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IFPRI Discussion Paper 01577

December 2016

Energy Use and Rural Poverty

Empirical Evidence from Potato Farmers in Northern China

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Contents

Tables

Figures

ABSTRACT

Rising energy expenditures due to more intensive use of energy in modern agriculture and increasing energy prices may affect rural households' agricultural incomes, particularly the incomes of the rural poor in developing countries. However, the exact link between energy costs and income among the rural poor needs further empirical investigation. This paper aims to gain a deeper understanding of the relationship between energy use and family income, using household-level panel data collected from 500 potato farmers in a poor region of Northern China, where eliminating poverty by 2020 is now the top government priority. The findings indicate that potato plays an important role in the surveyed families' incomes, and the energy costs of potato production have a significant negative relationship with family income. However, the significance of the negative relationship is robust only for farmers with low economic standing, such as those living below the poverty line or just above it. Energy costs also have a significant negative relationship with the family incomes of those cultivating a certain size of potato-sown area, but this relationship becomes insignificant when farmers have too small of a potato-sown area. These findings indicate that in general, reducing energy costs helps the poor increase their income but is not necessarily helpful to those with high economic standing or a relatively small potato-sown area. If rural development policies are to support poverty reduction and energy savings (at least in major potato production regions), interventions aimed at energy cost reduction may be effective only for the poor whose family income depends, to a relatively high degree, on potato production.

Keywords: energy cost, poverty, potato farmers, China

ACKNOWLEDGMENTS

The authors would like to acknowledge financial support from ESRC Grant ES/J017841/1 and Natural Science Foundation of China Project 71361140369. This work was undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM), which is led by the International Food Policy Research Institute (IFPRI) and funded by CGIAR Fund Donors. This paper has not gone through IFPRI's standard peer-review process. The opinions expressed here belong to the authors, and do not necessarily reflect those of PIM, IFPRI, or CGIAR.

1. INTRODUCTION

As modern agricultural production relies increasingly on energy-intensive inputs such as fertilizer, pesticides, machinery, and electricity (Yilmaz, Akcaoz, and Ozkan 2005; Karkacier, Goktolga, and Cicek 2006; Mandalet al. 2002), energy consumption have been rising in agricultural production. Globally, the energy consumption in agricultural production in 2012 (8.7 million terajoules, MTJ) was almost six times the consumption in 1970 (1.5 MTJ) (FAO 2016). In Chin, from 2001 to 2012, energy consumption in agriculture increased by 65 percent (NBS 2016a). Meanwhile, prices of energy-intensive inputs, such as fertilizer and pesticides, among others, have also been increasing with rising prices of energy (Hanson, Robinson, and Schluter 1993; Henderson 2008; Dhuyvetteret al. 2005; Li and Lopez 2015; Nazlioglu 2011). The rising energy consumption and increasing prices of energy-intensive inputs can lead to an increase in energy costs in agricultural production.

The rising energy costs may affect rural households' agricultural incomes. However, the exact link between the two is still inconclusive. Some hold that increasing energy prices may decrease agricultural income, at least in the short run: when the prices of energy-intensive inputs increase, agricultural producers may not be able to adjust their input use in a timely manner and thus their agricultural income may decrease (see, for example, Dhuyvetteret al. 2005; Sandset al. 2011). Others have also noted that higher energy-related production costs generally lower agricultural output (see, for example, Sands et al. 2011). Some others, however, have argued that net agricultural income may remain unchanged or even increase if the rising productivity associated with more intensive energy use can offset the rising cost of the energy used in production (see, for example, Manes and Singh 2005; USDA NASS 2006; Yadavet al. 2013). Thus, the relationship between energy costs and agricultural income remains to be an interesting research topic under debate and calls for more empirical evidence.

From policy point of view, the link between energy costs and agricultural income has particularly important implications for the rural poor[1] in China, where energy costs in agricultural production is rising rapidly while eliminating poverty by 2020 has been listed as the top government priority in China's 13th Five-Year (2016–2020) Plan for Economic and Social Development. Between 2003 and 2012, energy consumption in Chinese agriculture increased by 37 percent (from 49.55 million tons of coal equivalent [TCE] to 67.84 million TCE), although China's agricultural production increased by 37 percent (from 430.67 million tons to 589.57 million tons) as well (NBS 2016a). From 2001 to 2012, the diesel price and the gasoline price both tripled (NDRC 2016). Since rising energy costs may be associated with declining agricultural incomes, as mentioned by some scholars (for example, Dhuyvetteret al. 2005; Sands et al. 2011), understanding the relationship between energy costs and farm income among the rural poor could help to provide some useful insights for China's poverty reduction policies in achieving their ultimate goals. Nonetheless, the empirical evidence in this regard is still limited in China.

This paper aims to fill some of gaps in the current literature by focusing on potato farmers, considering that potato[2], the fourth most important staple crop in China, plays a significant role in food security and farm incomes in China's poor regions. Potato is expected to supply 50 percent of the increase in food demand in China over the next two decades (International Potato Center2011). It is mainly produced in regions that overlap with a number of poverty-stricken regions in China (Qu 2013): among 592 national-level poverty-stricken counties in China, 233 (about 40 percent) are located in the top five provinces for potato production and 344 (58 percent) are located in the top 10 provinces for potato production.[3] The overlap between poverty incidence and potato production may be partly explained by

[1] In China in 2014, 70.2 million people still lived below the national poverty line, defined as an annual per capita income of less than 2,300 yuan at 2010 constant prices (NBS 2016a).

[2] Potato is the fourth most important staple crop after wheat, rice, and corn in China (China, Ministry of Agriculture 2016).

[3] The top five and top 10 provinces for potato production accounted for 60 percent and 83 percent, respectively, of total potato-sown area in China in 2012.

the fact that 84 percent of the 592 national-level poverty-stricken counties are located in upland or mountainous regions, where potato is one of the few crops suited to the relatively harsh biophysical conditions.

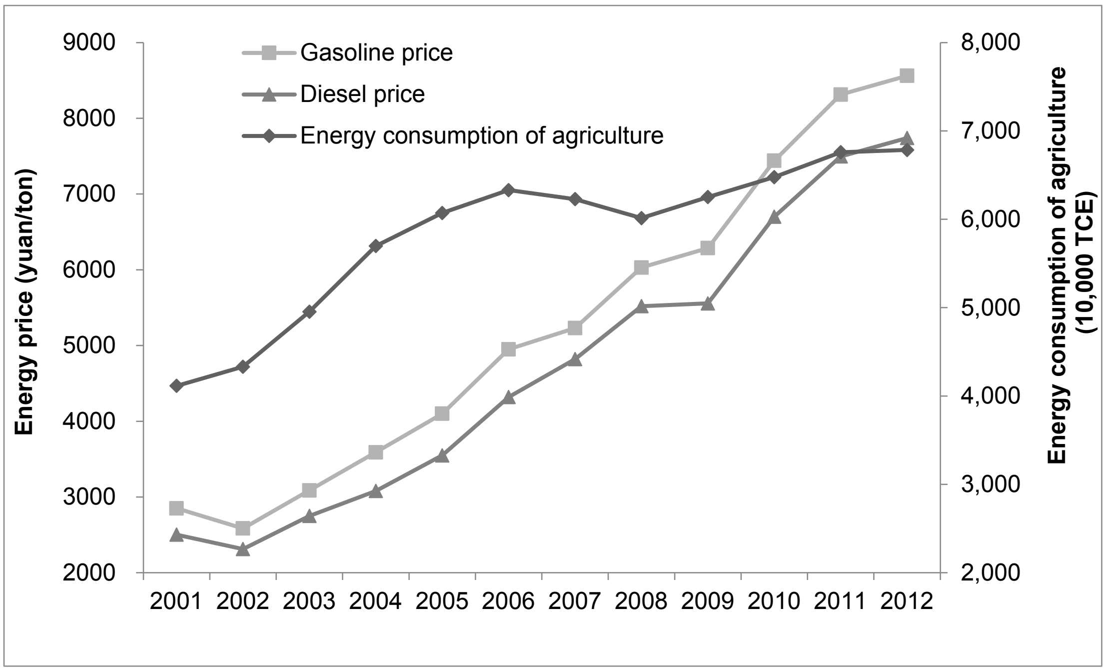
The paper uses household survey data collected from six counties in a poor region in northern China in 2013. Overall, the paper finds that increased energy use is associated with increased family income. However, it only finds a strong association between energy use and family income for those farm households living below the poverty line or just above the poverty line, but not for those living well above the poverty line.

The paper makes a twofold contribution. First, it is one of few micro-level empirical studies in China that links energy use in farm production to household income. Second, it looks separately at the association between energy use and family income for farmers with different economic standings and scales of production. Such analysis may help the government better target the groups that need additional policy support in the future.

2. ENERGY USE AND POTATO PRODUCTION IN CHINA

There appears to be a recently rapid increase in energy costs in China due to growing energy consumption in agricultural production and rising energy prices. Between 2001 and 2012, energy consumption in China's agricultural production was increased from increased from 41.45 million TCE to 67.84 million TCE (Figure 2.1). Of total energy consumption (67.84 million TCE) in 2012, diesel accounted for 39 percent (Zhang et al., 2015). During 2001-2012, the prices of diesel and gasoline in China both tripled, with the diesel price rising from 2,503 yuan/ton to 7,705 yuan/ton and the gasoline price from 2,850 yuan/ton to 8,561yuan/ton (Figure 2.1). The rapid increase in energy use and the relatively high share of diesel in total energy consumption in agriculture imply rapidly increasing energy costs in China's agricultural production.

Figure 2.1 Energy prices and energy consumption in agriculture in China, 2001–2012



Source: NBS (2016a); NDRC (2016).

Notes: TCE = tons of coal equivalent.

Potato can grow in all regions in China, but its main production area is concentrated in the top 10 potato-growing provinces, which are primarily located in the poorest region in China. More than 80 percent of potato in China is grown in these10 top provinces:[4]Sichuan, Gansu, Inner Mongolia, Guizhou, Yunnan, Chongqing, Shaanxi, Heilongjiang, Hubei, and Ningxia. Except for Heilongjiang and Hubei, which account for14 percent of total potato production in the top 10 provinces, the top provinces are all located in western China, the poorest region in the country. The top 10 potato provinces are home to344 of 592 national poverty-stricken counties. The top five provinces, Sichuan, Gansu, Inner Mongolia, Guizhou, and Yunnan—which are home to233 (68 percent) of the 592 national poverty-stricken counties and produce 71 percent of the top 10 provinces' total potato production—are all located in landlocked

[4]In 2012, the potato-sown area in the top 10 provinces accounted for 83 percent of the national total and potato production in these provinces accounted for 80 percent of the national total.

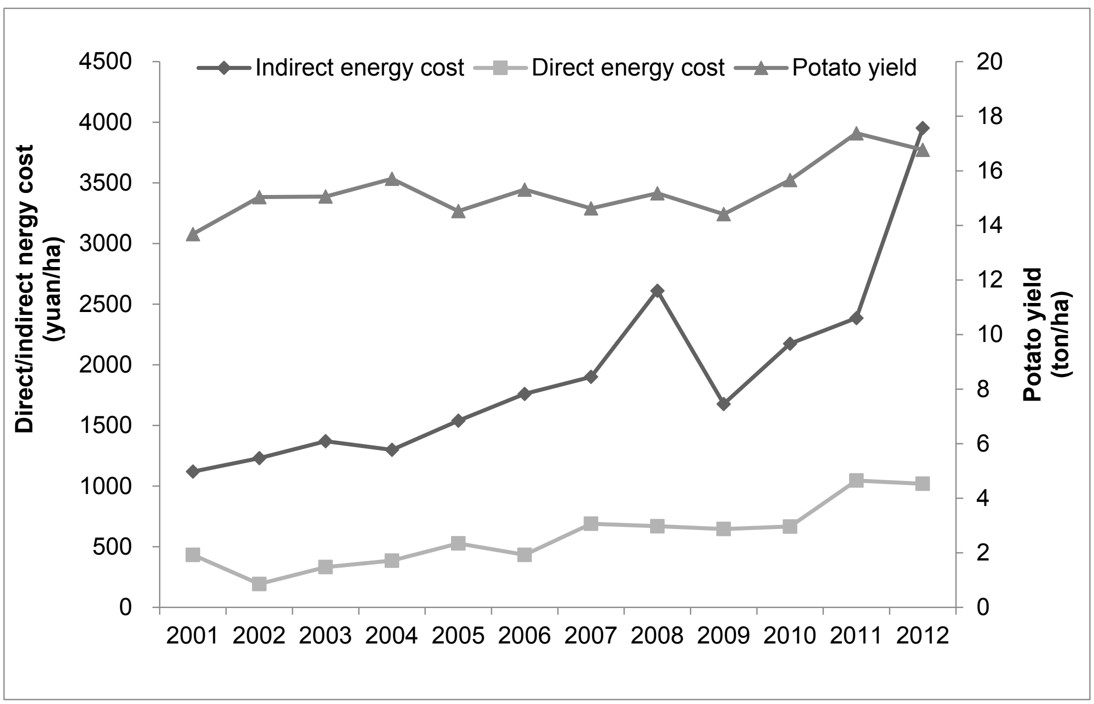
western China and contain highland (for example, the Yunnan-Guizhou Plateau and Mongolian Plateau) and mountains. Inner Mongolia, stretching across a plateau averaging around 1,200 meters in elevation and covered by extensive loess and sand deposits, is the third-largest province for potato production in China. Its potato-sown area and potato production account for 15 percent and 12 percent, respectively, of the total sown area and total production of the top 10 provinces. Because potato is drought-resistant and able to grow in cooler high-altitude and mountainous regions, it has played a unique social-welfare role by creating income for impoverished rural households in these regions.

Potato has been expanding and will become more important for food security in China, the world's largest country for potato consumption. From 2001 to 2012, potato-sown area and potato production both increased: the area cultivated with potatoes increased from 4.72 million hectares to 5.53 million hectares, and potato production increased from 64.56 million tons to 92.76 million tons. With increasing water constraints and limited agricultural land to feed a growing population, the Ministry of Agriculture has affirmed that potato will play a pivotal role (along with rice, wheat,

and corn) in China's food production, due to its lower water demand, its resistance to drought and its adaptability to infertile soil that is often associated with marginal land.

Potato yield has increased slightly in the past decade in China, while energy costs have grown at a more rapid rate (Figure 2.2). During 2001–2012, potato yield increased by 25 percent (from 13.68 tons per hectare to 17.09 tons per hectare), but total energy costs (including direct costs and indirect costs) more than tripled (increasing from 1,554 yuan per hectare to 4,972 yuan per hectare).

Figure 2.2 Energy cost in potato production and potato yield in China, 2001–2013



Source: National Agricultural Product Cost and Income Yearbooks 2002–2014 (NBS 2016b).

Despite the slight increase in potato yield in recent years, China's current potato yield is only about 87 percent of the global average and 90 percent of the average in Asia (FAO 2016). As potato has been identified by Chinese government as the fourth staple food, it is expected that potato yield will be increased through a number of measures, such as modern technology that commonly relies on energy-intensive inputs. As such, energy costs will be possibly increased in China's potato production.

In the Figure 2.2, a separate look at changes in direct energy costs and indirect energy costs further reveals that indirect energy costs (mainly fertilizer and pesticides) grew faster and fluctuated more than direct energy costs. Indirect energy costs more than tripled (from 1,120 yuan per hectare to 3,952 yuan per hectare), while direct energy costs more than doubled (from 434 yuan per hectare to 1,020 yuan per hectare). A closer look at the structure of energy costs finds that the share of indirect costs in total energy costs was more than 70 percent, with the lowest level (70 percent) reached in 2012 and the highest in 2002 (86 percent). These figures demonstrate that the gradual growth in potato yield in China has been associated with rapid growth in energy costs, in particular indirect energy costs. Put differently, high energy inputs did not bring correspondingly high outputs. Therefore, reducing the energy cost for each unit of potato produced has strong implications for poverty reduction.

3. METHODOLOGY

Data Source

The study was carried out in Inner Mongolia and Hebei Province, China. Inner Mongolia and Hebei Province lie in northern China's potato production region (Jin et al. 2013), which accounted for 47 percent of total potato-sown area in China during 2012 (NBS 2016a).Inner Mongolia is among the top three provinces in China in terms of potato-sown area and total potato production. In 2011, its total potato-sown area reached 713,000 hectares and produced nearly 10 percent of China's total potato harvest. It is home to 31 of 592 counties listed as poverty-stricken by the national government.

Wulanchabu Prefecture has an average elevation of 1,000–1,500 meters above sea level. It is the top prefecture in China in terms of potato production and the most important potato production area in Inner Mongolia. Its potato-sown area and potato production both accounted for 40 percent of the provincial total in 2011.Within Wulanchabu, potatoes are mainly grown in six counties: Siwangzi County, Chayouzhong Qi, Chayouhou Qi, Shangdu County, Xinghe County, and Fengzhen City. The total potato-sown area in these counties accounted for more than70 percent of the total sown area in Wulanchabu.

Hohhot is the third most important region for potato production in Inner Mongolia.in 2011, its potato-sown area and potato production accounted for 13 percent (93,000 hectares) and 11percent (1,076,000 tons), respectively, of the provincial total. Wuchuan County is the top county in Hohhot for potato production. Half the farmland in Wuchuan is cultivated with potato. In 2011, the potato-sown area and production in Wuchuan County accounted for 30 percent and 25 percent, respectively, of the total in Hohhot.

Zhangjiakou Prefecture has the most potato production in Hebei Province, where potato-sown area accounted for 3 percent of the national total in 2012 (NBS 2016a).It is home to10 of 592 poverty-stricken counties. Potato is the most important food crop in Zhangjiakou. In 2011, the potato-sown area and potato production in Zhangjiakou accounted for 68 percent and 65 percent, respectively, of the provincial total. Zhangjiakou is in the transitional area on the border between the Northern China Plain and the Mongolian Plateau. One-third of its geographic area lies on the edge of the Mongolian Plateau (with an average elevation of 1,400 meters) and two-thirds of its area is characterized by mountainous and hilly terrain. The high-elevation area covers four counties, Guyuan, Kangbao, Shangyi, and Zhangbei, which have very similar biophysical characteristics to their neighbor, Wulanchabu Prefecture in Inner Mongolia. The potato-sown area and potato production in these four counties accounted for 68 percent and 65 percent, respectively, of the prefectural total in 2013.

In our study area, most people are a national minority and have a language barrier for them to migrate to other regions to be engaged in non-agricultural activities. Indeed, our survey shows that income from non-agricultural wages was only 14 percent and 12 percent of the surveyed families' income in 2007 and 2012, respectively (see Appendix Table A.1). Agriculture is the main source of income, accounting for 76 percent and 77 percent of family income in 2007 and 2012, respectively. Potato-sown land represented about 40 percent of their total farmland and potato income accounted for about one-third of their total income. Although farmers can also plant other crops, such as wheat, corn, and hulless oats, they preferred potato, as it is the most drought resistant and tolerant of barren soil. This is why potato is the main crop in poor areas in China that are located in upland or mountainous regions with harsh biophysical conditions.

Data Collection

Household surveys were conducted in five counties by the International Center for Agricultural and Rural Development at the Chinese Academy of Agricultural Science between November 2013 and January

2014. We collected the information for2012 and 2007 during the survey, and data for 2007 are recall information.

A mixture of sampling methods was used to choose the survey respondents. After Wulanchanbu, Hohhot, and Zhangjiakou were identified as study areas based on their importance in potato production, the survey team chose five counties, three from Inner Mongolia and two from Zhangjiakou. Specifically, the survey team chose Wuchuan County from Hohhot, Chayouzhong Qi and Siziwang Qi from Wulanchabu, and Kangbao County and Zhuolu County from Zhangjiakou. Except for Zhuolu, the counties are national-level poverty-stricken counties.

In each county, three townships were chosen randomly; in each township, two administrative villages were randomly selected; and in each administrative village, two natural villages were randomly chosen. In total, 61 natural villages from 30 administrative villages in five counties were chosen.

Compared to many other parts of China, Inner Mongolia has a relatively low population density. Given this particular context, the survey team chose slightly different numbers of families in villages with different population densities. For natural villages with a small number of households, the survey team randomly chose 6 families; for natural villages with a relatively large number of households, the team randomly chose 20 families. In Zhangjiakou city, the population density in villages is more or less the same as in other parts of China, so the survey team randomly selected 20 families to be surveyed from village rosters. In total, 500 families were surveyed.

In-person surveys were conducted with family heads by means of well-structured questionnaires. The family heads were asked to provide information on their family demographics, economic activities, income sources, potato production and inputs used (including energy and other inputs), family assets, and so on. They were asked to provide the above information for 2012 and 2007.

Regarding the energy they used in potato production, respondents were asked to provide the following detailed information: (1) energy used for land preparation and planting seeds,(2) energy used during the potato growing season (for example, fuel used to pump irrigation water),(3) fertilizer and pesticides applied on their potato plots,(4) energy used to harvest their potatoes, and(5) energy used to transport their potatoes to market. If some potato production or transportation activities were rented out, information on energy use was collected for rental services.

Conceptual Framework and Data Analyses

Agricultural income accounted for nearly 80 percent of the surveyed families' income (76 percent and 77 percent of family income in 2007 and 2012, respectively). In terms of production, the surveyed families cultivated nearly 40 percent of their farmland with potato, and potato was the largest crop of the surveyed families (see Appendix Table A.2). Income from potato production was about one-third of family income. In our sample, only 11 families (2 percent of 500 families) did not plant potato in 2012 and 16 families (3 percent of 500 families) did not plant potato in 2007. Though the surveyed families are not potato specialists, potato production can be considered their main source of income.

To analyze the link between poverty and energy use among the surveyed families, we conducted econometric analyses. Since the main focus of the analyses is to understand the association between energy use and poverty, it is important to first have a good understanding of the link between energy use and income for the surveyed families. For farmers in major potato-production regions, potato production is assumed to play a significant role in household income and livelihood. Thus, one channel to be used to link energy use to family income is through its roles in potato production. In this section, we first present the simple conceptual framework used to guide econometric model specifications. We then discuss the empirical model specifications and estimation strategies.

To guide the empirical data analyses, we use a simple framework to elaborate how energy use may be linked to the household income of potato farmers. Under this framework, farmers' energy use is viewed as an equilibrium outcome of farmers' profit maximization. We may write potato farmers' profit maximization of potato production as follows:

$$\pi = P * Q(E, L, K, Land) - w_e * E - w_l * L - w_k * K - w_{land} * Land \quad (1)$$

In equation (1), farmers' profit is determined by two components: revenues from potato production, $P*Q(E, L, K, Land)$, and the cost of production, $w_e*E+w_l*L+w_k*K+w_{land}*Land$. Four inputs are used to produce Q, namely, energy (E), labor (L), capital (K), and land. The energy (E) used includes(1)direct energy, such as fuel (diesel, gasoline, and electricity) used to operate machines, pump water, and transport potatoes to the market, and(2) indirect energy used in farm production, mainly fertilizer and pesticide. L is the labor, including family labor and hired labor, used in potato production. K is capital inputs, such as machines used to plow the land, plant seeds, and harvest potatoes, and some other capital. *Land* is the land used for growing potatoes.

The energy used in potato production has a total cost of w_e*E, where w_e is the unit cost of energy used in production and $E$is the total amount of energy used in potato production. Holding other things constant, the marginal revenue from energy use is $MR_e=P* \partial Q\ (\cdot)/\partial E$, where P is the potato price. The marginal cost of energy used in production is $MC_e=w_e$. Therefore, the net profit from each unit of energy used in potato production is $P* \partial Q(\cdot)/\partial E- w_e$. Farmers choose an optimal level of production $Q^*$to maximize their profit when $MR_e= MC_e$, holding other things constant. At the optimal production level Q^*, we can compute the average energy cost for one unit of output as $AEC=w_e*E/Q^*=w_e*(E/Q)^*$. AEC is determined by (1) energy price, w_e, and (2) energy intensity, E/Q^*, defined as the energy used to produce one unit of potato. When energy efficiency increases, energy intensity decreases. Therefore, two alternative means may be used to reduce AEC: reducing the energy price or increasing energy efficiency. For a given potato price, P, we can calculate the net gain from one unit of potato produced as $Gain=P-AEC$. Thus, for a given potato price (P), the lower the AEC, the lower the gain from producing one unit of potato.

Farmers' family income may be from potato production, other agricultural income, husbandry, off-farm income, and so on. The investment in potato production, including energy, labor, capital, and land, will also affect investment in other activities that can generate income, such as off-farm income and husbandry. Thus, we write a reduced form as follows to guide our model used for econometric analyses:

$$income = f(AEC, L, K, Land, X), \quad (2)$$

where *income* is the family's net income from potato production, off-farm activities, husbandry, and so on. AEC is the average energy cost for producing one unit of potato; L, *Land,* and K are the labor, land, and capital, respectively, used for potato production. X is other control variables that may affect family income. Holding other things constant, we may expect the following relationship between energy use and family income: a higher AEC is associated with a lower family income.

A panel dataset was formed based on survey information collected for the years 2007 and 2012.We first conducted descriptive statistical analyses to describe the key socioeconomic characteristics of the surveyed families and their poverty status. Following the conceptual model discussed earlier, we specify the following empirical model for econometric analyses:

$$y_{it} = \beta_0 + \beta_1 AEC_{it} + \beta_2 L_{it} + \beta_3 K_{it} + \beta_4 Land_{it} + \beta_5 X_{it} + c_i + \varepsilon_{it}, \quad (3)$$

where y_{it} is the total income of family i in year t (t=2007 or 2012); AEC_{it} is the average energy cost of family i in year t to produce one unit of potato. L_{it}, $Land_{it}$, and K_{it} are the labor, land, and capital, respectively, invested in potato production. In our model, $Land_{it}$ is measured by potato-sown area of family i in year t. X_{it} is a set of other controlling variables that may affect family income, such as size of farmland area and dependent ratio. In rural areas, farmland often serves a good proxy to measure family wealth and indispensable inputs for families to generate farm income. The dependent ratio is a good proxy for the family's potential income-earning labor supply: the higher the dependent ratio, the less family labor supply. c_i is the household-specific and time-invariant variables. ε_{it} is the error terms.

To estimate equation (3), we use household fixed effects models to control for the possible effect of time-invariant and household-specific characteristics, which may be correlated with the independent variables included in the models. Such characteristics may include (1) differences in household initial endowments; (2) differences in risk preferences, which may affect energy use, since the adoption of energy-intensive technology such as pesticides and machines involves certain risks; and (3) household preferences for children, which may be correlated with a family's dependent ratio.

We first ran a regression for all farmers in our sample. We then ran two separate regressions for families living below the poverty line and those living above the poverty line in surveyed years, in order to see whether the link between energy use and family income differed when poverty status differed between the two years.

As discussed above, there appeared to be three different groups of farmers who had different economic standings and different changes in their poverty status during 2007–2012: some were never below the poverty line, some rose out of poverty between 2007 and 2012, and some stayed poor. We then split our samples into three groups (as categorized in Table 4.2) and ran separate regressions for them to examine potential differences across these three groups in terms of the link between energy use and family income.

We ran ordinary least squares models to estimate the above models. We used clustered standard errors at the natural village level to account for unobserved heterogeneity within the villages.

4. DESCRIPTION OF DATA

From 2007 to 2012, the family income of the surveyed families as a group was increased and their family income appeared to have high dependence on agricultural production, particularly the potato production. On average, per capita annual income of surveyed families more than doubled during 2007–2012, from 4,399.51 yuan to 10,424.24yuan (Table 4.1, Row 1). For an average family, the share of income from agricultural production in its total family income was about 81 percent in 2007 and maintained to be about three-quarters (74 percent) of total family income was from agricultural production in 2012 (Table 4.1, Row 2); the share of income from potato production in its total family income was 37 percent in 2007 and this share remained to be one-fourth (24 percent) in 2012 (Table 4.1, Row 3). The above information shows that although family income came to rely less on agricultural production and potato production, agricultural production, in particular potato production, still played an important role in the family income of the surveyed families during 2007-2012.

Table 4.1 Household characteristics of surveyed families

Variables	(a) 2007	(b) 2012	t-test (a)-(b)
Per capita annual income (yuan)	4,399.51	10,424.24	-8.44***
	(6,852.21)	(14,406.07)	
Share of agricultural income in family income	0.81	0.74	1.85**
	(0.68)	(0.50)	
Share of potato income in family income	0.37	0.24	2.19**
	(1.26)	(0.49)	
Energy cost per unit of potato (yuan/ton)	150.78	253.50	-8.29***
	(150.55)	(232.51)	
Potato yield (ton/ha)	12.30	15.01	-6.28***
	(0.29)	(0.32)	
Potato-sown area (ha)	1.03	1.23	-0.70
	(1.97)	(6.18)	
Farmland area (ha)	2.72	3.29	-1.85*
	(2.38)	(6.46)	
Potato labor input (person*days/ha)	101.37	101.35	0.01
	(74.53)	(88.45)	
Capital input (yuan/ha)	1,084.02	2,726.06	-6.93***
	(3,472.90)	(3,996.78)	
Family dependent ratio	0.32	0.33	-1.03
	(0.25)	(0.31)	
No. of observations	500	500	

Source: Authors' calculations.

In terms of energy costs, the average energy cost for surveyed families to produce one unit of potato was increased more rapidly than potato yield from 2007 to 2012. For each ton of potato produced, the average energy cost was increased from 150.78 yuan in 2007 to 253.50 yuan in 2012, increased by 68 percent (Table 4.1, Row 4). During the same period, the potato yield was only increased by 25 percent, from 12 tons per hectare in 2007 to 15 tons per hectare in 2012, below the national average in both years[5]. As mentioned earlier, the increased average energy cost may arise from increasing energy prices and/or an increased energy intensity, that is, more energy is used to produce one unit of potato. Hence, farm profits may not have been necessarily increased with increased average energy cost spent on each unit of potato produced possibly due to increased energy prices or increased energy intensity.

The surveyed families cultivated significantly more farmland in 2012 than in 2007. On average, the size of farmland they cultivated increased from 2.72 hectares to 3.29 hectares, a 21 percent increase. Larger farmland areas, which include own farmland and farmland rented in, suggest that land consolidation may be emerging in the surveyed regions. Along with more farmland cultivated by the surveyed farmers, their potato sown area was also increased from 1.03 hectares to 1.23 hectares. The potato production of the surveyed families also became more capital-intensive. Expenditures on capital inputs (for example, machines and farming tools) increased significantly, from 1,084 yuan per hectare to 2,726 yuan per hectare.

Slightly less than two-thirds of the members of the surveyed families were available to be engaged in agricultural production and other economic activities. The last row of Table 4.1 shows that the family dependent ratio, that is, the share of family members whose age was below 16 or above 60, was about 0.32 and 0.33, respectively, in 2007 and 2012.

From 2007 to 2012, the surveyed families witnessed a clear reduction in poverty. The share of families living below the poverty line decreased from 45 percent (223 families of the total 500 surveyed families) in 2007 to 11 percent (55 families) in 2012. However, the change in poverty status from 2007 to 2012 varied considerably among different groups. Between 2007 and 2012, about 270 families (54 percent of the total 500 families) always lived above the poverty line, 48 families always lived below the poverty line, 175 families rose out of poverty, and 7families fell into poverty. These seven families lived just above the poverty line in 2007. Table 4.2 presents the main characteristics of these groups.

Among the three largest groups (we disregard the seven families that fell into poverty), we found that the 270 families living above the poverty line in both 2007 and 2012 had the highest income and appeared to spend the least on energy use per ton of potato produced. This implies that these farmers may have used energy more efficiently on their farmland. In contrast, the 48 families always living below the poverty line had the lowest income and spent most per ton of potatoes produced. They had the smallest farmland area and grew the smallest area of potatoes. They also had the lowest average labor input and capital input on their potato plots, along with the highest dependent ratio (Column b, Table 4.2). In order to understand whether or not the three groups were different in terms of their energy use and household characteristics, we performed one-way analyses of variance (ANOVA). We found significant differences across the groups in terms of annual per capita income, energy costs, labor inputs, capital inputs, and dependent ratios, at the 1 percent significance level.[6] We will more closely examine the link between energy use and family income for the different groups in the econometric analyses discussed below.

[5]The national average potato yield was 14.62 tons per hectare in 2007 and 16.77 tons per hectare in 2012 (NBS 2016a).

[6]We omitted the test results from Table 4.2 to save space. The results are available from the authors upon request.

Table 4.2 Socioeconomic characteristics of different groups of farmers

Variables	(a) Always above poverty line	(b) Always below poverty line	(c) Lifted out of poverty
Annual per capita income (yuan)	10,501.32	1,148.61	4,526.21
	(13,788.25)	(782.94)	(7,805.77)
Energy cost per unit of potato (yuan/ton)	178.16	294.53	213.05
	(173.09)	(295.46)	(195.45)
Farmland area(ha)	2.86	2.40	3.40
	(1.85)	(1.75)	(7.85)
Potato-sown area (ha)	1.02	0.52	1.50
	(1.16)	(0.79)	(7.60)
Labor input for potato (person*day/ha)	95.91	112.55	106.95
	(75.93)	(64.88)	(93.94)
Capital input (yuan/ha)	1,927.18	590.41	2,282.29
	(3,218.85)	(1,012.89)	(4,999.84)
Dependent ratio	0.30	0.43	0.33
	(0.28)	(0.27)	(0.33)
No. of families	270	48	175

Source: Authors' calculations.

Notes: Numbers in the three columns are mean values of the variables. Standard errors are in parentheses. To save space, we do not report information for the seven families that lived above the poverty line in 2007 but below the line in 2012.

5. RESULTS AND DISCUSSION

The results of the econometric analyses show a negative association between average energy cost and family income. However, the significance of the association varies between families living below the poverty line and those living above the line (Table 5.1).

Table 5.1 The association between energy cost and family income

Variables	(a) All farmers	(b) Below poverty line	(c) Above poverty line
Average energy cost	-3.73***	-0.93***	-2.91
	(1.08)	(0.27)	(1.97)
ln(potato labor input)	373.39	184.25***	75.66
	(259.79)	(68.77)	(486.71)
Potato-sown area	410.42	-257.42	1,888.65*
	(441.87)	(319.89)	(1,012.75)
ln(potato capital input)	4.81	-24.44	-244.47
	(117.18)	(40.20)	(181.35)
Farmland area	692.66	-90.85	628.01
	(431.10)	(99.66)	(716.70)
Dependent ratio	-5,245.96***	-404.73	-7,341.02**
	(1,497.76)	(247.63)	(2,975.08)
Constant	1,906.51	611.64*	4,790.20
	(1,829.96)	(347.35)	(3,668.52)
Household fixed effect	YES	YES	YES
Year fixed effect	YES	YES	YES
R-squared	0.35	0.49	0.22
No. of observations	1,000	278	722

Source: Authors.
Notes: Robust standard errors clustered at the village level are in parentheses; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

Looking at the “all farmers” column (Column a, Table 5.1), energy cost is negatively and significantly associated with annual income per capita, at the 1 percent significance level. This negative association could be because, holding other things constant, the lower energy cost associated with one ton of potato produced implies a higher gain from producing one unit of potato and thus a higher net family income. For the full group of farmers, labor input, land area allocated, and capital input used for potato production all have a positive but insignificant association with family income. Having a larger farmland area is associated with a higher income, but this association is not significant. A higher dependent ratio is negatively and significantly associated with a lower family income. One explanation could be that when a family has a higher dependent ratio, it has less family labor to be engaged in agricultural production and off-farm activities. Consequently, the family’s income may be lower. For families in our sample, the cost of energy used in potato production seems to be much more significantly associated with the cost of other inputs used in potato production.

Table 5.1 also shows that the negative association between energy cost and family income is significant only for families living below the poverty line in the surveyed years (Table 5.1, Column 3), but not for those living above the poverty line (Column c, Table 5.1).This could be because those living above the poverty line may have used energy relatively more efficiently. An alternative explanation may be that changes in energy prices may have had a much stronger association with family income for the poor living below the poverty line. We will present some further results by have separate analyses for three groups that have experienced different changes in their poverty status shortly.

One additional interesting message from Table 5.1 is that the potato-sown area is only strongly and positively associated with family income for families living above the poverty line (Column c, Table 5.1). This indicates that for wealthier families in our sample, larger-scale potato production may be associated with higher family incomes.

Looking at the farmers grouped by the change in their poverty status during 2007–2012, we also found different levels of association between energy cost and family income. The results are presented in Table 5.2.

Table 5.2 Energy cost and family income for different groups

Variable	(a) Always above poverty line	(b) Always below poverty line	(c) Lifted out of poverty
Average energy cost	-2.91	-0.93***	-3.69***
	(1.97)	(0.28)	(1.38)
ln(potato labor input)	75.66	184.25**	393.96
	(487.66)	(71.18)	(256.58)
Potato-sown area	1,888.65*	-257.42	-78.51
	(1,014.72)	(331.11)	(410.97)
ln(potato capital input)	-244.47	-24.44	219.23
	(181.70)	(41.60)	(138.24)
Farmland area	628.01	-90.85	1,145.31***
	(718.09)	(103.16)	(406.47)
Dependent ratio	-7,341.02**	-404.73	-1,503.43
	(2,980.86)	(256.32)	(1,639.90)
Constant	6,649.42*	579.94	-4,571.22**
	(3,661.93)	(377.84)	(2,117.28)
Household fixed effect	YES	YES	YES
Year fixed effect	YES	YES	YES
R-squared	0.22	0.49	0.80
No. of observations	540	96	350

Source: Authors.

Notes: Robust standard errors clustered at the village level are in parentheses; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively. We also ran regressions that included the seven families that fell into poverty in the sample of families that were lifted out of poverty. The results are not quantitatively changed.

Among the three different groups, energy cost had a significant and negative association with the group lifted out of poverty between 2007 and 2012 (Column c, Table 5.2) and the group always living below the poverty line (Column b, Table 5.2). However, the negative association was insignificant for the group living above the poverty line in both years. One possible explanation for the significant and negative association between energy cost and family income for those two groups could be that the poor have budget constraints preventing the purchase of equipment that is complementary with energy use, or they may have less knowledge of how to use energy efficiently. With increasing energy prices and increasing use of energy on their potato plots, they spent more on and gained much less from the energy used to produce each unit of potato. Consequently, their family income may be affected more.

It is noteworthy that in comparing the group living below the poverty line in both years and the group lifted out of poverty, the magnitude of the coefficient was larger (-3.69) for the latter than the former (-0.93).This result shows that when energy costs are reduced, family income increases more significantly for the group lifted out of poverty than for the group continuing to live below the poverty line. The result implies that reducing energy expenditures through increasing energy efficiency may be a viable policy intervention to consider for poverty alleviation in regions where potato cultivation is expected to expand and play a key role in increasing family incomes.

Similar to the result presented in Table 5.1, a larger potato-sown area is only positively and significantly associated with a higher family income for those families that lived above the poverty line in both years (Table 5.2, Column 2). This further shows that having a larger potato-sown area may have contributed to increased family incomes only for families staying out of poverty in both years.

Based on the econometric analyses, we also computed the income elasticity of energy costs. The results are presented in Table 5.3.

Table 5.3 Income elasticities of energy cost for different types of farmers

Variable	Elasticity
All farmers	-0.10
Panel A: Farmer type by economic standing	
Living below poverty line	-0.21
Living above poverty line	-0.06
Panel B: Farmer type by change in poverty condition	
Always above poverty line	-0.05
Always below poverty line	-0.24
Lifted out of poverty	-0.17

Source: Authors' calculations.

As indicated in Table 5.3, for all surveyed farmers, a one percent increase in average energy cost is associated with a 0.1 percent decrease in per capita annual income. This shows that a lower average energy cost due to improved energy efficiency or decreased energy intensity was associated with increased per capita income in the study area. However, the responsiveness of family income to changes in average cost is quite different among the different types of potato farmers.

For families living below the poverty line, a one percent increase in the average energy cost is associated with a 0.2 percent decrease in their per capita income; for those families living above the poverty line, a one percent increase in the average energy cost is associated with a 0.06 percent decrease in their per capita income. This suggests that the family incomes of those living below the poverty line are much more responsive to energy costs than are the family incomes of those living above the poverty line. Thus, improving energy efficiency or reducing energy intensity could help increase those poverty-stricken families' incomes more effectively.

In terms of the changes in families' poverty conditions between 2007 and 2012, for those families that always lived above the poverty line from 2007 to 2012, a one percent increase in average energy cost is associated with a 0.06 percent decrease in their per capita annual income. For families always living below the poverty line, a one percent increase in average energy cost is associated with a 0.24 percent decrease in their per capita annual income. For those families lifted out of poverty between 2007 and 2012, a one percent increase in the average energy cost is associated with a 0.17 percent decrease in their per capita annual income. These results further show that improving energy efficiency or reducing energy intensity could help increase those poor families' incomes more effectively.

6. ROBUSTNESS CHECKS AND DISCUSSION

We conduct three major robustness checks to better understand how energy use might be associated with family income for families with different economic standings, farm income structures, and farm sizes. This section discusses these robustness checks and their results.

Robustness Check on Association between Energy Use and Family Income with Differences in Income Strata

We conduct robustness check1to analyze whether the association between energy use and family income varies across families in different income strata. We split our sample into four income quartiles. The cutoff lines for the first, second, and third income quartiles in our sample are 2,056 yuan, 4,477 yuan, and 8,645 yuan, respectively. Accordingly, the families in the first quartile are also those living below the national poverty line (2,300 yuan), and the second quartile includes families living just below and above the poverty line. Table 6.1 shows the results of robustness check 1.

Table 6.1 Results of robustness check 1

Variable	(a)1st income quartile	(b)2nd income quartile	(c)3rd income quartile	(d) 4th income quartile
Average energy cost	-0.82*	-0.93*	0.06	22.17
	(0.45)	(0.54)	(0.68)	(14.89)
ln(potato labor input)	184.85***	-33.74	-323.63***	4,672.89*
	(60.87)	(157.16)	(116.49)	(2,629.66)
Potato-sown area	-401.34	32.99	1,207.85***	3,498.34*
	(399.30)	(338.33)	(303.70)	(2,091.01)
ln(other capital input)	-72.74*	59.40*	35.39	-969.81
	(41.06)	(34.85)	(110.58)	(697.48)
Farmland area	596.86	-326.50	-107.50	-850.73
	(410.58)	(475.22)	(308.25)	(1,616.46)
Dependent ratio	62.59	-544.67	287.89	-9,725.97*
	(245.70)	(680.05)	(905.84)	(5,648.77)
Constant	-1,274.01	4,041.13***	6,859.99***	-1.8e+04
	(1,210.35)	(1,249.63)	(886.33)	(15,176.55)
Household fixed effect	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
R-squared	0.54	0.24	0.37	0.46
No. of observations	248	251	249	252

Source: Authors' calculations.

Notes: Robust standard errors clustered at the village level are in parentheses; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

The results presented in Table 6.1 show that energy cost has a significant and negative association with income status for the groups in the lower income strata, but not for those in higher income strata. Specifically, the negative association is significant for those in the first and second quartiles. For families in the lowest-income group, the relative change in annual income per capita that would result from a change in average energy cost is greater than the change seen by families in the second income quartile, meaning that the lower-income families will benefit more from energy efficiency improvements. For families in the higher-income groups, an increase in income is associated with increasing energy costs. This might be because families in the higher-income groups invest more on energy-intensive inputs for potato production such as fertilizer and pesticides, they may have earned a higher income from increased energy-intensive inputs (Appendix Table A.3). The above results again indicate that increasing energy efficiency has a much more significant effect on poverty-stricken families, further supporting the evidence that average energy cost has much more significant association with family income for families with lower economic standing than for wealthier families.

Potato-sown area only has a significantly positive association with family income for those families in the higher income strata (Columns c and d, Table 6.1). This result, together with that in Column a of the Table 5.2, show that potato sown area may be more closely associated with family income of those wealthier families than those poorer families.

Robustness Check on Association between Energy Use and Family Income with Different Agricultural Income Structures

We conduct robustness check 2 to understand whether the association between energy use and family income is different for families whose agricultural income has different levels of dependence on potato production. We divide our sample into two groups, with one group having more than 50 percent of its agricultural income from potato production and the other having 50 percent or less (Table 6.2).

As shown in Table 6.2, the association between energy use and family income differs significantly between families whose potato income accounted for more than 50 percent of agricultural income and those whose share of potato income in their agricultural income was 50 percent or less. For the former group, the average cost of energy input for potato production is significantly and negatively associated with family income; for the latter group, the average cost of energy input for potato production is negatively but insignificantly associated with family income. With a one percent increase in the average energy cost, annual income per capita will decrease 22 percent for the former group and three percent or the latter group (see Appendix Table A.3).This result shows that reducing energy costs would be much more important for families with a high dependence on potato production for their agricultural income. This has particularly important implications for regions where local farmers have limited outside options to earn income and potato is one of the most important crops for agricultural income. These regions could include, for example, regions in western China where highlands or mountains dominate the landscape and local people (especially ethnic minorities) have language barriers and low education that may hinder them from earning off-farm income.

Table 6.2 Results of robustness check 2

Variable	(a) Share of potato income in family's agricultural income > 50%	(b) Share of potato income in family's agricultural income ≤ 50%
Average energy cost	-7.28**	-1.32
	(3.60)	(1.27)
ln(potato labor input)	225.00	1,082.18**
	(500.58)	(429.12)
Potato-sown area	652.81*	2647.08*
	(376.47)	(1,423.99)
ln(potato capital input)	-152.22	-216.90
	(208.49)	(198.75)
Farmland area	423.94	177.85
	(359.53)	(863.50)
Dependent ratio	-6,403.39***	-3874.85*
	(1,642.19)	(2,028.58)
Constant	2,796.06	-753.58
	(3,576.40)	(2,184.54)
Household fixed effect	YES	YES
Year fixed effect	YES	YES
R-squared	0.77	0.32
No. of observations	414	586

Source: Authors.

Notes: Robust standard errors clustered at the village level are in parentheses; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

Robustness Check on Association between Energy Use and Family Income with Different Sizes of Farmland Area

We conduct robustness check 3 to understand whether energy use is associated with family income differently for families cultivating farmland areas of different sizes. This robustness check is conducted in light of the government position regarding the role of land consolidation in increasing agricultural productivity and family incomes. In the particular context of our surveyed areas, land consolidation has been strongly encouraged by local governments to increase potato yields. In our surveyed areas, land consolidation is often accompanied by the development of large-scale irrigation facilities, which may have a strong negative effect on long-term sustainability in water-constrained regions. In this robustness check, we divide our sample into four groups according to the size of their potato-sown area. As we did with income strata, we divide our sample into four quartiles, with the cutoff lines for the first, second, and third quartiles of farmers' potato-sown area at 0.20 hectare, 0.67 hectare, and 1.25 hectares, respectively. The results of robustness check 3 are shown in Table 6.3.

Table 6.3 Robustness check 3

Variable	(a)1st quartile	(b)2nd quartile	(c)3rd quartile	(d)4th quartile
Average energy cost	-0.79	-1.18	-4.66**	-6.48
	(1.15)	(3.56)	(2.26)	(9.02)
ln(potato labor input)	308.20	2,487.40	-2,566.91**	1,296.11
	(548.83)	(1,535.98)	(1,281.02)	(1,599.12)
Potato-sown area	-4,281.63	-3,262.58	644.19	491.85
	(24,963.21)	(5,168.41)	(5,553.13)	(804.77)
ln(potato capital input)	122.60	-366.23	-477.94*	-283.60
	(191.23)	(253.25)	(282.73)	(460.72)
Farmland area	-1,092.55	500.08	2,599.86***	475.17
	(1,097.24)	(830.99)	(817.47)	(828.14)
Dependent ratio	-2,442.31*	-1,542.01	-5,803.69*	-17,563.98
	(1,416.60)	(2,526.32)	(3,127.37)	(11,106.15)
Constant	5,071.38**	-8,516.09	19,781.73**	-286.53
	(2,292.26)	(8,919.79)	(10,514.43)	(14,196.20)
Household fixed effect	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
R-squared	0.20	0.30	0.66	0.43
No. of observations	227	326	206	241

Source: Authors.

Notes: Robust standard errors clustered at the village level are in parentheses; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

We find that average energy cost is negatively associated with family income for all four groups of potato farmers with different sizes of potato-sown area. However, the negative relationship is significant only for the group having an average potato-sown area of between 0.67 and 1.25 hectares. With a 1 percent increase in the average energy cost, families in the second quartile will see their annual income per capita decrease 13 percent, families in the fourth quartile will see their annual income per capita decrease 12 percent, families in first quartile will see their annual income per capita decrease 4 percent, and families in the second quartile will see their annual income per capita decrease 3 percent (see Appendix Table A.3).

This result shows that families cultivating a certain size of potato-sown area may benefit more from reduced energy costs. Farmers with a potato-sown area that is too large or too small may not benefit as much.

7. CONCLUSIONS AND RECOMMENDATIONS

Potato plays an important role in China's food production and in the family incomes of people living in poor regions in China. This paper uses unique household-level data collected from potato farmers in a poor region in northern China to gain a deeper understanding of the relationship between energy use and family income among the rural poor with a high dependence on potato production for their incomes. Several major findings emerge:

First, poverty decreased among the surveyed families and their farm income significantly increased between 2007 and 2012.Agricultural production, particularly potato production, played an important role in the family incomes of the surveyed families.

Second, farmers paid much more for each unit of potato produced in 2012 than in 2007.Theaverage cost of the energy they used in potato production rose significantly (almost doubling), while potato yield rose at a much slower pace.

Third, the average cost of energy used for producing potatoes has a significant and negative association with family income for all the farmers surveyed. Given rising energy prices, increasing efficiency at the farm level appears to be a significant factor in farmers' ability to increase their income.

Fourth, the negative relationship between energy cost and family income is much more significant for poorer families than for wealthier families. This result is found to be robust. As China still has low energy efficiency, including in agriculture, it is important that the government of China find effective solutions to reduce energy intensity. Given that China still has more than 70 million people living below the poverty line and the central government is strongly promoting potato to play a pivotal role in China's food production in the next several decades, reducing energy costs through the more efficient use of energy in potato production has important implications for poverty reduction and food security. The poor will benefit most from reducing the cost of energy use, such as increasing energy efficiency. Without effective measures, the poor will suffer the most from rising energy costs in their production.

Fifth, energy costs appear to have a more significant association with family income for potato farmers who have a certain size of potato-sown area. Families with potato-sown areas that are either too large or two small are less likely to benefit from reduced energy costs.

Sixth, increasing potato-sown area (for example, through land consolidation) is significantly associated with increasing family income only for families with relatively good economic standing, such as those above the poverty line or in higher income strata. The implication is that, in general, reducing energy costs may help the poor increase their income, but it may not necessarily be helpful to those poor who have a relatively small potato-sown area. Hence, if poverty reduction and energy saving are goals of rural development policies (at least in major potato production regions), interventions for energy cost reduction may be viable only for the poor whose family incomes depend, to a relatively high degree, on potato production. These policies, however, may not be effective for the poor who have small potato-sown areas. For this group of poor farmers, alternative interventions will need to be carefully crafted.

In sum, even though potato is a less energy-intensive food crop than other food crops, such as rice and wheat, a rapid increase in the energy costs incurred by potato farmers in their potato production has been observed, and a significant relationship exists between energy costs and family income in our data. As other food crops appear to be more energy intensive, the rate of increase in energy expenditures ought to be higher for other food crops. Therefore, if China aims to increase farm incomes, reduce poverty, and secure the country's food supply, it is important that the government design effective policies to increase farm-level energy efficiency. While energy cost reduction may be beneficiary to the poor, reducing energy costs may not be enough to lift those with a small potato-sown area out of poverty.

APPENDIX: SUPPLEMENTARY TABLES

Table A. 1 Income structure

	2007		2012	
Item	**Value (yuan)**	**Share (%)**	**Value (yuan)**	**Share (%)**
Per capita income	4,399.51	100.0	10,424.25	100.0
Wage income	614.66	14.0	1,206.30	11.6
Agriculture income	3,330.17	75.7	8,000.39	76.7
Potato income	1,128.11	25.6	2,756.83	26.4
Income from other crops	1,660.75	37.7	4,009.68	38.5
Animal husbandry income	541.31	12.3	1,233.89	11.8
Other operating income	123.44	2.8	275.71	2.6
Property income	133.33	3.0	462.78	4.4
Transfer income	175.73	4.0	418.83	4.0
Other income	22.18	0.5	60.23	0.6

Source: Authors' calculations.

Table A.2 Agriculture structure

	2007		2012	
Variable	**Area (ha)**	**Share (%)**	**Area (ha)**	**Share(%)**
Farmland	2.72	100.00	3.29	100.00
Potato	1.03	37.90	1.23	37.40
Wheat	0.49	18.00	0.49	14.90
Oats	0.40	14.70	0.49	14.90
Corn	0.23	8.50	0.29	8.80
Sunflower	0.07	2.60	0.23	7.00
Carrot	0.04	1.50	0.05	1.50
Flax	0.05	1.80	0.03	0.90
Beet	0.01	0.40	0.02	0.60
Chinese cabbage	0.01	0.40	0.01	0.30
Total other minor plants	0.39	14.20	0.45	13.60

Source: Authors' calculations.

Table A.3 Income elasticity of energy costs for different farmer groups

Variable	Elasticity
By economic standing	
1st income quartile	-0.23
2ndincomequartile	-0.06
3rdincomequartile	0.00
4th income quartile	0.21
By income structure	
Share of potato income in agricultural income> 50%	-0.22
Share of potato income in agricultural income ≤50%	-0.03
By farm size	
1st quartile	-0.04
2ndquartile	-0.03
3rdquartile	-0.13
4th quartile	-0.12

Source: Authors' calculations.

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