**Identifying a Sustained Pathway to Multidimensional Poverty Reduction: Evidence from Two Chinese Provinces**[[1]](#footnote-1)†

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**Abstract**

Poor rural households in developing countries often endure many-faceted burdens including monetary poverty, nutrition deficiency and energy shortage due to reliance on limited local natural resources with low utilisation efficiency. We investigate a sustained pathway in rural China to escape the vicious circle between three important dimensions of poverty – deficiency of income, malnutrition and a low energy consumption profile in terms of reliance on firewood. By exploiting household panel data and a dynamic and recursive multi-equation mixed mode, we identify inter-locking deprivations in income, nutrition and energy consumption. Firewood plantations only offer short-term solutions to break them through income effects, while the sustained pathways in the long-term are increasing agricultural labour productivity and provision of agricultural loans.

**Key words:** multidimensional poverty, energy, nutrition, firewood, dynamic causal effect, China

**JEL classifications:** C33, I31, Q23, O53

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**1. Introduction**

China has successfully reduced the incidence of poverty, measuring household per capita income against the US$1.25/day, from 81.6% in 1981 to 10.4% in 2005, which is equivalent to lifting 608.8 million people’s livelihoods above the aforementioned poverty line (Chen and Ravallion, 2010). About 99% of this achievement was realised in rural areas, which benefited from agricultural growth (Montavol and Ravallion, 2010). In contrast to rapid income growth and better economic conditions, there has been sluggish improvement in other dimensions of poverty. In particular, energy poverty – i.e. household reliance on firewood and biomass fuels in their energy consumption as opposed to commercial, more efficient and cleaner fuels (IEA, 2010 and UNEP, 2010) remains at stubbornly high levels, which contradicts the “energy ladder” theory.[[2]](#footnote-2)

Despite income growth, rural households are still not able to afford commercial fuels of higher combustion and utilisation efficiency and lower environmental risk.[[3]](#footnote-3) In rural Gansu province where the data used in this paper were collected, the average household per capita annual expenditure on commercial energy was 536.51 *yuan*, accounting for 8.69% of its annual net income (Li *et al.*, 2009). Straw and firewood are still the main energy source for Chinese rural households (more than 85% found by Pachauri and Jiang, 2008), especially in northern regions where there are long cold winters (Zhou *et al.*, These include property right before2008). Heavy dependence of Chinese households on less effective heat sources (such as firewood and biomass) has long led to energy deficiency which is interdependent with and may cause other deprivations.

First, given a proportionally higher share of income from depleting natural resources out of total income among the poor compared to that of the non-poor (Anglesen *et al.*, 2014), there exists a poverty-environmental degradation nexus (Ekbom and Bojo, 1999) predicting a close and direct link between low income and energy poverty in terms of high environmental reliance, such as excessive firewood planting and collection.[[4]](#footnote-4) Moreover, over two thirds of straw and other woody biomass fuels are being used for domestic purposes in Chinese rural areas instead of being ploughed-in to re-nourish soils (Wang and Feng, 2001), which significantly attenuates land productivity. This in turn would threaten poverty reduction in the long-term, as agricultural income, which is the main source of income for Chinese rural households, suggests the strongest poverty-reducing impact among all income sources compared with other types of income such as out-migration, transfers or agricultural tax abolishment (Christiaensen *et al.*, 2013).

Second, households’ energy consumption also affects their nutrient intake. As predicted by the “energy ladder” hypothesis and the poverty-environmental degradation nexus described above, poor households could be trapped in firewood reliance because of their low income and the high cost of commercial fuels. As woody biomass is used mainly for cooking and heating in developing countries, inefficient cooking energy can impose direct and negative nutritional effects on food. Firewood shortage in poor communities that have been affected by over-exploitation of natural resources can further induce household shifts to less nutritious foods requiring less fuel to cook (McMullin *et al.*, 2015). Indirectly, energy poverty in terms of excessive firewood reliance may also be associated with deficient nutrient intake through low incomes under the income-nutrition poverty trap which is predicted by Dasgupta and Ray’s (1986) “efficiency wage hypothesis”.[[5]](#footnote-5) Taken together, income-poor households are likely to suffer from insufficient nutrient intake as well as energy poverty.

Third, given that most Chinese rural households plant or collect rather than purchase firewood, firewood plantations, as a non-tradable input, enter households’ coordinated decision-making process. Decisions on firewood production and consumption are non-separable and determined jointly by the household’s unobserved traits. Firewood plantations thus exhibit “feedback” effects on income poverty by providing directly additional income from selling or supporting households’ basic needs and thus allowing them to invest in other livelihood activities (de Janvry and Sadoulet, 2016). In the Democratic Republic of Congo, Schure *et al.* (2014) find both kinds of “feedback” and document 12-75% increases in wood-fuel revenues, especially those of charcoal, for firewood producers. Nevertheless, (excessive) firewood planting might make livelihoods volatile if it crowds out natural forests or undermines agroforestry as natural forests and agroforestry can serve as “safety nets” (Fisher *et al.*, 2010), support income growth and diversification (Fabe *et al.*, 2014), and contribute to food security (McMullin *et al.*, 2015).

Therefore, beyond focusing on monetary wellbeing, it is essential to bring into the analysis of welfare changes other important dimensions of poverty, in particular, those of nutrition and energy consumption. Moreover, such an analysis should recognise that these three dimensions of poverty (income, nutrition, and energy consumption) are co-determined jointly with labour allocation decisions across different livelihood arrangements, including firewood plantations (Baland *et al.*, 2010). This paper aims to identify, in relatively impoverished areas of northwest China, whether there could be a “sustained pathway” to multidimensional poverty reduction, i.e., improving income, nutrition, and energy consumption in the long-term without necessarily over-exploiting/relying on local natural resources, typically firewood.

In doing so, this paper contributes to the literature by the following ways. Conceptually, it takes into account the complexity in household’s livelihood decision making and its many-faceted welfare outcomes. For one thing, it analyses “conventional” poverty components, namely income and nutrition, together with environment conservation for the poor, which has long been called for since Sanderson (2005) but remains under-researched in the existing empirical literature.[[6]](#footnote-6) For another, it frames households’ multi-dimensional wellbeing status and livelihood plans within a coherent behavioural system. Thus, it can identify not only the interplay between various deprivations, but also the feedbacks of households’ environment-related livelihood decision-making on multi-dimensional deprivation outcomes.

Empirically, to accomplish our research aim and comply with the conceptual framework in the previous paragraph, the present study proposes a dynamic and recursive multi-equation mixed model incorporating three methodological improvements. First, it consists of a system of four equations, of which three equations represent three dimensions of poverty and one equation captures the integrated decision-making on firewood production. Aggregated multidimensional indices have been widely constructed in developing countries (e.g., India in Mishra and Ray, 2013 and 100 developing countries in Alkire and Santos, 2014) and have recently been extended to developed countries (e.g., the Europe in Whelan *et al.*, 2014 and the U.S. in Dhongde and Haveman, 2016). In contrast, we explicitly model alternative dimensions of poverty separately in a system of equations. In doing so we allow different deprivations to play their own and possibly different roles in households’ coordinated decision making. In particular, each deprivation and firewood production behaviour also enter the system as independent variables, to shape a recursive decision-making process. Second, all equations are determined jointly under time-invariant and jointly distributed unobservables. This captures endogeneity in households’ coordinated decision-making process. Third, not only can endogeneity be controlled for, our model also distinguishes between the static (short-term) and dynamic (long-term) interplay between deprivations. Overall, our modelling strategy more clearly allows us to identify a sustained long-term pathway to poverty reduction that accounts for the dimensions of income, nutrition and energy consumption.

The paper proceeds as follows. Section 2 presents the dataset and describes the sample population. Empirical models are sketched out in Section 3 with results being discussed in Section 4. Section 5 concludes and summarises the policy implications that can be derived.

**2. Data**

We exploit a panel dataset in two western provinces, Gansu and Inner Mongolia (Figure 1), with 5 annual waves of survey data from 2000 to 2004 covering separately individual, household and village surveys.

[Figure 1]

Data was collected by local branches of the National Bureau of Statistics (NBS), covering 1,500 households in 150 villages from 15 counties. Of these, 700 households in 7 counties are in Gansu and the remaining 800 households resided in 8 counties of Inner Mongolia. Enumerators regularly visited respondents throughout the year and income and consumption data were collected by the daily diary method. Therefore, the data were more accurate than those relying on one-time interview and recall questions. The individual non-response rate and attrition were negligible because of regular visits by local officials of the NBS and there was zero attrition at the household level (Christiaensen *et al.*, 2013).[[7]](#footnote-7) We use household equivalent as the unit in the analysis. The modified OECD equivalence scale is used to calculate the equivalent household size and household per capita monetary variables. All monetary values are converted into real terms by using spatial price indices to obtain compatibility over time as well as between two provinces. See Table A.1 in Appendix for detailed definition and descriptive statistics for all variables.

Consistent with the overall trend of rural development in China, sampled households experienced an average annual growth rate of 7.8% in their per capita net income from 2000 to 2004. The income poverty rate dropped from 18.2% below the US$1.25-a-day line in 2000 to 10.3% in 2004. However, nutrient intake decreased from 67.8% to 75.9%, resulting in a high and even increasing be nutrition poverty rate.[[8]](#footnote-8) More than 60% of our sampled households in each survey wave relied on firewood as their main energy source in their daily life. The proportion of wood areas in the household’s total land holdings increased gradually from 5.1% in 2000 to 6% in 2002, but decreased thereafter to 1% in 2003 and 2004. The proportion of households relying on woody biomass for daily energy consumption (i.e., the energy poverty rate) slightly declined from 66.2% to 63.6%. However, the quantity of firewood purchased increased between 2000 and 2002 and then decreased in 2003 and 2004 when there were substantial income losses due to a plague of locusts in 2003 and severe drought in 2004. Households switched to firewood plantations within our analysis period: households on average expanded firewood production in their remaining forest land from 0.04 acres in 2000 to 0.47 acres in 2004. Nevertheless, the total forest areas under each households’ cultivation and management shrank quickly from an average of 14 acres in 2000 to 4.8 acres in 2003 and dropped to 0.86 acres in 2004 because of the Sloping Lands Conversion Programme (SLCP, or Grain for Green Programme) launched in 2002.[[9]](#footnote-9) Consequently, both the quantity of firewood plantations and its proportion in the household’s total wood areas expanded over the sample period. See Table A.1 in Appendix for descriptive statistics.

**3. Empirical methodology**

We consider households’ energy-related behaviour and many-faceted welfare outcomes as a coherent and complete system. The unobserved capability and heterogeneity underlie various decisions made by the same household. The household *i*’s observed income () and nutritional status () and energy consumption () at time *t* is indexed by dichotomous outcomes  which are driven by its unobserved capability . Let  (or ) if *i* has suffered from income (or nutritional) poverty and  if its main energy source is woody biomass and zero for fossil fuel (coal or gas).[[10]](#footnote-10) Further, under non-separability of income and consumption behaviour for households in developing countries, household *i* at the same time determines its environment-related production decisions which in our model is captured by  which denotes the proportion of firewood plantations out of *i’*s total forest land holdings.[[11]](#footnote-11) Proportions are typically used to study households’ adjustments in livelihood decisions (e.g., in studies of labour allocation). They also moderate the scale effects caused by the household size and the structural changes brought about by the SLCP in 2003 and 2004 to the absolute size of forest areas and to the proportion of forest land in total land managed by households. In Section 4.3 we will discuss alternative results of using absolute terms of firewood plantations.

We estimate the following equations simultaneously, with three latent regressions from (1) to (3) representing separately the household’s probabilities of being income poor, deprived of nutrition and reliant on firewood as their main energy source rather than more efficient commercial fuels, and one uncensored regression (4) representing its observed firewood production plans:









Eqs. (1)-(3) are dynamic probit models with household unobserved heterogeneity,[[12]](#footnote-12) while (4) is an outcome equation without censoring. The recursive components (s) depict the (short-term) simultaneous inter-dependence between three deprivations and the firewood-planting decision. In comparison, the dynamic components (s) reflect their linkages in the long run. A sustained pathway out of, or into (one or more dimensions of) poverty will be identified by cross-comparing the short- and long-term impacts of firewood plantations on three welfare outcomes and their feedback to households’ firewood plantations.

The error terms are jointly and non-identically normally distributed  where the variance-covariance matrix is expressed by



The correlation coefficients are thus  for . They reflect the unobservables determining both households’ livelihood choices and their deprivation status. In other words, livelihood arrangement in terms of firewood plantations enters endogenously into each household’s multidimensional poverty profile. The vector  controls for households’ demographic and socio-economic characteristics. The vector  with  are excluded instruments helping better identify each equation. It includes the lagged household per capita equivalent income in 1999 in the income equation, the unit prices of grain and meat for the nutritional equation, the unit price of coal in the energy consumption equation, and distance to the household’s main energy source in the firewood production equation. The first differencing process can eliminate time-invariant characteristics that might bias estimation and thus, lagged variables can be used as excluded instruments in poverty studies (e.g., see an application from rural China in Jalan and Ravallion, 2004), while admittedly such excluded instruments might be weak and result in small sample biases (Meghir and Pistaferri, 2004). The choices of prices for nutrition and firewood consumption are based on existing studies that find direct correlation between food prices (e.g., see findings from both rural and urban China in You *et al.*, 2016) and nutrient intake and between prices of fuels and energy consumption (e.g., see results from rural China in Pachauri and Jiang, 2008 and from rural Nepal in Malla, 2013). It is less likely that prices of food (coal) impose direct influences on firewood (food) consumption, while those prices might be indirectly linked to household income. According to Roodman (2011), the simultaneous system can be identified without instruments and can be better identified even under weak instruments.[[13]](#footnote-13)

The likelihood function for the static system (without dynamic components) is written by the product of all 8 possible observed combinations of outcomes in (1)-(3) and the probability of observing  in (4):



where  denotes the combination plane including 8 possible observed outcomes of  at each time *t*;  is the joint four dimensional normal density function for all equations. As  involves double and triple integrals over the probability region of , we evaluated numerically the likelihood function (5) by using the GHK agglomeration (i.e., maximum simulated likelihood (MSL)), in order to achieve convergence and to yield consistent estimators (Roodman, 2011). When considering the dynamics of the household’s multi-outcome behaviour, (5) changes to



where the initial distribution of all outcomes is made exogenous to the household’s subsequent behaviour. As in the static situation, MSL is used to evaluate (6) for consistent estimators.

To facilitate interpretation of the magnitude of the impact, we also calculate the average marginal effects after estimation. Specifically, for each explanatory variable in each equation, we first calculate the marginal effect for each household and then average them across all households to obtain the average marginal effect. The average effects calculated in this way can acknowledge heterogeneous influence of the same explanatory variable across households. The marginal effect for a continuous variable  in a latent regression  for *N* households is calculated as follows:



where  is the linear combination of all independent variables in the equation *j*. If  is a dichotomous variable in Eqs. (1)-(3), its average marginal effect is written as:



where  denotes the linear combination of the remaining independent variables except . The average marginal effects in the uncensored regression (Eq. 4) are directly shown by the estimated coefficients.

**4. Estimation results and discussion**

**4.1. Static interactions between income, nutrition, commercial fossil fuel consumption and firewood production**

We first estimate the system with  and  only (Columns 1-4 of Table 1) and then, include the recursive components (Columns 5-8 of Table 1). The absolute value of the log-likelihood in the latter is only 20% of that in the former. This means that there is remarkable improvement in goodness-of-fit of the whole model when enabling inter-dependence and/or feedback effects between household income and nutrition poverty status and energy-related livelihood strategies. Treating recursive components as endogenous variables, we re-estimated Columns 5-8 of Table 1 separately by a standard two-stage instrumental variable (2SLS) approach. The log-likelihood under inter-dependent dimensions as Columns 5-8 of Table 1 is 77%-90% larger than that of the 2SLS estimation in each (independent) dimension. This reaffirms the gains in model performance by MSL estimation compared with the standard 2SLS approach.[[14]](#footnote-14) The presence of households’ correlated unobservables driving four outcome variables is also evident as the correlation coefficients between residuals of the four equations reach as large (in absolute terms) as -0.899 in Columns 5-8 as opposed to nearly zero in Columns 1-4 of Table 1. The recursive specification is therefore justified to take into account endogeneity as well as the staggered impacts of four dependent variables. Our discussion will thus focus on Columns 5-8 of Table 1.

[Table 1]

We thus proceed to examine the inter-play between four dependent variables in the recursive specifications. The statistically significant and positive coefficients of income and nutrition poverty status in Columns (5)-(6) of Table 1 indicate inter-locking low income and nutrition in Gansu and Inner Mongolia. We further calculate the marginal effects by substituting the estimators in Columns 5-6 of Table 1 to Eq. 8. Nutrition poverty produces a 20.2% increase in the probability of falling into income poverty, and income poverty insures a 30.6% increase in the probability of falling into nutrition poverty. Moreover, income poverty induces energy poverty as shown by Démurger and Fournier’s (2011) study in poor rural villages north to Beijing supporting the “poverty-environment hypothesis”: household wealth, which is proxied by an aggregated wealth index, relates negatively to the quantity of firewood consumption, but there is a “floor effect” where firewood consumption no longer declines. The recursive components in Column 7 of Table 1 also show that households in our dataset are more likely to experience energy poverty in terms of using firewood as their main energy source when living on income below the poverty line of US$ 1.25/day. The average marginal effect of income poverty on energy poverty incidence is 12.8%, based on the estimator of 0.364 in Column 7. This is predictable from the perspective of affordability – our data suggest that the household’s total expenditure on firewood was negligible (2 *yuan* per annum), as rural households collected or harvested firewood rather than purchasing it from markets, in sharp contrast to 167 *yuan* per annum for the expenditure on commercial fuels. Another piece of supporting evidence to the income-energy poverty nexus is that the distance to the main fuel source increased by 13.4% from 2000 (1.79km) to 2004 (2.03km) for poor households defined by per capita net income against US$1.25/day, which is understandable if they collect or harvest more firewood from nearby to farther forests. By contrast, the distance decreased by 4.2% (1.9km to 1.82km) for non-poor households, as they are likely to switch to commercial fuels that are accessible in nearby markets.

In comparison with the one-way effect of income poverty on energy poverty, we find two-way effects between nutrition shortage and reliance on firewood consumption. Nutrition poverty incurs energy poverty (0.580 in Column 7 of Table 2), which could be realised through the nutrition-income poverty nexus. Nevertheless, the magnitude of this effect nearly doubles the size of the aforementioned direct impact of income poverty on firewood consumption: we find on average a 21.8 percentage points higher likelihood of using firewood as the main energy source if the household falls into nutrition poverty. At the same time, energy choices also produce feedback effects on the incidence of nutrition poverty (0.090 in Column 6 of Table 1). Based on Eq. (8), the average marginal effect of mainly using firewood on the likelihood of suffering from nutrition poverty is 2.9%.

As expected, those experiencing energy poverty tend to grow more firewood (0.014 in Column 8 of Table 1), but the magnitude of this impact is very small: the average marginal effect across all households is 0.3 percent and even the maximum is only 2.5 percent. At the same time, those growing more firewood would also use more firewood (3.232 in Column 7 of Table 2): a one percent increase in the proportion of firewood areas adds one percentage point to the household’s probability of using firewood.

In the production side, households tend to plant more firewood when their income rises, as indicated by the negative estimated coefficient of income poverty (-0.029) in Column 8 of Table 1. This indicates that households may have used firewood as a means to further increase income but this may also entail a threat to sustainable land use and local biological diversity along with economic prosperity. The calculations of marginal effects based on the estimated coefficients in Column 8 of Table 1 and Eq. (8) suggest that earning more than US$1.25/day is associated with 1.2 percent more firewood plantations in the household’s total wood areas. By drawing the distribution of household-specific marginal effects, we find that their magnitude only differs in the fourth decimal with the standard deviation at 0.00003, indicating a highly homogeneous preference in households’ firewood plantations. If the proportion of firewood plantations in total forest land increases by one percentage point, the household would be 29.8% less likely to fall into income poverty. We suspect that this is more of an indirect income effect of firewood plantations as opposed to a direct income-generating effect given on average forest income making only 2.2% of household total income in our data. Moreover, there were basically no firewood markets in rural areas and extremely low prices should the household need to purchase some. The indirect effect can be seen from two aspects: households used firewood to substitute commercial fuels, in order to save costs; this could in turn allow them to invest more in agricultural productive assets and living standards.[[15]](#footnote-15) In this sense, firewood planting and agricultural production are complementary in households’ livelihoods, which has also been found in a global comparative analysis by Angelsen *et al.* (2014).

By contrast, the estimated effect of nutrition poverty on the proportion of firewood planting is significantly positive (0.019 in Column 8 of Table 1) and vice versa (1.297 in Column 6 of Table 1), indicating a vicious circle between under-nutrition and environmental degradation. The calculation of average marginal effects shows that being short of nutrition increases the proportion of firewood plantations by 0.7 percentage points. This might be triggered by borrowing constraints faced by those deficient in nutrition. The data show that their annual borrowing (2,136.3 *yuan*) was 30% higher than that of the non-nutritionally poor (1,640.1 *yuan*). Although we do not have data on the purposes for taking on loans, we find that the nutrition-poor with such a large amount of loans did not switch to commercial fuels – they even spent 13% less on buying commercial fuels – but invested more in local non-agricultural activities such as family businesses, processing agricultural products, commercial services and retails. Suggestive evidence is that those consuming fewer calories than the nutrition threshold spent 6% less time on agricultural production (at the 1% significance level), which is predictable as agricultural production requires considerable energy, but 5% more time per annum on local non-agricultural work (at the 5% significance level compared with those living above the nutrition threshold). However, the above behaviour is at the expense of a vicious circle between firewood reliance and deficiency of nutrition. An additional one percent firewood area would in turn push up the incidence of nutrition poverty by 41.8 percentage points.

**4.2. Dynamic impacts on poverty, energy consumption and firewood production**

Table 2 reports the results of our model that controls for both recursive correlations and the dynamics in households’ three deprivations and the single energy production-related behavioural response. The dynamic components are all significantly positive in their own regressions (i.e., 0.199, 0.666, 2.338 and 0.740 at the diagonal line in Table 2), indicating strong persistence in three deprivations and firewood production behaviour.

[Table 2]

There are distinct short- and long-term cross influences between household firewood production behaviour and the three-faceted welfare outcomes. The income-nutrition association found in Table 1 still holds, but only in the short-term, as indicated by statistically significant and positive coefficients of income and nutrition status at period *t* (1.406 and 1.358 in Columns 1-2 of Table 2). Being income poor is only correlated with contemporaneous energy poverty at the 1% significance level (0.587 in Column 3 of Table 2) with an average marginal effect of 12.6%. Nutrition poverty still discourages households to use commercial fuels, but again this effect is more of a short-term (0.781) than long-term phenomenon (-0.248).[[16]](#footnote-16) Correspondingly, the feedback effect of energy poverty on low nutrient intake only exists in the short-term (0.655 in Column 2 of Table 2).

Growing more firewood could offer a short-term palliative effect on income poverty (-5.909 in Column 1 of Table 2), which is similar to that obtained by the static analysis in Section 4.1, but with a greater marginal effect (63%). Firewood planting also alleviates nutrition poverty (-3.191 in Column 2 of Table 2). Nevertheless, it diminishes households’ long-run welfare in all three dimensions as the estimated coefficients of the lagged firewood production are significantly positive in Columns 1-3 of Table 2.[[17]](#footnote-17) On average, households would be respectively 44%, 95.3% and 53% more likely to be deprived in income, nutrition and energy consumption on one more percentage of the proportion of firewood in total forest land.

Column 3 of Table 2 suggests that the static and negative relationship between firewood plantations and using commercial fuels in Section 4.1 only exists in the long-term. In the short-term, more firewood plantations would on the contrary encourage consumption of commercial fuels (-2.535). This may be because households become more able to afford commercial fuels as the expanded firewood production brings more income, either directly or indirectly as discussed in Section 4.1, which is indicated by the aforementioned substantially short-term income poverty-reducing effect of firewood plantations. More importantly, as income increases (and thus income poverty reduces), nutrition poverty decreases simultaneously (1.358 in Column 2 of Table 2) through the income-nutrition link, which in turn would immediately push people to prefer commercial fuels to firewood given the income-energy and nutrition-energy nexuses (0.587 and 0.781 in Column 3 of Table 2) and therefore, households would be able to escape energy poverty in the short run. Such a favourable transition in energy consumption (i.e., away from firewood to commercial fuels) would in turn encourage households to grow more firewood immediately (i.e., -0.049 in Column 4 of Table 2, equivalent to an average marginal effect of -1.4%), while not continuously (or excessively) in the long-term as the sign of the estimated coefficient turns to positive (i.e., 0.045 in Column 4 of Table 2, equivalent to an average marginal effect of 1.3%).

Overall, income growth seems to be a starting point for a short- rather than long-term solution to promote a sustainable livelihood in terms of switching from firewood consumption to commercial fuels and weakening reliance on firewood plantations. Nevertheless, it is important to consider where these income increases may likely come from. If income growth is achieved by growing more firewood in the short-term, this seems to improve welfare in all three dimensions, either directly or by triggering sequential and positive movements through substantial income increases brought about by initially expanded firewood production. Nevertheless, this strategy may carry negative outcomes in income, nutrition and energy choices in the long-term.

**4.3. Other factors influencing household multi-dimensional poverty status and firewood production behaviour**

Demographics matter in multidimensional poverty analyses. Households led by older household heads are more likely to suffer from nutrition poverty (Columns 2 and 6 of Table 1 and Column 2 of Table 2) and use firewood (Column 4 of Table 2). A higher (lower) dependency ratio in terms of the share of children (<18 years old) and the elderly (>60 years old) relates to higher (lower) incidence of income and energy (nutrition) poverty (Table 1). We are unable to check gender differences as only 7 out of 1,500 households were headed by women. Alternatively, we inserted the share of men in adult household members (18≤age≤60) as an additional regressor and re-estimated Tables 1 and 2. The average share was around 0.52 with little variation across the different survey waves, indicating a stable demographic structure. Its estimated coefficients are largely insignificant.

One more year of education relates to a 0.1 percent reduction in the proportion of firewood areas in the household’s total forest land holdings (Column 8 in Table 1), which only marginally echoes Démurger and Fournier’s (2011) finding in the relatively poor rural areas surrounding Beijing. Education seems to be irrelevant in the long-term as the estimated coefficients lose statistical significance in Table 3. This raises concern about the “term of validity” of this conventional instrument in promoting sustained and comprehensive rural development in relatively poor rural communities.[[18]](#footnote-18)

Table 1 also documents the gains of labour productivity in multidimensional poverty reduction. A one percent increase in agricultural labour productivity would reduce the probability of income poverty by 6.6 percentage points at the 1% significance level, which is calculated based on the estimator (-0.349) in Column 5 of Table 1 and Eq. (7). This is followed by average marginal effects of labour productivity gains in local off-farm activities and out-migration of 2.5% and 2.1%, respectively.[[19]](#footnote-19) The important role of agriculture in rural poverty reduction has been widely found in developing economies dominated by smallholder agriculture (Ravallion, 2009). More importantly, in the most general model specification in Table 2 labour productivity gains, regardless of source, appear to be able to address duel challenges: they alleviate income poverty (Column 1 of Table 2) without necessarily more (or even with less) firewood plantations (Column 4 of Table 2).This implies the importance of (profitable) livelihood arrangements in tackling multiple challenges of rural household development. Cao *et al.* (2009) also find in Fujian province of southeast China that the policy of compensating rural households’ energy consumption can only achieve ecological restoration as well as reduction in income poverty when it is combined with means to improve farmers’ livelihood (e.g., subsidies for planting fruit trees and raising livestock). While agricultural labour productivity in our sample provinces was the most effective means among the three livelihood arrangements of tackling income poverty, it is worth noting that Mullan *et al.* (2010) find that in Guizhou province of southwest China labour re-allocation towards rural-to-urban migration under the Natural Forest Protection Program addressed both monetary poverty and ecological rehabilitation in terms of less logging. Government’s provision of formal agricultural loans can supplement the labour productivity gains by weakening households’ reliance on firewood in the short-term (Column 7 of Table 1), as these loans were designed to release households’ credit constraints.

Rural electrification, which has long been pledged by the Chinese government, is surprisingly never relevant to household poverty status or energy-related decision making regardless of model specifications. We suspect this might be caused by the measurement of the indicator of rural electrification. We use the household’s rather than the sample village’s access to electricity. As found by Khandker *et al.* (2013) in rural Vietnam, village-level electrification construction is likely to be pro-poor and yields welfare spill-overs to villagers, while household level electrification brings negative returns.[[20]](#footnote-20) A limited role of electrification in accelerating energy transition at the household level has also been observed in other developing countries, such as South Africa (Davis, 1998), especially for lower income households who still tend to combine the use of electricity with other energy sources (Thom, 2000).Mover, the insignificant impact of electrification on nutrition, albeit nutrition poverty-reducing, suggests that the benefit of electrification on health in previous studies (e.g., Spalding-Fecher, 2005) may hinge on the specific indicators used and cannot be generalised to the dimension of nutrition poverty.

We also investigated the impact of infrastructure proxied by access to roads. The dataset has this information at both the household and village levels. To proxy for the former we used the dummy variable of whether the household has access to a road. To capture village level proximity to road we use the proportion of natural villages being accessed by a Grade IV road within the administrative village.[[21]](#footnote-21) The complete dynamic and recursive model in Table 2 was re-estimated after inserting separately the above indicators as additional regressors. Roads stimulate households’ adoption of commercial fuels (0.296) and discourages firewood plantations (-0.009), both at 1% significance levels.[[22]](#footnote-22) Access to roads does not impose significant impacts on either energy consumption or production.

In contrast to infrastructure construction, Tables 1 and 2 show consistently that higher village income helps alleviate households’ income poverty, encourages commercial fuel consumption, while slightly decreasing nutrient intake.[[23]](#footnote-23)

Institutional instruments may also appeal to policy makers to bypass an initially huge expansion in firewood production, typically the SLCP launched in 1999. In the early 2000s, the SLCP gave annual subsidy for one *mu* (≈667m2) cultivated land consisted of 100kg grains plus a cash transfer of 20 *yuan*. The subsidy was to last for at least 8 years if the reforested plots were to primarily offer ecological benefits, 5 years if they offered economic revenues to farmers and 2 years if the cropland was converted to grasslands. In our data, 320 and 369 households received the SLCP subsidies in 2003 and 2004 respectively. The information relevant to this programme was collected by the last two waves of our dataset. The average amount received among recipients was 867 *yuan* in 2003 and 688 *yuan* in 2004.

We re-estimated the dynamic and recursive model (Table 2) for the last two waves with the amount of subsidies as an additional regressor. This worsens considerably the overall fit of the model as the log-likelihood drops sharply to -1,020.82. All short-term feedback effects between four dependent variables lose statistical significance and the magnitude of the dynamic feedback effects in the long-term becomes smaller. Although as Groom *et al.* (2010), the SLCP *per se* tends to benefit “win-win” outcomes by addressing the dual challenge of poverty and environment, the magnitude of its marginal effects in the long-term is trivial. The subsidies of 100 *yuan* can suppress the proportion of firewood plantations in total forest areas by 0.05 percentage points, possibly because of the main purposes of the programme: namely the majority of land was converted for ecological protection rather than to produce fuelwood. The subsidies also increase the probability of consuming commercial fuel by 0.9 percentage points, and alleviate the incidence of income and nutrition poverty by 0.54 and 0.37 percentage points, respectively.

**4.4. Sensitivity analysis and robustness checks**

We adopted higher poverty lines to check the sensitivity of our results. The income poverty is measured against US$2/day, which is the median poverty-line across all developing countries. The nutritional threshold is set at 2,400 kcal per person per day, as suggested by Park and Wang (2001) for rural China. We re-estimated the full sample under higher poverty lines in the most general model specification including both dynamic and recursive processes as in Table 2. Table 3 reports these results. The above findings hold in general. However, it is worth highlighting the following differences.

[Table 3]

The short-term multidimensional poverty reduction impact of firewood plantations and the reverse impact in the long-term still hold, while the magnitude of these effects changes. For example, the income-increasing effect of firewood planting is dampened: -2.238 in Column 1 of Table 3, equivalent to on average 0.5% reduction in the probability of income poverty for every one percentage point increase in the proportion of firewood, as opposed to -5.909 in Column 1 of Table 2 with an average marginal income poverty-reducing effect of 1.1%. This implies that using firewood plantations as a means to escape poverty can still work in the short-term for those who are not-so-poor in income and nutrition.

The contemporaneous link between nutrition and energy poverty is also weakened. The average marginal effects of nutrition poverty on energy poverty remain similar, 18.6% (0.590 in Column 3 of Table 3), as opposed to 19% (0.781 in Column 3 of Table 2). In comparison, energy poverty adds 10% to the probability of nutrition poverty against higher thresholds (0.352 in Column 2 of Table 3), while only 27% under lower ones (0.655 in Column 2 of Table 2).

What is qualitatively different from the static analysis is in Column 4 of Table 3, where both income and nutrition poverty immediately result in more firewood planting in the short-term while, in the long-term, plantations are not responsive to income and decrease with nutrition poverty. This may be because households are not as poor as before and are therefore able to adjust production quickly. In other words, those just crossing the low nutrition poverty line may be tempted to plant more firewood by its income-poverty reducing effect (-2.238 Column 1 of Table 3), although this livelihood strategy would hurt their future nutrient intake (4.413 in Column 2 of Table 3) and undermine income generation in the future (1.041 in Column 1 of Table 3).[[24]](#footnote-24)

It is worth noting that the benefits of labour productivity gains in reducing income poverty become smaller and the negative impact of agricultural labour productivity on firewood plantations disappears. Labour productivity gains in local off-farm activities begin to encourage firewood plantations. Together with still significant income effects of firewood plantations, this implies that those who have survived from extreme poverty would continue to grow more firewood, even though this may bring about the return of the three deprivations. The benefit of formal agricultural loans provided by the government also dissipates. Those who have escaped extreme poverty need a different income-supporting policy. In this respect, local economic prosperity in terms of village income growth maintains reduction of household income poverty (-1.5 in Column 1) without necessarily requiring more firewood plantations (-0.011 in Column 4 of Table 3).

**5. Conclusion**

This paper uses a household panel dataset in two poor provinces of northwest China to investigate the complex interactions between households’ multidimensional wellbeing (income, nutrition and energy use) and behavioural responses in decision making on firewood planting. The analytical framework draws upon a mixed dynamic and recursive model, accounting for the household’s correlated unobserved heterogeneity underlying its dynamic livelihood arrangements and interdependent welfare outcomes.

The empirical results document the possibility of inter-locked traps among deprivations in income, nutrition and energy dimensions and firewood plantations. We find that household reliance on firewood plantations offers only short-term palliative in reducing deprivations of income, nutrition and energy consumption. Our dynamic model reveals that in the long-term these impacts cannot be sustained for the poor. More sensitivity and robustness checks suggest that the multi-dimensional poverty reducing impact of firewood plantations diminishes when rural households become better-off in income and/or nutrition. Overall, reliance of firewood plantations does not seem to be a pathway for sustained welfare improvement.

Agriculture still plays an important role in sustained poverty reduction in relatively poor communities. In particular, increases in agricultural labour productivity appear to tackle income poverty without necessarily relying on more firewood production, while the government’s provision of agricultural loans reduces energy poverty by stimulating transitions in energy consumption towards commercial fuels. The government’s institutional innovations (e.g., the SLCP) also help address the dual challenges in poverty and environment, while the magnitude of this impact is trivial in the long-term uncles complementary subsidies are offered (Groom *et al.*, 2010). Other factors that have traditionally been associated with beneficial effects on alleviating poverty, such as education, rural electrification, and infrastructure in terms of access to roads, either suggest distinct effects in different time horizons or work only at village level rather than at household level.

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**Figure 1 Sample provinces**



Note: Shaded areas are two sample provinces – Gansu and Inner Mongolia.

**Table 1 Estimation results of mixed models with latent and observed variables (static)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Non-recursive | | | | Recursive | | | |
| Independent variable | Income poverty | Nutrition poverty | Energy poverty | Firewood production | Income poverty | Nutrition poverty | Energy poverty | Firewood production |
|  | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| *Contemporaneous inter-dependent feedback effects* | | | | | | | | |
| Income poverty |  |  |  |  |  | 1.269 (0.045)\*\*\* | 0.364 (0.097)\*\*\* | -0.029 (0.004)\*\*\* |
| Nutrition poverty |  |  |  |  | 1.230 (0.031)\*\*\* |  | 0.580 (0.069)\*\*\* | 0.019 (0.003)\*\*\* |
| Energy poverty |  |  |  |  | -0.001 (0.045) | 0.090 (0.043)\*\* |  | 0.014 (0.003)\*\*\* |
| Firewood production |  |  |  |  | -1.574 (0.190)\*\*\* | 1.297 (0.163)\*\*\* | 3.232 (0.172)\*\*\* |  |
| *Household and village characteristics* | | | | | | | | |
| Ln(age of hh head) | 0.034  (0.104) | 0.348 (0.089)\*\*\* | -0.274 (0.125)\*\* | 0.009 (0.009) | -0.013 (0.090) | 0.332 (0.087)\*\*\* | -0.070 (0.186) | 0.009 (0.009) |
| Dependency ratio | 0.274 (0.116)\*\* | -0.191 (0.096)\*\* | 0.342 (0.121)\*\*\* | 0.012 (0.008) | 0.327 (0.096)\*\*\* | -0.251 (0.098)\*\* | 0.559 (0.204)\*\*\* | 0.013 (0.008) |
| Ethnicity of hh head | -0.301 (0.084)\*\*\* | 0.048 (0.088) | 0.482 (0.146)\*\*\* | 0.012 (0.002)\*\*\* | -0.360 (0.068)\*\*\* | 0.002  (0.095) | -0.238 (0.296) | 0.009 (0.002)\*\*\* |
| Years of education of hh head | -0.016 (0.008)\*\* | 0.017 (0.006)\*\*\* | -0.009 (0.009) | -0.001 (0.001) | -0.022 (0.007)\*\*\* | 0.019 (0.006)\*\*\* | -0.020 (0.013) | -0.001 (0.0006)\* |
| Ln(labour productivity in agriculture) | -0.417 (0.019)\*\*\* | -0.027 (0.013)\*\* | 0.035 (0.012)\*\*\* | 0.004 (0.001)\*\*\* | -0.349 (0.019)\*\*\* | 0.039 (0.015)\*\*\* | 0.041 (0.025)\* | 0.002 (0.0008)\*\*\* |
| Ln(labour productivity in local off-farm activities) | -0.164 (0.011)\*\*\* | -0.006 (0.009) | -0.015 (0.010) | 0.001 (0.001) | -0.130 (0.009)\*\*\* | 0.036 (0.009)\*\*\* | 0.015  (0.015) | 0.001 (0.001) |
| Ln(labour productivity in out-migration) | -0.126 (0.014)\*\*\* | 0.001 (0.010) | -0.007 (0.011) | -0.0002 (0.001) | -0.109 (0.014)\*\*\* | 0.025 (0.012)\*\* | 0.004 (0.0008)\*\*\* | -0.0004 (0.001) |
| Ln(agricultural loans) | 0.009 (0.006) | 0.003 (0.004) | -0.014 (0.005)\*\*\* | -0.0002 (0.0003) | 0.003  (0.005) | 0.002 (0.004) | -0.025 (0.011)\*\* | -0.0001 (0.0003) |
| HH access to electricity | -0.022 (0.088) | -0.051 (0.073) | 0.025 (0.101) | -0.002 (0.006) | -0.049 (0.072) | -0.061 (0.072) | -0.052 (0.187) | -0.002 (0.006) |
| Ln(village average household per capita income) | -1.229 (0.080)\*\*\* | 0.124 (0.044)\*\*\* | -0.385 (0.053)\*\*\* | -0.017 (0.003)\*\*\* | -1.252 (0.013)\*\*\* | 0.210 (0.021)\*\*\* | -0.136 (0.090) | -0.018 (0.001)\*\*\* |
| Ln(time) | -0.171 (0.045)\*\*\* | 0.185 (0.032)\*\*\* | -0.033 (0.024) | 0.025 (0.003)\*\*\* | -0.154 (0.038)\*\*\* | 0.015 (0.032)\*\*\* | -0.265 (0.068)\*\*\* | 0.024 (0.003)\*\*\* |
| *Excluded instruments* |  |  |  |  |  |  |  |  |
| Ln(hh equiv. per capita income) in 1999 | 0.071 (0.045) |  |  |  | 0.054  (0.033)\* |  |  |  |
| Unit price of grain |  | 0.260 (0.060)\*\*\* |  |  |  | 0.216 (0.047)\*\*\* |  |  |
| Unit price of meat |  | -0.076 (0.013)\*\*\* |  |  |  | -0.077 (0.018)\*\*\* |  |  |
| Unit price of coal |  |  | 0.005 (0.003)\* |  |  |  | 0.012 (0.007)\* |  |
| Distance to the cooking fuel supply |  |  |  | -0.0002 (0.0001)\* |  |  |  | -0.103 (0.001)\*\* |
| No. of obs. | 7,479 |  |  |  | 7,479 |  |  |  |
| Log-likelihood | -5,180.63 |  |  |  | -977.06 |  |  |  |
| LR test (χ2 statistic) | 1,506.80 (0.000) |  |  |  | 3,002.87 (0.000) |  |  |  |
| *Correlation coefficients* |  |  |  |  |  |  |  |  |
|  | 0.074 |  |  |  | -0.899 |  |  |  |
|  | 0.013 |  |  |  | 0.106 |  |  |  |
|  | -0.003 |  |  |  | 0.194 |  |  |  |
|  | 0.037 |  |  |  | -0.295 |  |  |  |
|  | 0.016 |  |  |  | -0.151 |  |  |  |
|  | 0.014 |  |  |  | -0.490 |  |  |  |

Note: \*\*\*, \*\* and \* denote separately 1%, 5% and 10% significance levels. Household-clustered standard errors are in parentheses.

**Table 2 Estimation results of mixed models with latent and observed variables (dynamic and recursive)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Independent variables | Income poverty | Nutrition poverty | Energy poverty | Firewood production |
|  | (1) | (2) | (3) | (4) |
| *Contemporaneous inter-dependent feedback effects* | | | | |
| Income poverty at *t* |  | 1.358 (0.080)\*\*\* | 0.587 (0.083)\*\*\* | -0.046 (0.005)\*\*\* |
| Nutrition poverty at *t* | 1.406 (0.095)\*\*\* |  | 0.781 (0.062)\*\*\* | -0.032 (0.003)\*\*\* |
| Energy poverty at *t* | 0.228 (0.146) | 0.655 (0.043)\*\*\* |  | -0.049 (0.005)\*\*\* |
| Firewood production at *t* | -5.909 (1.231)\*\*\* | -3.191 (0.287)\*\*\* | -2.535 (0.271)\*\*\* |  |
| *Dynamic inter-dependent feedback effects* |  |  |  |  |
| Income poverty at *t-1* | 0.199 (0.065)\*\*\* | -0.080 (0.090) | 0.017 (0.089) | 0.009 (0.003)\*\*\* |
| Nutrition poverty at *t-1* | -0.217 (0.067)\*\*\* | 0.666 (0.045)\*\*\* | -0.248 (0.099)\*\*\* | 0.012 (0.005)\*\*\* |
| Energy poverty at *t-1* | -0.301 (0.170)\* | -0.586 (0.168)\*\*\* | 2.338 (0.133)\*\*\* | 0.045 (0.005)\*\*\* |
| Firewood production at *t-1* | 8.831 (1.820)\*\*\* | 2.136 (0.486)\*\*\* | 1.919 (0.470)\*\*\* | 0.740 (0.062)\*\*\* |
| *Household and village characteristics* |  |  |  |  |
| Ln(age of hh head) | -0.020 (0.124) | 0.252 (0.092)\*\*\* | -0.101 (0.084) | 0.013 (0.007)\* |
| Dependency ratio | 0.210 (0.110)\* | -0.083 (0.147) | -0.102 (0.245) | 0.017 (0.008)\*\* |
| Ethnicity of hh head | -0.379 (0.128)\*\*\* | 0.165 (0.072)\* | 0.171 (0.182) | 0.015 (0.006)\*\*\* |
| Years of education of hh head | -0.023 (0.009)\*\*\* | 0.015 (0.012) | -0.010 (0.011) | -0.0005 (0.0005) |
| Ln(labour productivity in agriculture) | -0.300 (0.041)\*\*\* | 0.082 (0.027)\*\*\* | 0.040 (0.028) | -0.012 (0.002)\*\*\* |
| Ln(labour productivity in local off-farm activities) | -0.111 (0.032)\*\*\* | 0.034 (0.030) | 0.022 (0.029) | -0.001 (0.023) |
| Ln(labour productivity in out-migration) | -0.089 (0.025)\*\*\* | 0.033 (0.027) | -0.015 (0.025) | -0.003 (0.019) |
| Ln(formal agricultural loans) | -0.004 (0.010) | -0.001 (0.007) | -0.009 (0.015) | -0.001 (0.0003)\*\* |
| HH access to electricity | 0.071 (0.153) | -0.009 (0.078) | 0.044 (0.104) | -0.0005 (0.005) |
| Ln(village average household per capita income) | -1.198 (0.103)\*\*\* | 0.149 (0.080)\* | -0.186 (0.007)\*\*\* | 0.004 (0.004) |
| *Excluded instruments* |  |  |  |  |
| Ln(hh equiv. per capita income) in 1999 | 0.080 (0.054) |  |  |  |
| Unit price of grain |  | 0.094 (0.034)\*\* |  |  |
| Unit price of meat |  | -0.049 (0.006)\*\*\* |  |  |
| Unit price of coal |  |  | 0.002 (0.0001)\*\*\* |  |
| Distance to the cooking fuel supply |  |  |  | -0.104 (0.001)\*\*\* |
| No. of obs. | 6,000 |  |  |  |
| Log-likelihood | -1,764.919 |  |  |  |
| LR | 7,428.94 (0.000) |  |  |  |
| *Correlation coefficients* |  |  |  |  |
|  | -0.621 |  |  |  |
|  | 0.358 |  |  |  |
|  | 0.383 |  |  |  |
|  | -0.511 |  |  |  |
|  | 0.277 |  |  |  |
|  | 0.453 |  |  |  |

Note: See Table 1.

**Table 3 Robustness checks at higher poverty lines (US$2/day and 2,400 kcal, dynamic and recursive)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Independent variables | Income poverty | Nutrition poverty | Energy poverty | Firewood plantation |
|  | (1) | (2) | (3) | (4) |
| *Contemporaneous inter-dependent feedback effects* | | | | |
| Income poverty at *t* |  | 1.046 (0.034)\*\*\* | 0.514 (0.029)\*\*\* | 0.032 (0.004)\*\*\* |
| Nutrition poverty at *t* | 1.227 (0.173)\*\*\* |  | 0.590 (0.041)\*\*\* | 0.085 (0.004)\*\*\* |
| Energy poverty at *t* | 0.411 (0.102)\*\*\* | 0.352 (0.051)\*\*\* |  | -0.106 (0.002)\*\*\* |
| Firewood production at *t* | -2.238 (0.154)\*\*\* | -5.140 (0.145)\*\*\* | -8.842 (0.291)\*\*\* |  |
| *Dynamic inter-dependent feedback effects* |  |  |  |  |
| Income poverty at *t-1* | 0.161 (0.050)\*\*\* | -0.177 (0.024)\*\*\* | 0.0003 (0.057) | 0.002 (0.003) |
| Nutrition poverty at *t-1* | -0.246 (0.115)\*\* | 0.592 (0.062)\*\*\* | -0.165 (0.067)\*\*\* | -0.023 (0.004)\*\*\* |
| Energy poverty at *t-1* | -0.327 (0.156)\*\* | -0.314 (0.041)\*\*\* | 1.173 (0.063)\*\*\* | 0.089 (0.006)\*\*\* |
| Firewood production at *t-1* | 1.041 (0.323)\*\*\* | 4.413 (0.390)\*\*\* | 6.497 (0.492)\*\*\* | 0.751 (0.071)\*\*\* |
| *Household and village characteristics* |  |  |  |  |
| Ln(age of hh head) | 0.058 (0.113) | 0.229 (0.091)\*\*\* | -0.082 (0.116) | 0.007 (0.006) |
| Dependency ratio | 0.252 (0.136)\* | -0.285 (0.101)\*\*\* | 0.016 (0.134) | 0.007 (0.008) |
| Ethnicity of hh head | -0.293 (0.101)\*\*\* | 0.108 (0.087) | 0.158 (0.126) | 0.004 (0.006) |
| Years of education of hh head | -0.018 (0.008)\*\* | 0.035 (0.007)\*\*\* | -0.005 (0.007) | -0.0003 (0.0004)\*\*\* |
| Ln(labour productivity in agriculture) | -0.290 (0.150)\*\* | 0.106 (0.049)\*\* | 0.073 (0.091) | 0.003 (0.005) |
| Ln(labour productivity in local off-farm activities) | -0.105 (0.037)\*\*\* | 0.043 (0.028) | 0.033 (0.030) | 0.002 (0.0008)\*\* |
| Ln(labour productivity in out-migration) | -0.035 (0.030) | 0.021 (0.029) | -0.024 (0.026) | -0.002 (0.010) |
| Ln(formal agricultural loans) | 0.005 (0.006) | 0.001 (0.005) | -0.002 (0.005) | -0.0004 (0.0003) |
| HH access to electricity | 0.042 (0.080) | -0.067 (0.062) | -0.008 (0.011) | -0.001 (0.005) |
| Ln(village average household per capita income) | -1.500 (0.108)\*\*\* | 0.077 (0.053) | -0.132 (0.114) | -0.011 (0.006)\* |
| *Excluded instruments* |  |  |  |  |
| Ln(hh equiv. per capita income) in 1999 | -0.064 (0.045) |  |  |  |
| Unit price of grain |  | 0.085 (0.026)\*\*\* |  |  |
| Unit price of meat |  | -0.036 (0.014)\*\*\* |  |  |
| Unit price of coal |  |  | -0.002 (0.004) |  |
| Distance to the cooking fuel supply |  |  |  | -0.106 (0.002)\*\*\* |
| No. of obs. | 6,000 |  |  |  |
| Log-likelihood | -2,874.185 |  |  |  |
| LR | 1,250.09 (0.000) |  |  |  |
| *Correlation coefficients* |  |  |  |  |
|  | -0.676 |  |  |  |
|  | -0.396 |  |  |  |
|  | -0.243 |  |  |  |
|  | -0.364 |  |  |  |
|  | -0.548 |  |  |  |
|  | 0.955 |  |  |  |

Note: See Table 1.

**Appendix: Table A. 1 Construction of variables and descriptive statistics**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | Definition | 2000 | | 2004 | |
| Mean | S.D. | Mean | S.D. |
| Modified OECD equivalent household size | Weighted sum of household members. The first adult in the household has a weight of 1. Each additional adult aged 14 and over has a weight of 0.5. Each child aged under 14 has a weight of 0.3. This definition can be found at Eurostat:  <http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Equivalised_disposable_income>  [accessed June 3, 2017] | 3.699 | 0.242 | 3.783 | 0.225 |
| Spatial rural price index | First, provincial rural CPI (previous year=1) is collected from China Statistical Yearbooks in relevant years. We set the rural CPI in 1999 in two provinces at 1 and compared rural CPI other years to 1, in order to construct a province-specific real price index. Second, we refer to the spatial price index from Table 2 in Brandt and Holz (2006) – in 2000 Gansu is 1.19 and IM is 0.97. We set the price level in Gansu as 1 and compare that in Inner Mongolia to it, i.e., Gansu=1 and IM=0.97/1.19=0.815. Third, we multiply 0.815 to the province-specific real price index obtained in the first step. | 0.907 | 0.088 | 1.027 | 0.093 |
| Household equivalent per capita net income | Household net income divided by equivalent household size. Household net income is total income (including agricultural and family business income, wages, transfer income and asset income) minus related costs, taxes and fees. All monetary values are transformed into real terms by dividing them by spatial CPI. | 2,379 | 1,833 | 3,117 | 2,461 |
| Household equivalent per capita daily nutrition | Household daily total nutrition intake divided by equivalent household size. The daily intake is the household annual total nutrition intake divided by 365 days. The household annual total nutrition intake is the sum of nutrition intake from food purchased by the household (in kg) multiplied by their energy intake (kcal/kg). Food includes grain (wheat, rice, and corn), potato, beans (soybeans and all other kinds of beans), vegetable and relevant products (root and tuber, melons, aubergine fruits, cabbage, green leafy vegetables, other fresh vegetables, dry vegetables, and salt vegetables), meat (pork, beef, mutton, poultry, and meet products), egg and relevant products, milk and dairy products, aquatic products (fish, shrimp, shellfish, crab, algae and others), sugar, liquor and beverage (spirit, beer, fruit wine, and beverage), fruit, and nuts and their relevant products. The energy intake for each food item comes from the Chinese Food Composition Table (FCT) 2002/2004 combined edition published by the National Institute of Nutrition and Food Safety at the Chinese Center for Disease Control and Prevention. | 1,913 | 109.1 | 1,686 | 686.06 |
| Energy poverty | Dummy taking the value of 1 if the household relies on woody biomass for living energy consumption and 0 if commercial fuels (including gas and coal). | 0.662 | 0.473 | 0.636 | 0.481 |
| Firewood production | Proportion of firewood plantations in total wood areas owned by the household | 0.0004 | 0.001 | 0.043 | 0.194 |
| Ln(age of hh head) | Ln(age (in years) of household head) | 3.699 | 0.242 | 3.783 | 0.225 |
| Dependency ratio | Proportion of children (<18 years old) and the elderly (>60 years old) in all household members. | 0.334 | 0.213 | 0.295 | 0.220 |
| Ethnic minority | Dummy taking the value of 1 if the household head has non-Han nationality and 0 otherwise. | 0.921 | 0.269 | 0.921 | 0.269 |
| Yrs of edu of hh head | No. of years completed by the household head. | 17.012 | 9.653 | 17.452 | 10.035 |
| Ln(labour productivity in agriculture) | The annual agricultural net income divided by the labour allocated to local agricultural production (days per year). The agricultural net income is the total income from local agricultural production, net of relevant production costs, taxes and fees. | 2.740 | 1.339 | 5.067 | 1.341 |
| Ln(labour productivity in local off-farm activities) | The annual local off-farm net income divided by the labour allocated to local off-farm activities (days per year). The local off-farm net income is the total income from all local off-farm activities, including local non-agriculture and family businesses, net of relevant production costs, taxes and fees. | 0.624 | 2.132 | 0.592 | 1.881 |
| Ln(labour productivity in out-migration) | The annual net income from out-migration divided by the labour allocated to out-migration (days per year). This net income is the total income from circular migration, net of relevant costs, taxes and fees. | -0.621 | 1.769 | -0.624 | 1.495 |
| HH access to electricity | Dummy taking the value of 1 if the household has access to electricity and 0 otherwise. | 0.093 | 0.219 | 0.097 | 0.297 |
| Ln(loans) | Ln (total loans including both cash and the value of in-kind goods borrowed by the household in the last year). | 3.100 | 4.196 | 1.272 | 3.820 |
| Ln(village per capita net income) | Natural logarithm of average household per capita net income in the sample village. | 7.054 | 0.526 | 7.397 | 0.565 |
| Unit price of grain/meat/coal | Prices are calculated by the expenditure (in *yuan*) the household paid for this variety of good over the amount it bought. The monetary values of prices are translated into real term by dividing them by the spatial price index. The price of meat is the average unit prices of pork, beef and lamb. | 2.400 | 1.332 | 2.200 | 1.265 |
| Distance to the cooking fuel supply | Distance from the sample village to its main cooking fuel supply (km). | 0.383 | 0.736 | 0.500 | 0.908 |

Source: Authors’ calculation based on our household panel data in Gansu and Inner Mongolia. Other supplementary indicators used in calculations come from various sources, which have been specified where necessary in the Table.

1. † This research is supported by the Fundamental Research Funds for the Central Universities, and the Research Funds of Renmin University of China (Grant No.: 15XNA005). Any remaining errors are the sole responsibility of the authors. [↑](#footnote-ref-1)
2. The “energy ladder” hypothesis postulates a complete transition away from traditional fuels such as crop residuals and firewood to more sophisticated fuels as their economic status improves (e.g., an early empirical study for Zimbabwe in Hosier and Dowd, 1988). Using national longitudinal data for 175 countries, Burke and Dundas (2015) do not find insignificant association between higher income and reduction in use of biomass energy. [↑](#footnote-ref-2)
3. Typically, an upward transition along the energy ladder is to use more efficient fuels like liquefied petroleum to replace biomass fuels like firewood and agricultural residuals (e.g., Pachauri and Jiang, 2008 for India and China, and Malla, 2013 for Nepal), as the former generates more heating and energy for daily livelihood. [↑](#footnote-ref-3)
4. See for example, the case of Shaanxi province in China (Olivia *et al.*, 2011) and in Peru (in Swinton and Quiroz, 2003). [↑](#footnote-ref-4)
5. See Jha *et al.* (2009) for empirical evidence on income-nutrition poverty traps in India. [↑](#footnote-ref-5)
6. It is acknowledged that other dimensions such as education and health are crucial in wellbeing, but including them into our multi-equation system would add much complexity in modelling sequence and feedbacks in multidimensional decision making and would undermine achieving identification. The present study thus focuses on more “root” dimensions such as income and nutrition that are likely to lead to other dimensions and relate them to sustainable livelihood such as energy use and production. [↑](#footnote-ref-6)
7. It is worth noting that the sample period over 2000-2004 might be limited in its capacity to capture the current poverty situation in rural China given the rapid economic development across the country. Yet, considering the persistently low income levels in Gansu and Inner Mongolia, the results based on our dataset do have wider implications for low- or lower middle-income countries experiencing similarly low economic wellbeing and facing similar difficulties in sustainable and multidimensional development as our sample areas. For example, according to the World Development Indicators at the World Bank, Nepal, Vietnam, Zimbabwe and Honduras showed the rates of access to commercial fuels for cooking of 26.1%, 50.9%, 31.3% and 48.1% respectively in 2014, which are similar to the rates of 34%-36% in our data. The household annual per capita expenditure in 2004 was US$ 604.8 in rural Gansu and US$ 860.8 in rural Inner Mongolia, measured by 2010 constant US$, which are also similar to those of Nepal (US$ 554.1), Vietnam (US$ 1,121 US$), Zimbabwe (US$ 605.5) and Honduras (US$ 1,806) in 2015, measured by 2010 constant prices. [↑](#footnote-ref-7)
8. It should be noted that nutrient intake is likely to be over-estimated in our data. Sample households’ food records might be less precise when time elapsed, given the diary method (on the monthly basis) lasting for 4 years. This might result in under-estimated nutrient intake and thus, higher nutrition poverty rate. By comparison, another nation-wide survey, the China Health and Nutrition Survey from 1989 to 2011, adopted a 24-h recall diary on three consecutive days for household food consumption. It indicates lower rural nutrition poverty rates in 8 provinces (but without Gansu and Inner Mongolia) between 15% and 20% over the period 2000 and 2004 (You *et al.*, 2016). Nevertheless, the increasing trend of nutrition poverty rates is very consistent between our data and the CHNS. It would thus better treat our estimated coefficients of nutrition poverty incidence *y2it* in Eqs. (1), (3) and (4) as lower bounds of its genuine effects. [↑](#footnote-ref-8)
9. Chinese government initiated the SLCP in 1999 and implemented it all over the country in 2002 for the purposes of ecological restoration as well as economic sustainability of land. The SLCP requires rural households to convert their cropland with a slope of or greater than 25 degrees to forests or grasslands. The converted forests could be either ecological (e.g., timber-producing) or economic forests. The sample households in our data were affected by the SLCP only in 2003 and 2004. Section 4.3 discusses the robustness of our results to the introduction of SLCP. [↑](#footnote-ref-9)
10. It is worth noting that binary indicators only capture significant changes, while the poor might gradually improve their livelihood. Ideally one should use continuous income and nutrition for robustness checks, though in our case the empirical model using such variables does not yield convergence and entails considerable multicollinearity. The reason might be attributed to sluggish changes in income and nutrient intake in our data (with the latter effect being more likely). Household per capita net income per annum was 592.1 *yuan* in 2000. It increased to 680.7 *yuan* in 2003 and decreased to 548.8 *yuan* in 2004. Nutrient intake was 1,408.1 kcal per day in 2000 and remained roughly stable over the sample period ending at 1,393.1 kcal in 2004. Poverty gap in both deprivations only dropped in 2001, while became “stable” between 2002 and 2004. See You *et al.* (2017) for more detailed poverty profiles. [↑](#footnote-ref-10)
11. Land allocation is made on a per capita basis within the village. Villages determine whether and when to reallocate land. The frequency of reallocation across regions and villages varies considerably, despite the 15-year rotation period suggested by the central government (Brandt *et al.*, 2002). The right of using forest land was not allowed to be transferred until 2003 when pilot property right reforms on forest land began in Fujian and Jiangxi provinces. The nation-wide reform has begun since 8 June 2008 when the State Council issued “Guidance of Comprehensively Promoting Reforms on Collective Forest land Property Right”. The provinces in our sample were not subject to structural changes in land allocation in the study period. Nevertheless, the sample provinces were subject to the national Sloping Lands Conversion Programme (SLCP) promoting conversion of cultivated land to forests since 2003. Given the high eligibility standards for including land in the SLCP, the proportion of forest areas in the household’s total land holdings only increased marginally by about 1 percentage point. Section 4.3 will further discuss robustness of our results to the SLCP. [↑](#footnote-ref-11)
12. This actually makes the joint distribution of household poverty and energy behaviour in subsequent time periods the same as their exogenously initial joint distribution in 2000 (Wooldridge, 2005). This implicit assumption simplifies substantially the maximisation process, and could be justified if there were no structural changes in households’ behaviour or preferences between 2000 and 2001. [↑](#footnote-ref-12)
13. We also estimated each of Eqs. (1)-(4) independently by standard two-step least square estimation (2SLS) with their own excluded instruments. The first-stage *F*-statistic cannot reject the null hypothesis of joint significance of instruments. The over-identification tests (Hansen *J* statistic) yield *p*-values between 0.149 and 0.622. Our selection of excluded instruments appears to be valid. [↑](#footnote-ref-13)
14. See You *et al.* (2017) for another empirical application of the mixed equation model in multidimensional poverty. [↑](#footnote-ref-14)
15. Our data suggest that an average non-poor household (living above the US$1.25-a-day line) used 85.4kg firewood per annum as opposed to 13.2kg used by its poor counterpart. The non-poor invested 45% more in fixed productive assets per annum compared to poor households, typically, 4 percentage points’ increases in irrigated cropland out of total cropland and 2.8 percentage points’ increases in the proportion of harvests using machines out of all harvests. The non-poor also had better access to tap water, sanitation and housing in terms of using concrete rather than wood or clay compared with the poor, at 1-5% statistical significance levels. [↑](#footnote-ref-15)
16. This long-term impact can be understood through the income effect. As mentioned in Section 2, Chinese rural households’ nutrient intake declines as income rises, and higher income is associated with using commercial fuels as indicated by 0.587 in Column 3 of Table 2. [↑](#footnote-ref-16)
17. Using the size of firewood plantations gives qualitatively the same results. In the short-term, the estimated coefficients of the size (measured by the Chinese unit *mu*) of firewood plantations on income and nutrition poverty are -0.095 (at the 5% significant level) and -0.352 (at the 1% significance level), respectively. In the long-term, the lagged size of firewood plantations has positive impact on nutrition poverty. The estimated coefficient is 0.136 at the 10% significance level. [↑](#footnote-ref-17)
18. One may also notice that more education may also slightly increase the likelihood of nutrition poverty (Columns 2 and 6 of Table 1). As mentioned in Section 2, this can be explained by the dietary changes towards more fat and oil but less calories when Chinese get richer, which is usually related with more education. The form of education also matters. See Shimokawa (2013) for further investigation into the role of education in Chinese nutrient intake. [↑](#footnote-ref-18)
19. This echoes Christiaensen *et al.* (2013) who use the same dataset as is used in this paper and find labour productivity increases in agriculture are the most effective pathway out of poverty. This is also consistent with Imai and You (2014) who use the CHNS (1989-2009) dataset and find both agriculture and out-migration are effective means to enable households to escape poverty, and agricultural income helps prevent households from returning into poverty again. [↑](#footnote-ref-19)
20. Unfortunately, we cannot test this in our data. The indicator of whether the village has access to electricity jumped approximately 16 fold in 2003 compared to average values in previous years and dropped back in 2004. There may well be substantial measurement errors in 2003. [↑](#footnote-ref-20)
21. In rural China, within each administrative village, there are several “natural villages” defined as household clusters living nearby. The Grade IV road is also known as the “township road”, which is the lowest grade in the Chinese road system and provides basic traffic between villages and towns. The Grade IV roads are 3.5m wide and have speed limits at 20-40km per hour, depending on the slope of the roads. [↑](#footnote-ref-21)
22. Relevant average marginal effects based on Eq. (7) are 10.3 percentage increases in the probability of using fossil fuels and 0.4 percent decreases in the proportion of firewood plantations. [↑](#footnote-ref-22)
23. The positive correlation between village income growth and the incidence of nutritional poverty can be explained by the wealth effect on household dietary changes and nutrition intake, which has been discussed in Section 2. See You *et al.* (2016) for more investigations. [↑](#footnote-ref-23)
24. The existing literature also suggests a nonlinear link between resource extraction and income (López-Feldman, 2014). For example, firewood collection in Nepal rises rather than decreases with the growing local economy (Baland *et al.*, 2013). [↑](#footnote-ref-24)