Biomass Energy Use, price changes and imperfect labor market in rural China: an Agricultural Household Model-Based Analysis

by

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Abstract

The impacts of exogenous price changes on biomass energy use are complex, since household's consumption, production and labor allocation decisions are interlinked. A comprehensive analytical framework is thus developed in this paper based on an agricultural household model. Under the imperfect labor market, the total behavioral effect that consists of a direct (i.e. the consumption of biomass energy and the labor demand for biomass collection responds to an exogenous shock) and an indirect (i.e. the consumption of biomass energy and the labor demand for biomass collection adjustments to the endogenous variations in the shadow wage induced by this exogenous shock), is estimated by adopting a two-stage estimation strategy: the shadow wage of household labor is firstly estimated and then used to estimate consumption and labor demand systems. The results show that neglecting the indirect effect can bias the final effect on household biomass energy using behaviors, implying that market failures reduce the flexibility in household's behaviors. The findings of this paper also provide important policy implications for future biomass energy development in rural China: the market prices should be adjusted to control the demand for biomass energy, and the measures aiming at eliminating the market failures should be attached importance at the same time.

1. Introduction

As a kind of renewable resource derived from biological materials, biomass energy provides a link between agriculture and human living. It plays an important role in agriculture-based rural livelihoods. To date in China, due to the limited access to advanced energy technologies and modern energy services, a considerable share of the rural population still depends heavily on direct combustion of traditional solid biomass (i.e. crop residues and firewood) for cooking and space heating (Chen et al., 2016). In the case of Sichuan Province, available official statistics indicate that the amount of traditional biomass energy consumed by rural households is about 26.76 Million tsce[1], accounting for approximately 48.7% of the total rural energy consumption by the end of 2013 (SCREO, 2013). Use of traditional biomass energy has several significant negative impacts on rural livelihoods. One of them is the competition between biomass collection and income-earning activities for labor resource. Many studies have shown that household members, especially women and children, usually spend a large proportion of their time gathering and collecting biomass and make great effort to prepare biomass energy. As a result, they are constrained from engaging in other working activities to increase their incomes (Van der Kroon et al., 2013). Meanwhile, reliance on traditional biomass energy is also considered to be a non-ignorable contributor to food insecurity, because the labor input for agricultural production has to be reduced in order to collect

[1] tsce = ton standard coal equivalent.

more biomass (Li et al., 2001). Additionally, a constant increase in the prices of food and other marketed goods will put a further burden on poor rural households and make them trapped in poverty. Hence, household biomass energy use has become an important issue within the topic of rural sustainable development in China. Building on the growing interest in the role of biomass energy use in poverty reduction and food security, the main objective of this study is to robustly investigate how different positive and negative price shocks potentially influence household biomass energy using behaviors under the imperfect labor market in rural China.

With regard to the impacts of biomass energy use due to exogenous shocks caused by price changes, most research takes into account only the direct effects of price changes on both consumption and production, which do not affect consumption and production behaviors at all (Amacher et al., 1996; Meckonnen, 1999; Heltberg et al., 2000; Guta, 2014). However, the indirect behavioral effects jointly concerning time allocation, consumption and production decision are rarely considered. In general, a rural household plays a double role of producer and consumer in traditional biomass energy use. Exogenous shocks can affect production decisions by increasing or decreasing household incentives to collect biomass with respect to agricultural production, or they can influence the relative use of labor inputs in these two production activities. Similarly, household is likely to adjust biomass energy consumption responding to the changes in exogenous prices. In the context of labor market imperfections, the exogenous shocks can affect the endogenous shadow wage of household labor and, therefore, household time allocation. The total behavioral effect can thus include a direct (i.e. the supply or demand responds to an exogenous shock) and an indirect (i.e. the supply and demand adjustments to the endogenous variations in the shadow wage induced by this exogenous shock) component. Both of them have important empirical and policy implications. Under large exogenous shocks, neglecting the indirect behavioral effects can cause bias in analyzing the total impacts of price changes on biomass energy use. Similarly, policy interventions, such as those focusing on eliminating the sources of market failure, can generate indirect behavioral effects on household production and consumption decisions regarding traditional biomass energy. Therefore, the main contribution of this study is to propose an appropriate approach for systematically examining these effects.

As shown in Figure 1.1, given the features of rural China, a typical agricultural household allocates its labor to agricultural production, biomass collection, off-farm work to get returns for its livelihood enhancement, while maximizing its welfare by changing its consumption, which includes self-consumed agricultural products and biomass energy, commercial energy, purchased goods and leisure. When all the other markets are complete and efficient, market prices support a separation of household production and consumption decisions (Benjamin, 1992). This implies that household labor allocation depends only on the wage rate and, the consumer and producer sides of the model are allowed to be estimated separately. Considering the labor market with a binding constraint on off-farm employment, household jointly makes its decisions on the production and consumption. As for the model estimation, we adopt a two-stage strategy, which is similar to the works by Henning and Henningsen (2007). Firstly, we estimate the shadow wage of labor and the shadow price of biomass energy, then, in the second stage, we use them to estimate consumption and labor demand. The parameters obtained from the different estimations are subsequently applied to compute the consumption and labor demand elasticities for biomass energy, based on which the effects of exogenous price changes on the shadow wage are calculated.

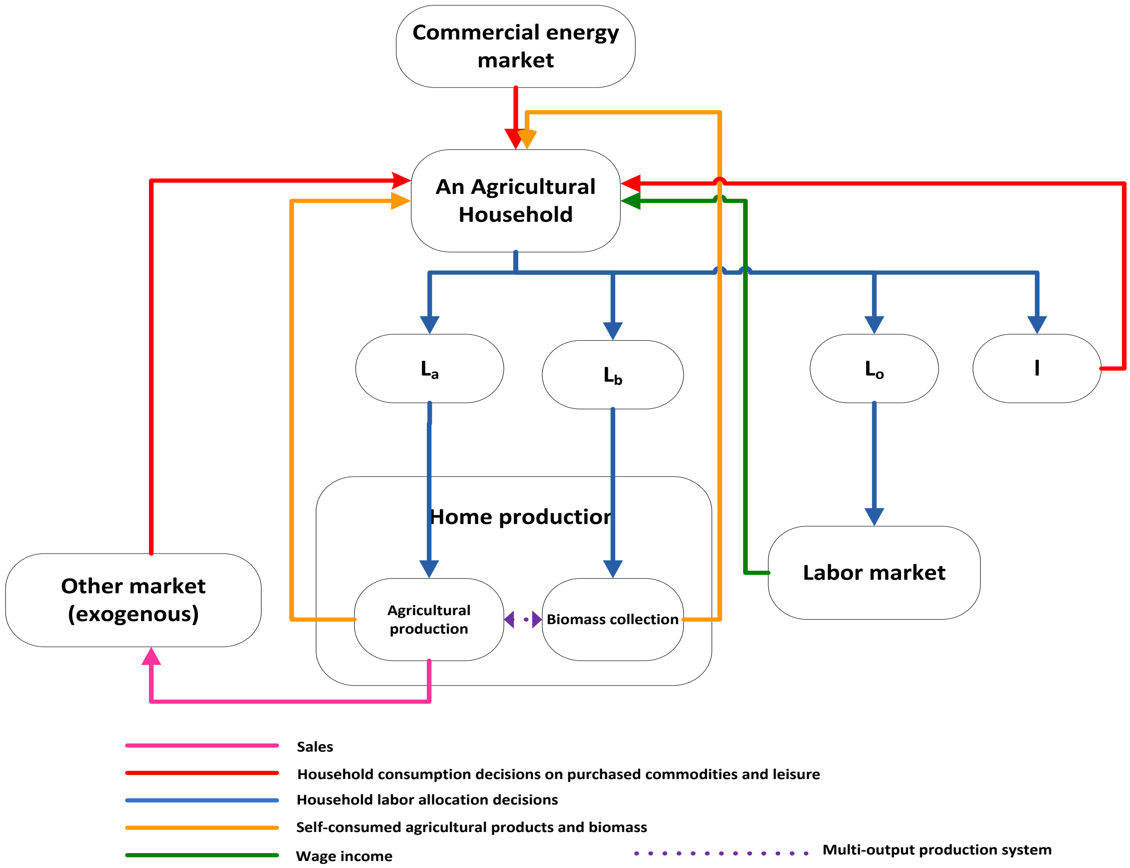

Figure 1.1 Conceptual framework
Source: author's conceptualization

In addition, few previous studies have been done in rural China to estimate household biomass energy using behaviors taking into account the direct and indirect effects of price changes on production and consumption decisions. This study fills this gap by giving a systematical analysis of household decision-making on traditional biomass energy use. The rest of this paper is organized as follows. Section 2 establishes the theoretical framework based on an AHM. The empirical specification and estimation strategy of the AHM are described in Section 3. Section 4 presents the data used in analysis and reports the estimation results of the AHM. Section 5 summarizes the main findings of this study and gives policy implications.

2. Theoretical analysis

2.1 Household biomass energy using behaviors in an agricultural household model

In this study, an agricultural household model (AHM) with biomass energy utilization is considered. The model is adapted on the basis of the classic model provided by Benjamin (1992). It integrates biomass collection and biomass energy consumption into the intra-household economic activities for investigating how a household makes decision on biomass energy utilization and how it would, in turn, influence household livelihoods.

A twice-differentiable quasi-concave household utility function can be defined as follow:

$$U(C,l;a) \quad (1)$$

Where the vector a is a set of household characteristics which can influence preferences; l is leisure and C is household total consumption, the sum of the market purchased and home produced agricultural commodities. Then, we divide C into two categories following Heltberg et al. (2000): consumption of goods and services that requires energy inputs C_h and other marketed goods and services C_m. It can be expressed in an equation as:

$$C = C_h + C_m \quad (2)$$

In the context of Sichuan Province, household goods and services, including cooking, heating and lighting, are mainly produced with commercial energy C_e and biomass energy C_b :

$$C_h = \Gamma(C_e, C_b; S) \quad (3)$$

Where S is a set of factors that influence the energy using efficiency (i.e. possess of improved stove, and cooking or heating habit etc.).

The agricultural production of the household is assumed to be continuous and monotonic in L_{ai}, twice-differentiable and strongly concave. It is represented by the function:

$$q_a = F_a(L_a; B) \text{ with } F_a' > 0, F_a'' < 0 \quad (4)$$

Where B is a set of all inputs except labor (i.e. land, water, and all the other inputs) which is assumed to be exogenous.

Similarly, we assume that the labor supplied to biomass collection is $L_b (\geq 0)$, and define the biomass collection function as:

$$q_b = F_b(L_b; Z) \text{ with } F_b' > 0, F_b'' < 0 \quad (5)$$

Where Z is an exogenous vector of household characteristics pertaining to the accessibility and availability of biomass resources such as the distance from the forest or the field to the house, the transportation cost, and the stock of biomass resources.

We also assume that a household has fixed time endowment T which can be allocated to four non-overlapping livelihood activities: working on farm for production profits (L_a), working for biomass collection (L_b), working off-farm for wage (L_o), and leisure for welfare maximization. Hence, we have:

$$T = L_a + L_b + L_o + l \quad (6)$$

Before going into deep analysis of household biomass energy using behaviors, we firstly introduce biomass collection into our household model. In previous studies using the AHM, the biomass collection was usually integrated into agricultural household model by adding a separate production function (Heltberg et al. 2000; Fisher et al. 2005; Chen et al. 2006). In this approach, there is an implicit assumption that labor allocation decisions are separable and can be made independently of allocation decisions on agricultural production and biomass collection (Weaver, 1983). However, in Sichuan Province, the labor allocated between agricultural production and biomass collection cannot be distinguished by any physical indicator such as gender and age. The members of the household engaged in farm work, in most cases, are also responsible for biomass collection. They often collect firewood on their way to and from the fields or pick up crop straws after harvesting. Besides, the simple aggregation of the production functions in past studies lacks the information on the internal relationship between agricultural production and biomass collection. Rural households usually rely on the market to provide signals through the price system to choose the proportions of available labor inputs that should be allocated to each activity (Debertin, 2012). In other words, household labor allocation should on the basis of the decisions regarding these two activities. Therefore, the forgoing separable labor allocation assumption will not be held in this study. To better simulate household production behaviors in our study region, a multiple output production function that embodies behavioral relationship as well as technical relationship based on the single-input production functions (4) and (5) is considered. It is defined as:

$$f(q_a, q_b) = g(L; B, Z); \quad L = L_a + L_b \tag{7}$$

Where the function $f(\cdot)$ is concave in q_a and q_b. It shows the behavioral relationship that defines the transformation curve for the agricultural products and collected biomass (Debertin, 2012). The function $g(\cdot)$ reflects the technical relationship that specifies possible combinations of the output q_a and q_b produced from the mix of labor inputs L_a and L_b (Debertin, 2012), and it may be concave in L (the total labor input for intrahousehold production activities). Using the implicit function theorem, we can write:

$$q_a = F_a[L - F_b^{-1}(q_b)] = h(q_b, L; B, Z) \tag{8}$$

According to the separation property given by Benjamin (1992), household behaves in a recursive process. It firstly maximizes its profits π from the multi-output production without any consideration of its consumption or leisure preferences[2]:

$$Max\pi = g(L; B, Z) - wL = f(q_a, q_b) - w(L_a + L_b) \quad w.r.t.\ L, L_a, L_b \tag{9}$$

The first-order conditions are in the following:

$$\frac{\partial \pi}{\partial L} = \frac{\partial g(L; B, Z)}{\partial L} - w = 0 \Rightarrow MPL = w \tag{10}$$

$$\frac{\partial \pi}{\partial L_a} = \frac{\partial q_a}{\partial L_a} - w = 0 \Rightarrow MPL_a = w \tag{11}$$

$$\frac{\partial \pi}{\partial L_b} = \frac{\partial q_b}{\partial L_b} - w = 0 \Rightarrow MPL_b = w \tag{12}$$

Based on the conditions from (10) to (12), the equilibrium of household labor allocation is determined by:

$$MPL = MPL_a = MPL_b = w \tag{13}$$

The equation (13) indicates that the optimum of household labor allocation will occur at the point where the marginal productivity of the labor allocated to home production activities is equalized to the marginal productivity of the farm labor and labor in biomass collection. It also demonstrates that household labor allocation on agricultural production and biomass collection is determined by market wage rate.

[2] We normalize prices of all other goods by agricultural output price in order to simply our analysis.

Thus, the solution to the maximization problem yields the household labor allocation functions for these two activities:

$$\left.\begin{array}{l} L_a \\ L_b \end{array}\right\} = L'(w; B, Z) \tag{14}$$

Based on the maximum profits π^*, household then decides how much goods and leisure to consume and how much labor to supply off-farm:

$$\left.\begin{array}{l} C_e \\ C_b \\ C_m \\ l \end{array}\right\} = C'(w, M^*; B, Z, S, a) \tag{15}$$

$$L_o = T(a) - L_a - L_b - l \tag{16}$$

Where $M^* = \pi^* + wT(a) + E$ is the optimal budget of the household.

2.2 Household biomass energy using behaviors in a non-separable agricultural household model

It is well recognized that, in developing countries, market imperfections are pervasive in rural areas. As the case in Sichuan Province, there may be an exogenously imposed binding constraint on the labor market in rural areas. There are several plausible reasons for this in Chinese context: the relatively low educational level of rural household for getting a job off-farm, the high transaction cost caused by the inconvenient transportation system in some remote areas, the fear of losing the land use rights of the household members working off-farm (Wang et al, 2007; Jia, 2012) and so on. With regard to the energy market in rural area, the domestically produced biomass energy is almost not traded. Rural households face two choices, and choose either to purchase different kinds of commercial energy from the market or to collect biomass by themselves based on their valuations of their own labors (Amacher et al., 1996). Under these circumstances, the separation property breaks down, and we should consider a non-separable household model.

Now, we assume that the market for commercial energy is perfect. Meanwhile, the biomass collected by households is assumed to be non-tradable, that is, the amount of biomass consumed as energy is lower than the total collected amount[3]. Then, we have the constraint for household biomass energy consumption:

$$C_b \leq q_b \tag{17}$$

Particularly, the labor market imperfections are introduced in the agricultural household model as a binding constraint on off-farm labor:

$$L_o \leq H \tag{18}$$

Here, we also assume that the markets for all other goods and services are perfect. In order to capture the effects of price changes on household biomass energy using behaviors, we denote the market price of

[3] A part of the agricultural residues are used as fertilizer in most of the cases in our study region.

goods by p_x (i.e. a =agricultural products; e =commercial energy; and m [4]=all the other purchased goods.) and get a new full income constraint for the household:

$$p_m C_m + p_e C_e = p_a q_a + wL_o + E = p_a h(q_b, L; B, Z) + wL_o + E \tag{19}$$

Then we solve the optimization problem of the household by establishing a Lagrangian function subject to the constraints (17), (18) and (19):

$$\begin{aligned} U^L &= U[C_m + \Gamma(C_e, C_b; S), T(a) - L_a - L_b - L_o; a] + \lambda[p_a h(q_b, L; B, Z) + wL_o + E \\ &- p_m C_m - p_e C_e] - \mu(L_o - H) - \eta(C_b - q_b) \quad w.r.t.\ C_b, C_e, C_m, L_o, L, L_a, L_b, q_b \end{aligned} \tag{20}$$

Reorganizing the Kuhn-Tucker conditions, the new equilibrium of household labor allocation in non-separable model can be obtained:

$$\frac{\partial U}{\partial C_m} = \lambda p_m \tag{21}$$

$$\frac{\partial U}{\partial C_e} = \lambda p_e \tag{22}$$

$$\frac{\partial U}{\partial l} = \lambda \frac{\partial p_a q_a}{\partial L_a} = \frac{\partial U}{\partial \Gamma} \frac{\partial \Gamma}{\partial C_b} \frac{\partial q_b}{\partial L_b} = \lambda \frac{\partial p_a q_a}{\partial L} + \eta \frac{\partial q_b}{\partial L} = \lambda w - \mu \tag{23}$$

Condition (23) reveals that the household collects biomass until the point where the marginal utility of leisure equals to the marginal utility of biomass energy in household consumption times the marginal product of biomass collection labor which, in turn, is equalized to the marginal productivity of labor in agricultural production. In other words, the marginal value product of labor in biomass collection and labor working on-farm is equal to the opportunity cost of the household labor (the utility of leisure). This result is in line with the findings of Heltberg (2000) that biomass collection is determined by the opportunity cost of the time (shadow wage w_i^*) of the household labor. It also states that the time is allocated among biomass collection, farm work, off-farm employment and leisure relying on wage rate.

Therefore, under the conditions of non-separation, the reduced form of household labor allocation functions can be derived:

$$\left.\begin{matrix} L_a \\ L_b \end{matrix}\right\} = L'(w^*, p_x; B, Z, S, a) \tag{24}$$

And then yields the shadow full income of the household after calculating the maximum generalized profits π^*:

$$Y^* = \pi^* + w^*[T(a) - H] + wH + E = \sum C_x p_x + w^* l \tag{25}$$

As a consumer, the household decides the level of consumption to maximize its utility under the shadow

[4] Here, the purchased agricultural products are included.

full income constraint (de Janvry et al., 1991). This leads to a consumption system for the household as follow:

$$\left.\begin{array}{l} C_e \\ C_b \\ C_m \\ l \end{array}\right\} = C'(w^*, p_x, Y^*; B, Z, S, a) \tag{26}$$

As it is shown in the expressions for optimal labor allocation and leisure consumption of the household (See (24) and (26)), a change in any of the exogenous variables affecting the production choices of the household will influence the labor allocation and consumption decisions of the household, both directly and indirectly. The direct effects come from the changes in household's shadow profits, as in the separable model we discussed before, whereas, the indirect effects occur through the changes in the shadow wage (Skoufias, 1994). Both of the effects are further analyzed in the following subsections.

2.3.1 Internal Adjustment: Responses of Shadow Wage to the Exogenous Price Changes

We have already known that household allocates labor to agricultural production and biomass collection up to the point where the marginal value product of these activities equals to the opportunity cost of the time, that is, the shadow wage of the household labor. Therefore, how shadow wage changes in response to a change of prices in exogenous market gives a way to analyze the indirect effects of shadow wage on household labor allocation and consumption decisions.

Suppose now that there is only one constrained market for labor, and one exogenous market price p_x changes. Let L denote the optimal labor allocated to production activities. Following the method provided by de Janvry et al. (1991), total differentiation of the household time endowment $-L + (T(a) - H) = l$, which determines the endogenous shadow wage w^* and substitution of the quantity of labor allocated to intrahousehold activities and leisure consumption derived from the equations (24) to (26) gives:

$$-\frac{\partial L}{\partial w^*} dw^* - \frac{\partial L}{\partial p_x} dp_x = \frac{\partial l}{\partial w^*} dw^* + \frac{\partial l}{\partial p_x} dp_x + \frac{\partial l}{\partial Y^*}\left[\frac{\partial \pi^*}{\partial w^*} + (T(a) - H)\right] dw^* + \frac{\partial l}{\partial Y^*}\left(\frac{\partial \pi^*}{\partial p_x}\right) dp_x$$

After rearranging the above equation, we can get the following new expression in elasticity form:

$$-\left[E^* + \sigma^* \gamma + \theta^* \gamma S_l\right] \frac{dw^*}{w^*} = \left[E_x^* + \sigma_x^* \gamma + \theta^* \gamma S_x\right] \frac{dp_x}{p_x}$$

Where

E^* and E_x^* are the direct and cross-price elasticity of labor demand for home production.

σ^* and σ_x^* are the direct and cross-price elasticity of leisure consumption.

θ^* is the full income elasticity of leisure consumption.

γ is the ratio l^*/L^*, $\gamma > 0$.

$S_l = \dfrac{w^* l^*}{Y^*}$ and $S_x = \dfrac{C_x p_x}{Y^*}$ (or $\dfrac{wH}{Y^*}$ in the case of a change in market wage rate) are share parameters in shadow income.

Then, we can figure out the elasticity of the endogenous shadow wage w^* with respect to the exogenous price p_x:

$$E(w^* / p_x) = -\frac{E_x^* + \gamma(\sigma_x^* + \theta^* S_x)}{E^* + \gamma(\sigma^* + \theta^* S_l)} \tag{27}$$

In the elasticity (28), the numerator demonstrates the disequilibrium created by a change in the exogenous price p_x on the imperfect labor market. The first term E_x^* is for the change in labor time allocated to production activities while the two other terms shows the change in leisure consumption coming from the cross-price effect σ_x^* and the income effect θ^*. Analogously, the expression in the denominator reflects the disequilibrium caused by the change in the endogenous shadow wage. The first term E^* represents the effect of a change in the shadow wage on labor demand for intra-household production activities while the second term reveals the response of leisure consumption to a change in the shadow wage of household labor. The overall expression shows that the endogenous shadow wage (w^*) will change in response to an exogenous change of p_x in order for these two disequilibria to compensate each other and for labor market to be in equilibrium.

2.3.2 External Response: The Effects of Exogenous Market Prices on Household Biomass Energy Use

The global biomass energy consumption elasticity with constrained labor market can be directly got by differentiation of (26):

$$(\frac{dC_b}{dp_x})^G = \frac{\partial C_b}{\partial p_x} + \frac{\partial C_b}{\partial Y^*}\frac{\partial Y^*}{\partial p_x} + \frac{\partial C_b}{\partial w^*}\frac{\partial w^*}{\partial p_x} + \frac{\partial C_b}{\partial Y^*}\left[\frac{\partial \pi^*}{\partial w^*} + (T(a) - H)\right]\frac{\partial w^*}{\partial p_x}$$

In elasticity form, this is written as:

$$E(C_b / p_x)^G = E(C_b / p_x)^H + E(w^* / p_x)[E(C_b / w^*)^H + \theta_b S_l] \tag{28}$$

Where $E(C_b / p_x)^H = \sigma_{bx} + \theta_b S_b$ is the direct response of biomass energy consumption to a change in the exogenous prices, consisting of the standard cross-price elasticity of biomass energy consumption (σ_{bx}) and the income effect on biomass energy consumption ($\theta_b S_b$) specific to the household model. Particularly, s_b is the share of biomass collection consumption in full shadow income. $E(C_b / p_x)^H$ can be viewed as the direct effect of a change in the exogenous price p_x on biomass energy consumption, while the indirect effect through a change in the internal price (shadow wage w^*) is expressed as the second term on the right hand side of (28).

In the denominator of elasticity (27), the term in parentheses refers to the elasticity of demand for leisure which will be positive if the direct substitution effect $\left|\sigma^*\right|$ is smaller than the indirect full shadow income effect $\left|\theta^* \frac{w^* l^*}{Y^*}\right|$ due to the shadow wage w^* increase. Effects on production and consumption sides are thus offset against each other and the denominator is positive if the elasticity of leisure demand is greater than that of labor demand for home production. When the exogenous price that changes is that of agricultural products, commercial energy or other purchased goods, the numerator in (27) reveals that household's response to the price change comes from an indirect effect on the substitution between the consumption of self-consumed goods and purchased goods and, a direct effect on leisure demand. The former is positive according to the property of non-separable AHM. On the consumption side, demand for self-consumed goods responds positively to an increase in the price of purchased goods. On the production side, demand for labor input therefore will most likely increase to support the potential increase in the output of self-consumed goods. As the cross price elasticity of leisure consumption with respect to purchased goods is positive, the sign of the numerator in (27) is positive with the result that $E(w^* / p_x)$ is negative: an increase in the price of agricultural products, commercial energy or other purchased goods reduces the shadow wage of household labor.

The case of a change in market wage rate, i.e. the exogenous price of labor, is similar. The numerator in (27), in this case, represents a substitution effect between labor supply to home production and leisure. Its sign depends on the work-leisure decision of the household. Due to the binding constraint imposed on off-farm employment, if leisure consumption decreases with an increase in market wage rate, the labor allocated to production will definitely increase. By contrast, if leisure consumption increases as a result of market wage rate increase, the working time for household will decrease[5]. Thus, the sign of the elasticity $E(w^* / w)$ in (27) is ambiguous.

At the same time, as the direct effect of the external price via the internal price change (the second term on the right in equation (28)) has a sign which is opposite to that of the direct effect (the first term on the right in equation (28)), the global elasticity $E(C_b^* / p_x)^G$ with market failure, is thus unambiguously inferior to the elasticity when the labor market is perfect. This indicates that for the external price changes, the sum of both direct and indirect effects is most of the time smaller than the direct effect itself, implying that market failures reduce the flexibility in household's behaviors (Janvry et al, 1991).

3. Empirical Specification and Strategy

3.1 Shadow wage estimation

As described before, in non-separable household model, the shadow wage determines household decision on labor allocation, which in turns affects biomass energy using behaviors. It cannot be observed directly, since it is determined within the household (Singh et al., 1986). Thus, we estimate the shadow wage firstly. Considering the easiness of estimation and interpretation, the agriculture-energy production relationship can be specified as a Cobb-Douglas multioutput production function (Kumbhakar, 2011)[6]:

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[5] $\frac{\partial l}{\partial w} = \frac{\partial (T(a) - H - L)}{\partial w} = -\frac{\partial L}{\partial w} \Rightarrow E(l/w) = -E(L/w) \, L/l$

[6] We assume that both agricultural function and biomass collection function are Cobb-Douglas functions.

$$Y_i = AY_j^{\alpha_j} L^{\beta} \lambda^{\alpha_j} \qquad \forall i, j \in \{a,b\}$$

Where Y_i $(i \in \{a,b\})$ refers to the two outputs from agricultural production and biomass collection (i.e. agricultural products and biomass); L denotes the labor input jointly invested in these two activities; The term A captures the impact of observed and unobserved factors that affect the production system and the term λ^{α_j} measures output-oriented technical efficiency.

Considering the simultaneity issue and other non-joint inputs for each production activity, we then transform the production function and adopt the following specifications for estimating household production system:

$$\begin{cases} \ln Y_a = \gamma_0 + \alpha_1 \ln Y_b + \beta_1 \ln L + \sigma_1 \ln B + \sigma_2 d_l + \varepsilon \\ \ln Y_b = \gamma_1 + \alpha_2 \ln Y_a + \beta_2 \ln L + \sigma_3 Z + \mu \end{cases} \tag{29}$$

Where μ and ε are error terms. The agricultural output Y_a is measured by the total value of agricultural products produced by the farm household. Y_b is the total amount of collected biomass. B is a vector of other inputs for agricultural production (such as the areas of cultivated arable land and the quantity of intermediate inputs[7]), while Z includes influencing factors of biomass collection (including the distance to biomass collecting spots and household location dummies d_l).

Once the system (29) has been estimated, the shadow wage of household labor can be calculated according to the equilibrium condition outlined in (23)[8]:

$$w^* = MPL = \frac{(\hat{\alpha}_1\hat{\beta}_2 + \hat{\beta}_1)\hat{Y}_a}{(1-\hat{\alpha}_1\hat{\alpha}_2)L} + \frac{(\hat{\alpha}_2\hat{\beta}_1 + \hat{\beta}_2)\hat{Y}_b}{(1-\hat{\alpha}_1\hat{\alpha}_2)L} \tag{30}$$

Where $\hat{Y}_a$ and $\hat{Y}_b$ are the predicted value of agricultural and biomass output; $\hat{\alpha}_1$, $\hat{\alpha}_2$, $\hat{\beta}_1$, and $\hat{\beta}_2$ are the estimated coefficients associated with the multi-outputs and labor input, respectively.

The Ordinary Least Squares (OLS) estimates of the production system may be biased due to endogeneity problems. Therefore, we firstly include observable household characteristics such as the age, gender and educational level of the household head as proxies for management ability of the household labor. Moreover, as the observed data we collected in our field survey can only reflect the situation of the households who decide to participate in biomass collection, the potential bias should be corrected by using the standard two-stage Heckman sample selection model. In the first stage, a probit model which determines the probabilities that a given household will participate in biomass collection or off-farm work is estimated to obtain the inverse Mills ratio (R) for each household:

$$S_t = 1[\xi_t x_t + v_t > 0], \quad v_t \mid x_t \sim Normal\ (0,1) \qquad \forall t \in \{b,o\} \tag{31}$$

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[7] Due to the unavailability of the data, we use the total cost of fertilizer, pesticides and plastic films instead.

[8] We can also derive the elasticities of labor demand for home production $E\left(L^*/q_a\right) = \dfrac{1-\hat{\alpha}_1\hat{\alpha}_2}{\hat{\alpha}_1\hat{\beta}_2 + \hat{\beta}_1}$ and

$$E\left(L^*/q_a\right) = \frac{1-\hat{\alpha}_1\hat{\alpha}_2}{\hat{\alpha}_2\hat{\beta}_1 + \hat{\beta}_2}$$

For participants, $R_t = \phi(\xi_t x_t)/\Phi(\xi_t x_t)$

And for non-participants, $R_t' = \phi(\xi_t x_t)/(1-\Phi(\xi_t x_t))$

Where x is a set of independent variables affecting household participation decision[9].

In the second stage, parameter estimates of the production system are obtained by augmenting the biomass collection equation with the IMR (R_b) using IT3SLS method (Zellner, 1962).

3.2 Household consumption decisions

On the consumption side, the linear approximate almost ideal demand system model (LA/AIDS, see Deaton and Muellbauer, 1980 and Julian et al, 1994) is adopted to estimate the impacts of price changes on household biomass energy consumption behaviors. Let ES_i denote the expenditure share of the i th good, then the demand for consumption goods i is represented by a system of equations as follows (Buse, 1994):

$$ES_i = \alpha_i + \sum_j \gamma_{ij} \ln(p_j) + \beta_i \ln(Y/P^*) \qquad (32)$$

Constrained to

$$\sum_i \alpha_i = 1 \quad \sum_i \beta_i = 0; \quad \sum_i \gamma_{ij} = 0; \quad \gamma_{ij} = \gamma_{ji}$$

Where $\ln P^* = \sum_i ES_i \ln p_i$ is the linear Stone's price index suggested by Deaton and Muellbauer (1980)[10]; Y indicates total budget (e.g. shadow full income); p_j denotes the price of good *j*; α_i is the good-specific constant; β_i is the parameter of the budget effect of demand and γ_{ij} are the parameters of the effects of relative price changes.

We group household expenditure into five categories of goods: self-consumed agricultural products (including rice, maize, wheat, rapeseed, vegetables, and livestock products); biomass energy (composed of firewood and crop residues); commercial energy (consist of electricity, coal, natural gas, and LPG); other purchased goods and leisure time.

Since the variations in the prices for the households who are living in the same region are quite small, we set up household-specific prices by using sub-groups consumption structure under the assumption that the expenditure shares of the commodities in the same group are constant (Beznoska, 2014). The prices are then calculated by the sum of weighted prices of each term in that category (Castellón et al, 2012):

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[9] Here, we select household head characteristics (the age, gender and educational years), demographic characteristics (family size and fractions of female adults, male adults, children and elderly people), arable land areas, prices (agricultural products, labor, intermediate inputs), non-labor income, distance to the nearest biomass collecting spot, and location dummies as independent variables in estimating the selection equation, according to the reduced form of labor allocation function (24).

[10] However, this index could be seen as endogenous variable, because it depends on household expenditure shares. Therefore, we replace the individual expenditure shares with the sample mean ($\overline{ES_i}$).

$$p_j = \sum_{n=1}^{N} p_n ES_{nj} \quad \forall n = 1, 2, \cdots, N \tag{33}$$

Where, ES_{nj} is the expenditure share of commodity n in commodity group j and p_n is the price of commodity n [11]. Particularly, the shadow wage rate of household labor which has been estimated in the first stage is included in the model as the shadow price of leisure time. It is also used to calculate the shadow price of biomass energy[12].

The LA/AIDS model is estimated by using constrained iterative seemingly unrelated regression (Constrained ITSUR) method (Zellner, 1962). This method allows the estimation of contemporaneous correlation in error terms across system equations, which then to be used to derive more efficient estimates. In the ITSUR procedure, the demand equation of other marketed goods (ES_o) is excluded from the system. The parameters of this excluded equation can be figured out in terms of the parameters of other equations using the add-up restriction $\sum_i \alpha_i = 1$, since the sum of the shares of expenditure is equal to 1.

Considering the endogeneity problems related to the estimation of the LA/AID model, the zero-expenditure problem occurs in group of biomass energy due to household's nonparticipation decision regarding biomass collection. Therefore, estimating the system only with the households who participate in collecting biomass may induce biased results. In order to correct the potential sample selection bias, we adopt the method proposed by Heien and Wessells (1990) to include the inverse Mills ratio (R_b) as an instrument in the expenditure share equation of biomass energy in the LA/AID model.

Another endogeneity problem is caused by including the shadow wage of household labor and the shadow price of biomass energy in the model. As the allocation of budget (full shadow income) depends on the work-leisure decision which is determined within household, the term $\ln(Y/P^*)$ is also endogenous (Beznoska, 2014). As suggested by Henning and Henningsen (2007), these variables are affected by household characteristics poxied by demographic factors, household location as well as by the price of other commodities. Finally, the LA/AID model is estimated as specified by:

$$ES_i = \alpha_i + \sum_j \gamma_{ij} \ln(p_j) + \beta_i \ln(Y/P^*) + \rho_i X + \varepsilon_i \tag{34}$$

Where ρ is the coefficient of household characteristics affecting consumption X (such as demographic characteristics and household location).

Based on the estimation results of this LA/AIDS model, the compensated price elasticites can be calculated by using the formulas given in the work of Chalfant (1987):

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[11] For the group of other marketed goods, we adopt the method suggested by West and Parry (2009) using the price data to calculate a price index for the composite market goods. The price data were collected from the official website of Sichuan government: http://www.sc.gov.cn/10462/10464/10594/10601/2013/10/8/10279526.shtml and our field survey.

[12] $$Shadow\ price\ of\ biomass energy \approx \frac{w_i^*(CNY\ per\ hour) \times Collecting\ time\ (Hours)}{Total\ amount\ of\ collected\ biomass\ (kg)}$$

$$\sigma_{ij}^{*} = \quad \delta_{ij} + \frac{\hat{\gamma}_{ij}}{\overline{ES}_i} + \overline{ES}_j \tag{35}$$

Where if $i = j$, $\delta_{ij} = 1$, otherwise $\delta_{ij} = 0$. The average expenditure shares of the households are denoted by $\overline{ES}$. The $\hat{\beta}_i$ and $\hat{\gamma}_{ij}$ are the estimated parameters in LA/AIDS model. Moreover, the formula used to calculate the full income elasticity for *i*-th good is (See Green and Alston, 1990):

$$\theta_i = \frac{\hat{\beta}_i}{\overline{ES}_i} + 1 \tag{36}$$

3.3 Household labor demand

In order to investigate household labor demand for different income-generating activities, a translog cost function with multiple inputs is employed (Hamermesh, 1993). Following Fisher et al (2005), we assume all income generation (including shadow income) activities as a process of production. Then for a production function with three inputs (i.e. labor working off-farm, labor allocated to home production, and intermediate inputs for agricultural production including fertilizers, pesticides and plastic films), the translog cost function is given by (Dogan and Akay, 2016):

$$\ln TC = \alpha_0 + \alpha_i \ln p_i + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j + \alpha_y \ln Y_P + \mu_i \tag{37}$$

Constrained to

$$\sum_i \alpha_i = 1; \quad \sum_j \gamma_{ij} = 0; \quad \gamma_{ij} = \gamma_{ji}$$

According to Shephard's lemma, the input of a factor with minimizing cost can be got from the differentiation of the translog cost function with respect to its price (Mas-colell et al, 1995). Here, in order to solve the problem of singularity, we drop out the cost share equation of intermediate inputs from the system. Finally, two labor cost share equations will be estimated:

$$LS_i = \alpha_i + \gamma_{ij} \ln(\frac{p_j}{p_c}) + \gamma_{ii} \ln(\frac{p_i}{p_c}) + \varepsilon_i \tag{38}$$

Where α_o is the constant term; μ and ε are the error terms; TC represents total cost; Y_P is the total value of output; p_i is the prices of household labor (i.e. the market wage rate and shadow wage rate); LS_i denotes the cost share of labor inputs (i.e. labor in home production and off-farm employed labor); p_c is the weighted price of intermediate inputs[13]. The other factors such as area of arable land, the ratio of the dependence to labor and location dummies are also included in the model. Finally, the inverse Mills ratio (R'_o) is added in the off-farm labor cost share equation as an instrument to correct the potential sample selection bias.

The translog cost function (37) and the system of labor cost share equations (38) form a system of multiple equations with the three cross-equation parameter restrictions. This system is estimated also using the constrained iterative seemingly unrelated regression (Constrained ITSUR) method. Then, the

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[13] The weighted price of intermediate inputs is calculated by using the similar method described in (33)

formula given by Binswanger (1974) can be applied to calculate the own-wage elasticity and substitution elasticity of labor demand:

$$E_{ii} = \frac{\gamma_{ii}}{\overline{LS}_i} - 1 + \overline{LS}_i \tag{39}$$

$$E_{ij} = \frac{\gamma_{ij}}{\overline{LS}_i} + \overline{LS}_j \tag{40}$$

Particularly, as the unobservable shadow wage and shadow income are endogenously determined within household, we use the natural logarithm of non-labor income ($\ln OI$) and household head characteristics (the age, gender and educational level) as instruments[14].

4. Data and Empirical Results

4.1 Data

The data used in this paper were collected from a field survey of 576 rural households in 6 counties of Sichuan Province from August 2013 to February 2014. For the sampling procedure, 176 counties of Sichuan Province were sorted by the rural per capita income level in 2012. Then the province was divided into three zones-high, medium and low- in the light of income levels of rural area. In each zone, two counties were randomly selected. Further, two towns, each with three villages were randomly selected in each county. In every village, 15-16 respondents were randomly surveyed. After dropping out invalid questionnaires and outliers, our sample of 524 agricultural households was constructed.

4.2 Estimation Results

The IT3SLS estimates of the Cobb-Douglas production system are reported in Table 1. Most of the coefficients have the expected signs. Labor inputs have significantly positive effects on both agricultural production and biomass collection. The household head's schooling also has a significantly positive impact on both outputs, supporting the widely accepted role of human capital in improving production. For agricultural production, other inputs (i.e. arable land and intermediate inputs) have significant and positive impacts. Furthermore, household location is an important factor for household production. Compared with the households from hilly areas, households located in mountainous areas have more outputs from agricultural production, while those located in plain areas collect less biomass. The household shadow wage is estimated using the coefficients of the production system and then, included in our econometric analysis in next steps.

Table 1
Estimation results of the production system using IT3SLS

Variables	Total value of agricultural production ($\ln Y_a$)	Total amount of biomass ($\ln Y_b$)
Total value of agricultural outputs (log)		-0.068 (0.215)
Total amount of biomass (log)	-0.961 (0.399)**	

[14] As suggested by Beznoska (2014), these variables are exogenous and correlated with household allocation decision. Therefore, they are appropriate instruments.

Hours working on home production (log)	1.023 (0.217)***	0.447 (0.213)**
Areas of arable land (log)	0.283 (0.103)***	
Total value of intermediate inputs (log)	0.038 (0.021)*	
Age of household head	-0.008 (0.006)	-0.005 (0.005)
Gender of household head	0.215 (0.240)	0.185 (0.184)
Educational level of household head	0.065 (0.010)***	0.030 (0.017)*
Distance to biomass collecting spot		0.032 (0.014)**
Mountainous areas	0.337 (0.151)**	-0.135 (0.167)
Plain areas	-0.157 (0.334)	-0.534 (0.194)***
_cons	8.975 (2.193)***	5.678 (0.852)***
Sample selection (R_b)		-0.473 (0.256)*
Endogenous variables[a]	$\ln Y_a$, $\ln Y_b$	
No. of Obs.	394	

Note: The missing dummy for regions is Hilly area. The significance level are as *10%; **5% and ***1%. Values in parentheses are standard errors of estimated parameters.
The significant coefficient of the IMR indicates that sample selection bias would happen if the system of production functions was estimated without taking household participation decisions on biomass collection into consideration.
a. All other variables in this system are treated as exogenous to the system and uncorrelated with the disturbances. The exogenous variables are taken to be instruments for the endogenous variables.

The estimation results of the LA/AIDS demand system are provided in Table 2. The coefficients of the variables indicate that prices and budget are the most important influencing factors for household consumption. In addition, demographic characteristics and household location can also significantly impact the consumption.

Table 2
Parameter estimation of LA/AIDS model using censored SURE

Variables	Expenditure share of				
	Self-consumed agricultural products	Biomass energy	Commercial energy	Leisure	Other purchased goods
Price of self-consumed agricultural products (log)	0.0096***				
	(0.0027)				
Shadow price of biomass energy (log)	0.0024***	0.0116***			
	(0.0008)	(0.0007)			
Price of commercial energy (log)	0.0016***	-0.0002	-0.0013**		
	(0.0003)	(0.0003)	(0.0006)		
Shadow price of leisure (log)	-0.0364***	-0.0203***	-0.0029***	0.1376***	
	(0.0028)	(0.0014)	(0.0006)	(0.0076)	
Price of other marketed goods (log)	0.0228***	0.0064***	0.0029***	-0.0780***	-0.0942
	(0.0031)	(0.0010)	(0.0005)	(0.0067)	
$\ln(Y/P^*)$	0.0520***	0.0034	0.0048***	-0.2658***	0.2056
	(0.0093)	(0.0029)	(0.0012)	(0.0250)	
Family size	-0.0181***	-0.0039***	-0.0018***	0.0857***	
	(0.0029)	(0.0009)	(0.0004)	(0.0077)	

Fraction of female adults	0.0408	0.0097	0.0026	-0.1770***	
	(0.0250)	(0.0076)	(0.0031)	(0.0674)	
Fraction of male adults	0.0680***	0.0133*	0.0037	-0.1928***	
	(0.0234)	(0.0071)	(0.0029)	(0.0631)	
Fraction of children (≤14)	0.0244	0.0068	0.0011	-0.1207*	
	(0.0244)	(0.0074)	(0.0030)	(0.0661)	
Fraction of elderly (≥65)	-0.0143	0.0065*	-0.0022*	0.1056***	
	(0.0104)	(0.0035)	(0.0013)	(0.0281)	
Mountain areas (r_1=1)	-0.0206***	-0.0008	-0.0027***	-0.0098	
	(0.0052)	(0.0018)	(0.0008)	(0.0139)	
Plain areas (r_2=1)	0.0019	-0.0067***	0.0042***	0.0046	
	(0.0066)	(0.0024)	(0.0009)	(0.0178)	
Sample selection (R_b)		-0.0010			
		(0.0038)			
_cons	-0.4768***	-0.0003	-0.0450***	3.2699***	-1.7478
	(0.0859)	(0.0263)	(0.0120)	(0.2262)	
No. of Obs.			394		

Note: The missing dummy for regions is Hilly area. The significance level are as *10%; **5% and ***1%. Values in parentheses are standard errors of estimated parameters. The insignificant coefficient of the IMR indicates that sample selection bias would not happen if the system of production functions was estimated without taking household participation decisions on biomass collection into consideration.

Table 3 lists the estimation results of the system of the translog cost function and the labor cost share equations with the instrumental variables. The estimated parameters in labor share equations reveal that arable land areas, the ratio of dependence to labor, and household location are determinants for household labor allocation to working activities.

Table 3
Constrained ITSURE estimation results of translog cost function and labor cost share equations

Variables	Total Cost	Cost share of labor working on home production	Cost share of labor employed off-farm
$\ln p_c$	0.233 (0.042)***		
$\ln p_f$	0.496 (0.058)***		
$\ln p_d$	0.271 (0.070)***		
$(\ln p_c)^2$	0.075 (0.035)**		
$(\ln p_f)^2$	0.154 (0.047)***		
$(\ln p_d)^2$	0.010 (0.054)*		
$\ln p_c * \ln p_f$	-0.065 (0.045)		

$\ln p_c * \ln p_d$	-0.010 (0.051)		
$\ln p_d * \ln p_f$	-0.089 (0.016)***		
$\ln Y$	0.249 (0.182)		
$\ln(p_f / p_c)$		-0.089 (0.016)***	0.134 (0.019)***
$\ln(p_d / p_c)$		0.075 (0.017)***	-0.089 (0.016)***
Areas of arable land	0.017 (0.010)*	0.005 (0.003)*	-0.005 (0.003)
Ratio of dependence to labor	-0.460 (0.090)***	0.158 (0.029)***	-0.184 (0.035)***
Mountainous area (r_1=1)	-0.010 (0.080)	0.082 (0.025)***	-0.125 (0.030)***
Plain area (r_2=1)	-0.236 (0.085)***	0.060 (0.026)**	-0.072 (0.031)**
Sample selection (R'_o)			0.317 (0.008)***
_cons	5.632 (2.172)**	0.169 (0.026)***	0.673 (0.036)***
Hausman test statistic		39.01***	
No. of Obs.		524	

Note: The missing dummy for regions is Hilly area. The values in parentheses are standard errors, and the significance levels are *10%; **5% and ***1%. p_c represents the price of intermediate inputs; p_d denotes shadow wage rate; and p_f refers to market wage rate. The coefficient of the IMR is significant, indicating that sample selection bias would happen if the system of labor share equations was estimated taking households who do not participate in off-farm work into consideration.

4.3 Elasticities

As reported in Table 4, for the compensated direct price elasticities of commodities groups, all the signs are negative. These results are consistent with the theoretical postulate that the expenditure on commodities will decrease when the prices of them increase. In terms of their magnitudes, self-consumed agricultural products and biomass energy are price inelastic, as households' consumption of these two types of goods derives from their own production. The expenditure on other purchased goods is irresponsive to changes in their own prices; this is particularly true for rural households as basic necessities take up the largest shares in their total consumption of purchased goods. Additionally, the positive signs of income elasticities demonstrate that all the five types of commodities are normal goods. As regards the demand for leisure, its own price elasticity is quite small, while its income elasticity is relatively large and probably indicates that, as income increases, households proportionately allocates more time to leisure and reduce their time allocation to work activities.

Turning to the cross-price elasticities of consumption, the elasticities between biomass energy and self-consumed agricultural products are positive, implying that the relationship between agricultural production and biomass collection could be competitive. The cross-price elasticities of biomass energy consumption with respect to the price of commercial energy and other purchased goods are also positive, indicating that both of them are substitutes for biomass energy.

Table 4
Estimated simple price elasticities of sampled agricultural households (using mean value)

	Full income	With respect to the price of

	elasticity	Self-consumed agricultural products	Biomass energy	Commercial energy	Labor (shadow wage rate)	Other purchased goods	Labor (market wage rate)
Consumption							
Self-consumed agricultural products	2.111	-0.744	0.175	0.041	-0.008	0.640	-
Biomass energy	1.027	0.067	-0.783	0.007	0.604	0.216	-
Commercial energy	1.617	0.246	0.102	-1.163	0.396	0.530	-
Leisure	0.655	-0.001	0.096	0.004	-0.052	0.062	-
Other purchased goods	2.255	0.186	0.162	0.025	0.293	-1.177	-
Labor Demand							
Home production	-	-	-	-	-0.450	-	0.290
Off-farm employment	-	-	-	-	0.150	-	-0.186

On the other hand, we can compute the price elasticities of household labor demand using the estimated parameters of the labor share equations. The negative sign of the own price elasticity satisfies the requirement of concavity. Meanwhile, the cross-price elasticities of labor demand for home production and off-farm work are both negative, supporting the theoretical expectations on the signs of the production elasticities.

The estimated simple price elasticities in Table 4 are then used to calculate the effects of exogenous shock on household biomass energy. As it is shown in Table 5, the elasticity of the internal labor price (shadow wage rate) with respect to the exogenous market price $E(w^{*}/p_{x})$ reflects the internal response to price changes. External instability with the imperfect labor market is shown by the global elasticity of biomass energy consumption with respect to the exogenous market price $E(C_b/p_x)^G$. The difference between the consumption elasticity of the household model $E(C_b/p_x)^H$ and the global consumption elasticity $E(C_b/p_x)^G$ reveals the bias caused by ignoring the effects of internal instability.

Table 5
Effects of price changes on household biomass energy use

	With respect to the external price of			
	Self-consumed agricultural products	Commercial energy	Other purchased goods	Labor
The shadow wage rate $E(w^{*}/p_{x})$	0.020	-0.133	-0.572	0.439
Consumption of biomass energy $E(C_b/p_x)^H$	0.078	0.018	0.227	0.129
Consumption of biomass energy $E(C_b/p_x)^G$	0.104	-0.157	-0.528	0.709

Considering the case of a 1% increase in the price of self-consumed agricultural products, its demand falls (0.744%) as its price rises and there is a substitution by a rising demand for biomass energy (0.067%) in consumption. These effects lead to a shift in labor demand from agricultural production to biomass collection. However, due to the market failures, the leisure time is not allowed to significantly increase with the income effect created by the rising price (0.026%). Household's behavior of moving from agricultural production to biomass collection in response to a price increase of the agricultural products is thus exaggerated by the imperfect labor market with a binding constraint on off-farm work. Therefore, the demand for biomass energy increases by 0.104% instead of 0.078%. In this case, a 1% increase in the price of self-consumed agricultural products is associated with a 0.02% increase in the shadow wage rate.

By contrast, if the price of commercial energy or of other purchased goods increases (by 1%), demand for biomass energy increases (by 0.007% or 0.216%). Meanwhile, the consumption of self-consumed agricultural products increases (by 0.041% or 0.640%), resulting in an increase in labor demand for home production. Nevertheless, due to the market failures, a 1% increase in the price of commercial energy or other purchased goods induces a 0.133% or 0.572% decrease in the shadow wage rate. Thus, leisure consumption rises as a result of both substitution effects and income effects. Accordingly, the available time allocated to biomass collection falls. Since the decline in biomass collection is greater than the increase in biomass energy demand, the total effects lead to a decrease in biomass energy consumption (-0.157% or-0.528%).

Turning to household biomass energy use response to a 1% increase in the market price of household labor, the indirect effect of the external price via the internal labor price change has a positive sign (0.439%), indicating that the shadow wage rate responds positively to the market wage rate. The direct effect on biomass energy use is positive (0.129%), as labor demand for home production responds positively to the market wage rate (0.290%). The global elasticity is thus unambiguously positive, implying that a 1% increase in the market wage rate raises demand for biomass energy by 0.709%. This is due to the fact that with an increase in the market wage rate, the limited available off-farm opportunities increase the labor allocated to biomass collection.

5. Conclusions

This paper aims to investigate the effects of exogenous shocks caused by price changes on household biomass energy using behaviors. The potential influence of a price change on biomass energy use is complex, because household's consumption, production and labor market decisions are interlinked and markets are missing or imperfect. Thus, based on estimation of an agricultural household model with survey data from 36 villages in Sichuan Province, our results support the conventional wisdom that, holding other variables constant, higher market prices directly lead to more biomass energy consumption (Nyang ,1999; Wambua, 2011). However, we extend the literature by proposing a comprehensive analytic framework that simultaneously takes into account the direct impact on the supply and demand reactions due to the price change and the indirect impact on the supply and demand adjustments to the endogenous variations in the shadow wage generated by the price change. Our study shows that neglecting the indirect effects can bias the final effect on household behaviors. According to our findings, if the price of self-consumed agricultural products increases, the indirect effect via the internal labor price increase reinforces the direct positive effect, meaning that households consume more biomass energy in response to a price increase of self-consumed agricultural products. This also implies that agricultural production and biomass collection are competitive, as the consumption of these two categories of goods derives from their own production. At the same time, with positive cross-price elasticities of biomass energy consumption with respect to the market price of commercial energy and other purchased goods, the internal labor price decrease offsets the increase in biomass energy use that occurred in response to the exogenous price increase and causes further decline in biomass energy consumption. As for a change in the market wage rate, the positive indirect effect via the shadow wage rate increase reinforces the direct positive effect.

Since biomass energy plays an important role in rural livelihoods in China, the elasticity of household biomass energy use response to price incentives is crucial for food security enhancement and economic development. Thus, the results we have obtained indicate several elements of policy interventions that can be used to control this elasticity. One is the role of measures directed at reducing the incidence of market failures for specific households. This includes interventions that have capability to mitigate the binding constraint imposed on off-farm employment such as increasing investments in infrastructure construction, promoting education in rural areas and smoothing circulation of information on wages and job opportunities. Moreover, indirect sources of market failure also need to be eliminated by establishing a sound and effective social safety net to provide better access for rural households to services such as public transport system, health care, landless employment guarantee. In addition, our findings also have clear implications on future energy policy design in rural China. The Chinese government should attach more importance to reduce the price of commercial energy by developing energy technologies and exploring more types of renewable energy sources. This could not only decrease biomass collection, but also improve households' motivation of engaging in agricultural production.

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Appendix

Table A1
Variables used in this study

Variable	Mean	Std.Dev.
Shadow wage estimation		
Total value of agricultural outputs (CNY)	18258.5	47874.38
Total amount of collected biomass (Kgsce)	3736.65	4505.28
Total value of intermediate inputs (CNY)	4839.52	16262.75
Total hours working on home production (Hours)	1001.93	635.73
Arable land areas (Mu)	4.13	3.7
Age of household head (Years)	51.69	11.61
Gender of household head (share of male)	0.93	0.26
Educational level of household head (Years)	6.39	3.45
Distance to the nearest biomass collecting spot (Km)	2.22	4.5
d_1 (=1, if the household is from mountainous areas)	0.33	0.47
d_2 (=1, if the household is from plain areas)	0.32	0.47
IMR (R_b)	0.43	0.41
S_b (=1, if household participates in biomass collection)	0.75	0.43
S_o (=1, if household participates in off-farm work)	0.86	0.34
Household consumption decisions		
Expenditure share of self-consumed agricultural products	0.047	0.053
Expenditure share of biomass energy	0.012	0.018
Expenditure share of commercial energy	0.008	0.073
Expenditure share of leisure time	0.769	0.157
Expenditure share of other purchased goods	0.164	0.134
Weighted price of self-consumed agricultural products (CNY per kg)	4.01	3.27
Weighted shadow price of biomass energy (CNY per kgsce)	1.14	2.06
Weighted price of commercial energy (CNY per kgsce)	3.32	1.01
Price of leisure (CNY per hour)	12.72	13.31
Price index of other purchased goods (CNY per unit)	596.15	279.83
Shadow full income (CNY)	241175.9	200543.4
Linear Stone's price index (P^*)	2.73	0.69
Family Size	4.13	1.36
Fraction of children (≤14)	0.11	0.16
Fraction of elderly people (≥65)	0.12	0.23
Fraction of female adults	0.41	0.15
Fraction of Male adults	0.44	0.16
Household labor demand		
Total cost for all production (CNY)	52297.15	58110.22
Total value of outputs (CNY)	233393	199353.6
Cost share of labor allocated to home production activities	0.30	0.25

Cost share of labor allocated to off-farm work	0.58	0.32
Ratio of dependence to labor	0.32	0.36
Market wage rate (CNY per hour)	8.48	4.98
Shadow wage rate (CNY per hour)	12.72	13.31
Price index of intermediate inputs (CNY per kg)	7.23	14.62
Non-labor income (CNY)	2682.49	4428.59
IMR (R'_o)	1.91	0.68
No. of Obs.	524	

Source: author's own household survey (2013-2014)
Note: The variables used in estimating the selection equation (30) are also included in the three models respectively. Therefore, they are not listed separately.
The missing data of wage rate (for the households who did not participate in off-farm work) are replaced by the regional mean. The average market wage rate is lower than the estimated shadow wage rate, due to the fact that in our field survey, most households understated their wage income levels.
In order to unify the units of firewood and crop straw to standard coal equivalent (kgsce), we divide the quantities of them by their conversion coefficients respectively. Particularly, the data of conversion coefficients for all types of energy are collected from China Energy Statistic Yearbook (2009).