood in cough for women**

Variable	Mean	Std. Dev.
Predicted probability of Cough cond. firewood	0.378	0.129
Predicted probability of Cough cond. LPG	0.127	0.068
Treatment effect of firewood in cough	0.251	0.064
N	10483	

Table 8: **Treatment effect of cough in LFP for women**

Variable	Mean	Std. Dev.
Predict probability of LFP cond. cough	0.297	0.316
Predict probability of LFP cond. not cough	0.353	0.321
Treatment effect of cough in LFP	-0.056	0.033
N	10483	

7. Conclusions

The purpose in this paper is to response the main quiestion about which are economic losses generated by the use of firewood in Mexican households. Derived from this question arise specific questions such as: is there any mechanism within the household that defines which types of fuel use?; use of firewood causes helath problems in exposed people?, firewood is more harmful for health of people than LPG?; and, respiratory problems caused by firewood-based indoor pollution generates reductions in probability of participate in labor market?. We propose an integrated model, for each individual, that determines the household fuel choice, the effect of chosen fuel in presence of respiratory problems and the effect of the latter in labor force participation. After, this model is econometrically implemented, using Mexican Family Life Survey 2002 for people aged 15-65, people that potentially can be in labor market.

We use empirical models, one for each gender, that contemplates three important and related aspects: the fuel choice for cooking, presence of respiratory problems and participation in labor market. These aspects are interrelated because the literature review shows the influence of use of firewood in prevalence to respiratory diseases and in turn,the influence of diseases in labor force participation; these particularities generate endogeneity problems that if are not corrected derive in biased estimated. Due that three dependent variables are dummies, the most suitable formulation is a multivariate recursive probit model (Greene, 2008). Additionally, we calculate predicted probabilities and treatment effect variables on presence of cough and LFP. On choice fuel equation for men and women is observed that the probability of choice firewood is reduced when the percentage of households that use LPG in municipality rises, that is similar a accessibility to LPG. In households with total expenditure low is more possible that use firewood; the number of members is positively related with use of firewood both men and women. When man or woman is indigenous, increase the probability of use firewood. We can conclude that use of firewood is more associated with people live in rural areas, indigenous and lower education, variables related to context of poverty. Age of people is positively related to use firewood. Respect to household head, this variable is negatively related to use firewood and women, variable of children less 5 is negatively related to use of firewood.

For prevalence of cough equation, we observe a positive effect of exposure of IAP in prevalence of cough such as Pitt et al. (2006) but our result is causal because we control of endogeneity by to instrument use of fuel; this result is similar in men and women equations. Complete at least high school is negatively related to presence of cough. Age of person is positively related to presence of cough. Men and women that live in urban areas are not statistically different in suffer of cough respect to people that live in rural areas. Women have children less 5 are more propensity to suffer cough; men that are household head tend to suffer less cough that men non household head. For labor force participation equation is observed that cough reduces labor force participation in men and women. This fact is marked in literature: Zhang et al. (2009), Brown III et al. (2005) and Chatterji et al. (2011). But, our results are different because we use respiratory problem in this study and that we correct endogeneity of cough and fuel choice. For men, education is positively related to LFP. If we link signs of household head variable in three equations can observe something: negatively related to use of firewood, positively related to LFP and negatively related to probability of cough. We can supose that: when a man is household head work more, so he is less time in household, dedicate less cooking and therefore is less exposed to fuel. For women, LFP declines with age and when woman has children less 5. Women live in urban areas her participation increases. Women have children less 5 reduce their LFP and increase their home time and therefore are more exposed to IAP. Finally, men or women more educated increase their LFP, reduce their home time and therefore reduce exposure to IAP and they use LPG because are more educated and more efficient for produce health. Likelihood ratio for determine if to model trivariate probit is correct. The tetrachoric correlations are statistically significant.

With respect to results, is important to highlight the negative effect in health due to exposure to firewood. People more exposure is potentially more likely to have poor health and therefore less participation in labor market, which impact directly in their well-being, reducing probability of participate in labor market and this reduces their labor income and reduce household expenditure and this fact can increase impoverishment risk.

Respect to predicted probabilities and treatment effects we found that man that use firewood has higher probability of has cough respect to man that use LPG therefore treatment effect of firewood in cough is positive, the same result for woman. Woman or mand suffer cough has less probability of LFP than man or woman who not suffer cough.

This study is perfectible. Although is integrated framework, future researches would including more factors to control health status and to avoid errors due unobserved variables that can bias the estimates. Is important to include price and quantity of fuels for explore price-crossed elasticity among fuels. Is necessary to correct possible bias due cluster effects by household; there exist individuals that live in same household.

8. Appendix

Solution of theoretical model assumme Cobb-Douglas functions

We propose a Cobb-Douglas functional form to solve the maximization problem proposed in theoretical model. Equations (A) and (B) detail utility and health production function.

$$U = F_1^{\alpha_1} \dots F_J^{\alpha_J} C^{\alpha_{J+1}} H^{\alpha_{J+2}} \left(T^H\right)^{\alpha_{J+3}} \left(T^L\right)^{\alpha_{J+4}} \quad \text{Utility function} \tag{A}$$

$$H = F_1^{-\beta_1} \dots F_J^{-\beta_J} C^{\beta_{J+1}} S^{\beta_{J+2}} \left(T^H\right)^{\beta_{J+3}} \quad \text{Health production function} \tag{B}$$

In (A) the sum of $\alpha's$ is one; analogously, the sum of $\beta's$ is one too in (B). The negative sign in exponents indicate that fuels are harmful for health, i. e., $\dfrac{\partial H}{\partial F_i} < 0$. In (C)

$$L^w(w, H) = w^\gamma H^{1-\gamma} \quad \text{Labor supply function} \tag{C}$$

Replacing (B) in (A):

$$U = \Pi_{j=1}^{J} F_j^{\alpha_j - \beta_j \alpha_{J+2}} C^{\alpha_{J+1} + \beta_{J+1}\alpha_{J+2}} S^{\beta_{J+2}\alpha_{J+2}} T^{H^{(\alpha_{J+3} + \alpha_{J+2}\beta_{J+3})}} T^{L^{\alpha_{J+4}}} \tag{D}$$

The utility function is maximized subject to full-income and non-negativity constraints:

$$C + \sum_{j=1}^{J} P_j F_j + P_S S + w(T^H + T^L) = \overline{Y} + w\overline{T}$$

$$F_j \geq 0 \quad \text{For each j=1,...,J}$$

Taking derivatives and applying Kuhn-Tucker conditions:

$$\frac{\partial \mathcal{L}}{\partial F_i} = (\alpha_1 - \beta_1 \alpha_{J+2}) F_1^{\alpha_1 - \beta_1 \alpha_{J+2} - 1} \Pi_{j=2}^{J} F_j^{\alpha_j - \beta_j \alpha_{J+2}} C^{\alpha_{J+1} + \beta_{J+1}\alpha_{J+2}} S^{\beta_{J+2}\alpha_{J+2}} * \\ T^{H^{(\alpha_{J+3} + \alpha_{J+2}\beta_{J+3})}} T^{L^{\alpha_{J+4}}} - \lambda P_1 + \gamma_1 = 0 \tag{E}$$

The others KT- conditions (J-1 fuels)are analagous to (E).

$$\frac{\partial \mathcal{L}}{\partial C} = (\alpha_{J+1} + \beta_{J+1}\alpha_{J+2})\, \Pi_{j=1}^{J} F_j^{\alpha_j - \beta_j \alpha_{J+2}} C^{\alpha_{J+1}+\beta_{J+1}\alpha_{J+2}-1} S^{\beta_{J+2}\alpha_{J+2}} *$$
$$T^{H^{(\alpha_{J+3}+\alpha_{J+2}\beta_{J+3})}} T^{L^{\alpha_{J+4}}} - \lambda = 0 \quad \text{(F)}$$

$$\frac{\partial \mathcal{L}}{\partial S} = (\beta_{J+2}\alpha_{J+2})\, \Pi_{j=1}^{J} F_j^{\alpha_j - \beta_j \alpha_{J+2}} C^{\alpha_{J+1}+\beta_{J+1}\alpha_{J+2}} S^{\beta_{J+2}\alpha_{J+2}-1} *$$
$$T^{H^{(\alpha_{J+3}+\alpha_{J+2}\beta_{J+3})}} T^{L^{\alpha_{J+4}}} - \lambda P_S = 0 \quad \text{(G)}$$

$$\frac{\partial \mathcal{L}}{\partial T^H} = (\alpha_{J+3} + \beta_{J+3}\alpha_{J+2})\, \Pi_{j=1}^{J} F_j^{\alpha_j - \beta_j \alpha_{J+2}} C^{\alpha_{J+1}+\beta_{J+1}\alpha_{J+2}} S^{\beta_{J+2}\alpha_{J+2}} *$$
$$T^{H^{(\alpha_{J+3}+\alpha_{J+2}\beta_{J+3}-1)}} T^{L^{\alpha_{J+4}}} - \lambda w = 0 \quad \text{(H)}$$

$$\frac{\partial \mathcal{L}}{\partial T^L} = \alpha_{J+4} \Pi_{j=1}^{J} F_j^{\alpha_j - \beta_j \alpha_{J+2}} C^{\alpha_{J+1}+\beta_{J+1}\alpha_{J+2}} S^{\beta_{J+2}\alpha_{J+2}} *$$
$$T^{H^{(\alpha_{J+3}+\alpha_{J+2}\beta_{J+3})}} T^{L^{\alpha_{J+4}-1}} - \lambda w = 0 \quad \text{(I)}$$

$$\frac{\partial \mathcal{L}}{\partial T^L} = \overline{Y} + w\overline{T} - C - \sum_{j=1}^{J} P_j F_j - P_S S - w(T^H + T^L) = 0 \quad \text{(J)}$$

Finally, there are J slackness complementary conditions:

$$\gamma_j \geq 0, \quad F_j \geq 0, \quad \gamma_j F_j \geq 0 \quad \text{(K)}$$

There are 2^J cases but there is one case with interior solution and is when all $\gamma' s$ are zero. Applying many algebraic manipulations we obtains the solution such as equations (36) to (42)

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