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Global understanding of farmland abandonment: A review and prospects

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Abstract: Since the 1950s, noteworthy farmland abandonment has been occurring in many developed countries and some developing countries. This global land use phenomenon has fundamentally altered extensive rural landscapes. A review of global farmland abandonment under the headings of "land use change – driving mechanisms – impacts and consequences – policy responses" found the following: (1) Farmland abandonment has occurred primarily in developed countries in Europe and North America, but the extent of abandonment has varied significantly. (2) Changing socio-economic factors were the primary driving forces for the farmland abandonment. And land marginalization was the fundamental cause, which was due to the drastic increase of farming opportunity cost, while the direct factor for abandonment was the shrink of agricultural labor forces. (3) Whether to abandon, to what extent and its spatial distributions were finally dependent on integrated effect from the physical conditions, laborer attributes, farming and regional socio-economic conditions at the village, household and parcel scales. With the exception of Eastern Europe, farmland abandonment was more likely to occur in mountainous and hilly areas, due to their unfavorable farming conditions. (4) A study of farmland abandonment should focus on its ecological and environmental effects, while which is more positive or more negative are still in dispute. (5) Increasing agricultural subsidies will be conductive to slowing the rate of farmland abandonment, but this is not the only measure that needs to be implemented.

Due to China's rapid urbanization, there is a high probability that the rate of abandonment will increase in the near future. However, very little research has focused on this rapid land-use trend in China, and, as a result, there is an inadequate understanding of the dynamic mechanisms and consequences of this phenomenon. This paper concludes by suggesting some future directions for further research in China. These directions include monitoring regional and national abandonment dynamics, analyzing trends, assessing the risks and socio-economic effects of farmland abandonment, and informing policy making.

Keywords: farmland abandonment; farmland marginalization; Land-Use and Cover-Change (LUCC); research progress and prospects

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1 Introduction

An area's land use usually corresponds to its concomitant stages of social development. Consequently, land use transitions in lockstep with the stages of development (Long *et al*., 2002). During preindustrial and early industrialization periods, growing populations and economies led to increasing demands for food and wood. As a result, larger land areas were cultivated and developed, and the extent of forest cover declined. This stage was called, "national land use transition" by Grainger (1995). When the speed of urbanization and industrialization increases, however, the rate of net deforestation in the whole country slows down and stops, after which net deforestation gives way to net reforestation. This land-use transition process was named "forest transition" by British geographer Mather (1992). Over the last 20 years or so, the "forest transition" phenomenon has been very apparent in developed countries and regions such as Europe, the United States, and Japan, and it has been confirmed in developing countries that include China, Vietnam, India, and the Philippines (Rudel *et al*., 2005). Generally speaking, in developed countries forest transition is achieved by means of an "economic growth pathway," while the forest transition in developing countries occurs by following a "forest scarcity pathway" (Rudel *et al*., 2005; Lambin *et al*., 2010). Economic growth pathways describe economic development that creates enough non-farm jobs that farmers choose to leave their farms, thereby abandoning poor farmland and contributing to reforestation (Rudel *et al*., 2005). The forest scarcity pathway describes an increased demand for forest products or forest ecosystem services that drives afforestation on marginal farmlands. During the forest transition process, the expanding ecological land represented by forests is combined with the shrinking farmland (Barbier *et al*., 2010). On the economic growth pathway, farmland abandonment is the main reason for the shrinking farmland, and natural reforestation on abandoned land is the main reason for forest expansion.

The marginalization of farmland refers to the decline of farmland profits or rentals for certain types of land use. Agricultural abandonment is an extreme outcome of marginalization. The rural exodus induced by urbanization and industrialization normally leads to the marginalization of farmland (Li *et al*., 2011a), and then to the large-scale abandonment of marginal farmland. In developed countries, abandonment of farmland is already a major trend in agricultural land-use change (MacDonald *et al*., 2000). Many studies have shown that China experienced a forest transition in the 1980s, and suggest that China's forest transition is on the forest scarcity path (Li *et al*., 2011a). However, China's forest transition will likely shift from a forest scarcity pathway driven by policy, to an economic growth pathway. The reason for this is that as a result of China's rapid on-going industrialization and urbanization, larger numbers of rural laborers are moving to urban areas for manufacturing and service jobs, thereby greatly reducing the size of agricultural labor forces in rural areas, and contributing to farmland marginalization. The China Family Financial Survey and Research Center under the Southwestern University of Finance and Economics carried out two national household surveys of 262 counties in 29 provinces in 2011 and 2013. The results indicate that in 2011 and 2013, 13.5% and 15% of agricultural land, respectively, were idle (Gan *et al*., 2015). As rapid industrialization and urbanization continue, rural labor forces will decline further, and the labor-intensive practices used for sloping lands will be further

marginalized (Li *et al*., 2011a), further exacerbating farmland abandonment. Drafting informed policies to mitigate farmland abandonment depends on a better understanding of the complex interactions that lead to undesirable outcomes.

Farmland abandonment and the subsequent restoration of vegetation have significantly changed rural land use patterns, the agricultural landscape, and farmers' livelihoods. These practices have also had striking ecological and socioeconomic effects (Pointereau *et al*., 2008), especially in terms of reversing the long-term declines of forest areas induced by economic growth (Cramer *et al*., 2008). Hence, farmland abandonment has attracted increasing attention (Queiroz *et al*., 2014), and become an important component of LUCC research. Many studies have been conducted on the drivers and mechanisms of farmland abandonment, the spatial distribution of abandoned land, the factors that influenced these changes, the resulting ecological and social effects, and related policy designs. Most of these studies focused on developed countries, and especially on Europe, where land abandonment is widespread (Benayas *et al*., 2007; Queiroz *et al*., 2014). Nonetheless, research on global farmland abandonment still lacks a comprehensive review. Consequently, this paper systematically reviews existing across-the-board achievements related to global farmland abandonment. These include documenting the distribution of farmland abandonment, its causes and drivers, influencing factors, social and environmental effects, and the policies that have been drafted and applied, under the LUCC research general framework of "land use change – driving mechanisms – impacts and consequences – policy responses". We then provide some advice for the study of farmland abandonment in China, with the objective of promoting sustainable land use in mountainous areas.

Farmland, as used in abandonment research, describes agricultural land that usually includes cropland (sometimes called cultivated land or arable land) and meadows, especially in the European region. Farmland abandonment describes the cessation of using and managing agricultural land (Weissteiner *et al*., 2014), and the degradation of farmland facilities to the extent that they cannot easily be used again (FAO, 2006a), together with the natural restoration of vegetation (Díaz *et al*., 2011). This paper takes a broad view in order to achieve a full understanding of land abandonment.

2 Farmland abandonment has mainly occurred in developed regions

Although farmland abandonment became a global trend during the past half century, the "actual abandoned farmland" is difficult to define, identify, and estimate, because it is characterized by gradual change, complexity, variety, and a scattered distribution (Keenleyside *et al*., 2010). It is also more difficult to extract land use information on abandoned land using remote sensing than it is to gather land-use change information on other land. Mapping abandoned farmland with time-series vegetation indices using multi-temporal remote sensing data is a more effective approach (Alcantara *et al*., 2012). Alcantara *et al*. (2013) used time-series MODIS satellite imagery to map abandoned agricultural lands in Central and Eastern Europe; their results showed that 1/5 of the farmland in this region (52.5 million ha) had been abandoned by 2005. Due to the large number of mixed pixels of the remote sensing imagery, the accuracy of classifications of large regions is not high (user's accuracy is 40% to 75%), and it is lower in hilly and mountainous areas (Estel *et al*., 2015). There is still no

accurate value for global abandoned farmland, nor are there official statistics, except for Japan. Its national land abandonment survey shows that the total abandonment rate was 10.6% in 2010 (MAFF, 2011). According to existing knowledge, farmland abandonment has predominantly occurred in developed countries in Europe, in the United States, Australia, and Japan (Meyfroidt *et al.*, 2011; Queiroz *et al*., 2014). In addition, it has been reported that mountainous areas of China (Li *et al*., 2011a; Shao *et al*., 2015), Latin America (Aide *et al*., 2004), and Southeast Asia (Shively *et al*., 2001; Lambin *et al*., 2010) have also experienced this phenomenon. The distribution of abandoned farmland is not uniform across these countries. For example, abandoned farmland in the United States was concentrated in the east (Brown *et al.*, 2005; Ramankutty *et al*., 2010). In Europe, Central Europe, the Mediterranean, and Eastern Europe have the highest abandonment rates (MacDonald *et al*., 2000; Hatna *et al*., 2011; Weissteiner *et al.*, 2011; Alcantara *et al*., 2013). According to a historical reconstruction of arable land data, the abandoned area of farmland globally was estimated at 2.35 million km^2 from 1700 to 1990, and most of the farms were abandoned between 1900 and 1990 (Ramankutty *et al*., 1999). Another study of historical arable land data from HYDE 3.0 and SAGE indicated that the total area of abandoned farmland in the 20th century was 385 million to 472 million km^2 (Campbell *et al*., 2008), and accounted for 8% to 10% of the world's cultivated area in 2012.

To better understand the global distribution and evolution of farmland abandonment, we used long-term agricultural data from the Food and Agriculture Organization (FAO) to develop a rough estimate. Figure 1 shows that areas used for agriculture in developing regions such as Asia, Africa, and Latin America were increasing from 1961 to 2011, whereas areas

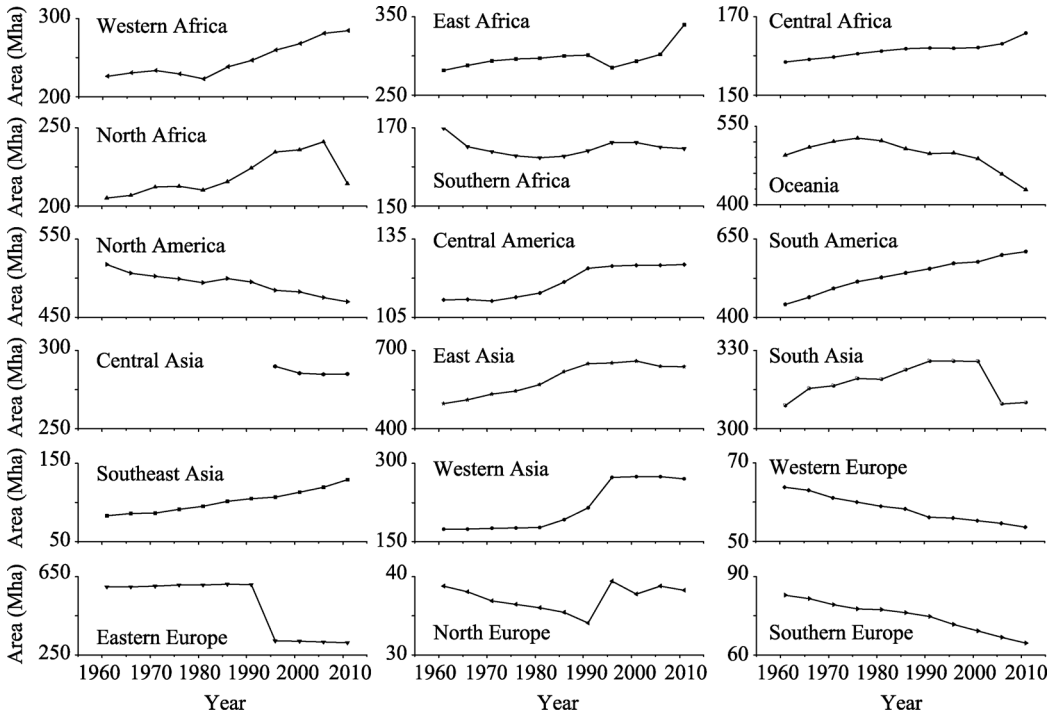

Figure 1 Farmland area changes on all continents from 1961 to 2011[1]

[1] Data source: FAO.

used for agriculture in Western Europe, Southern Europe, North America, and Oceania were steadily decreasing, and had a total reduction in agricultural area of 3.79 million km^2. Meanwhile, the forest cover in these regions has increased over the past 50 years (Gold *et al*., 2006). Generally, forest transition in developed regions is driven by economic growth (Rudel *et al*., 2005; Barbier *et al*., 2010), thus the reduction in agricultural area since 1960 illustrates the farmland abandonment in these high-income areas. Developed countries in Asia, such as Japan and South Korea, have also experienced similar reductions in agricultural areas since the 1960s. Contrary to the steady increase in farmland abandonment in developed countries, the number of agricultural areas in Eastern Europe decreased sharply during the early 1990s, because of the collapse of the Soviet Union (Baumann *et al*., 2011). This change implies that the driving force of abandonment in Eastern Europe is different from other regions.

3 Drivers and causes of farmland abandonment

3.1 Socioeconomic factors are the primary drivers of farmland abandonment

Research has confirmed that macro-level socioeconomic factors are the driving force behind farmland abandonment (Benayas *et al*., 2007). We summarized these factors as follows (see more examples in Table 1): (1) the out-migrations of rural populations and substantial reductions to the agricultural labor force due to urbanization and industrialization; (2) declining agricultural profits due to changing market demands, foreign trade developments, and the rising prices of agricultural products; (3) new agricultural policies; (4) land system reforms; and (5) new agricultural technologies and agricultural commercialization.

Urbanization and industrialization have been widely considered as the fundamental drivers of farmland abandonment in many areas, and especially in developed countries and regions such as Europe and Japan (MacDonald *et al*., 2000; Kozak, 2003; Romero-Calcerrada *et al*., 2004). The rapid development of secondary and tertiary industries has created a large number of non-agricultural jobs with higher incomes and shorter working hours. These jobs serve to widen the gap between urban and rural incomes and quality of life, and eventually lead to large rural-urban migrations. With a declining rural population and a smaller agricultural labor force, poor farmland with low output has been abandoned (Rudel *et al*., 2005; Strijker, 2005; Benayas *et al*., 2007). Decreasing demand (Doorn *et al*., 2007), rising agricultural prices (Rudel *et al*., 1996), and the development of foreign trade (Aide *et al*., 2004; van Meijl *et al*., 2006) have led to lower prices and/or higher costs for agricultural products, thereby reducing profits from farmlands, impelling farmers to move away from their farms in search of economic alternatives in non-agricultural sectors, and eventually abandoning their farmland. Agricultural subsidies increase incomes from farmland use, so policies promoting subsidies could slow farmland abandonment to some extent (Díaz *et al*., 2011). In the EU, the Common Agricultural Policy (CAP) and the fallow land subsidy policy have significantly influenced the abandonment of marginal land in Europe (Strijker, 2005; Estel *et al*., 2015).

The driving force for farmland abandonment in Eastern Europe is different from that in Western Europe and Southern Europe. In Eastern Europe, land system reform is the driver.

Table 1 Typical drivers of farmland abandonment in main research areas

Study region	Terrain	Drivers and causes	Study period	References
Northeastern Spain	Mountain	Depopulation, livelihood changed	1984–2007	Melendez-Pastor *et al*., 2014
Southeast of Portugal	Hilly	Implementation of EU common agricultural policy, rural exodus, marginalization of farmland	1985–2000	Doorn *et al*., 1996
The Pyrenees	Mountain	Changes in demand, marginalization of farmland	1950–2000	Mottet *et al*., 2006
Central and southern France	Mountain	Depopulation	1975–1998	Andre, 1998
Mountain Swiss	Mountain	Rural depopulation, increase of part-time households	1980s–1990	Gellrich *et al*., 2007a
Western Russia	Plain	Social and economic reform, subsidies stopped	1984–2010	Prishchepov *et al*., 2013
East of Albania	Mountain	Massive imports of low-cost agricultural products led to a decline in incomes for local agricultural production, which made many farmers move out and seek employment in a non-farm sector	1988–2003	Sikor *et al*., 2009
Southern Russia	Plain	Collapse of the Soviet Union, the central government stopped providing agricultural subsidies	1989–1998	Hölzel *et al*., 2002
Carpathians	Mountain	Social and economic reform, land system reform	1986–2000	Kuemmerle *et al*., 2008
Central Latvia	Hilly	Lack of agricultural laborers, privatization of land ownership	Since 1990	Nikodemus *et al*., 2005
Slovakia	Mountain	Market economy; an increase of imports led to a decline in both the demand for and price of local agricultural products, which led to marginalization of farmland; other causes included the lack of young laborers, an aging labor force, and a diversity of livelihoods	1990–2010	Lieskovský *et al*., 2015
Western Ukraine	Mountain	Collapse of the political system, an incomplete land system reform, and more opportunities for non-farm jobs	1989–2008	Baumann *et al*., 2011; Alix-Garcia *et al*., 2012
Southern Poland	Mountain	The mobility of the local population and increases in off-farm employment	1823–2001	Kozak, 2003
South Appalachian	Mountain & Hilly	Marginalization of farmland: low productive farmland that needed more input of fertilizers, and entailed higher farm costs	1935–1975	Rudel *et al*., 1996
Northern Thailand	Mountain	Land degradation, new forestry policy, economic reform, liberalization of the rice market	Since 1990s	Lambin *et al*., 2010; Tachibana *et al*., 2001
Latin America	Mountain	Rapid development of secondary and tertiary industries, rural-urban migration, shrinking numbers of agricultural laborers, large-scale commercial production in agriculture in plain areas, foreign trade development	Since 1980s	Aide *et al*., 2004
Puerto Rico	Mountain	Industrialization in the coastal region and aviation industrial development led large numbers of agricultural laborers to migrate to non-agricultural sectors in coastal areas and North America	1950–1990	Rudel *et al*., 2000

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Study region	Terrain	Drivers and causes	Study period	References
Acud Island in Chile	Hilly	Urbanization and industrialization	1985–2007	Díaz *et al*., 2011
Western Japan	Mountain	Out-migration of young labor forces, depopulation	1950s–1990s	Kamada *et al*., 1997
Southern Palawan, the Philippines	Mountain	Irrigation technology development increased the multiple cropping index in the coastal plain area, which provided higher incomes, and led to an increase in the cost of agricultural opportunities for mountain farmers	1990s	Shively *et al*., 2001
South of the Himalayas, Nepal	Mountain	Improved transportation; more off-farm job opportunities promoted the out-migration of the rural population and resulted in a shortage of agricultural laborers; an increase in the proportion of off-farm income reduced farmers' dependence on land Low incomes from marginal land, the decline of soil fertility, and land reform	1970s–2000	Khanal *et al*., 2006
Dadu River, Sichuan, China	Mountain	Land system reform, more farmers seeking employment in urban areas, marginalization of farmland	1967–2000	Yan *et al*., 2005
Southern Ningxia province, China	Mountain	Increase in farming opportunity costs, out-migration of agricultural laborers, marginalization of farmland	~2008	Tian *et al*., 2009
Chongqing, China	Mountain	Increase in farming opportunity costs, out-migration of agricultural laborers	~2010/2012	Zhang *et al*., 2011a; Shao *et al*., 2015; Yan *et al*., 2016a
Jiangxi province, China	–	Rising opportunity cost of agricultural production, out-migration of agricultural laborers	1990–2005	Xie *et al*., 2014
Bijie in Guizhou province, China	Mountain	Low income for agricultural production, poor farm conditions, lack of laborers	~2012	Ge *et al*., 2012

After the collapse of the Soviet Union in 1991, the public land ownership system was transformed into a private system, in which farmlands were obtained by people without farm management experience and/or without any interest in farm management. This not only resulted in weak links between farm ownership and management, but also increased transaction costs due to the fragmentation of farm ownership. The reduction or even cancellation of agricultural subsidies and the lack of agricultural technical services in an incredibly competitive market also contributed to the agricultural recession and high rural unemployment rates in Eastern Europe. With the impetus of urbanization and industrialization, growing numbers of rural laborers—and especially young laborers—moved to the cities. This migration eventually led to widespread abandonment of agricultural land (DGL, 2005; Baumann *et al*., 2011). Among Eastern European nations, Russia suffered its most severe agricultural abandonment since the collapse of the Soviet Union (Alcantara *et al*., 2013).

The land management system has been considered one of the important causes for farmland abandonment in China. In the context of China's imperfect rural social security system, although farmland's function of providing subsistence for the aged is weakening, farmers

have a "land complex" that inclines them toward retaining a landholding, even though they will not farm their land again (Cao *et al*., 2008). In some areas grain subsidies are disconnected from grain production, which is to say that some farmers receive subsidies for farmland that is not used for grain production, and this practice actually reduces farmers' economic incentive to farm or rent out their land (Jin, 2013), and increases the probability of farmland abandonment. Moreover, the stability of land contract management rights has increased the transaction costs and restricted the emergence of a land rental market (Deininger *et al*., 2009). Therefore, enhancing the marketization of agricultural tenancy could prevent high-quality arable land from being abandoned (Zhang *et al*., 2014a, 2014b). Still, we cannot ignore that the imperfections of the imperfect land rental system also hinder the transfer of rural labor forces, so combined with an increase in the number of part-time farmers, it could slow the pace at which farmland is being abandoned (Min, 2010).

The development of agricultural technology first improved grain yields, which then led to a reduced demand for arable land, which, in turn, may lead to farmland abandonment. Rudel *et al.* (2001) found that from 1953 to 1975, counties in the southern United States with the largest increases in crop yields per acre showed greater gains in forest cover, whereas counties that had lower increases in yields per acre showed declines in forest cover and increases in the acreages planted. Mather and Needle's farmland allocation model showed that, even without technological advances, farmers could learn to farm the fertile land intensively, and abandon marginally productive land (Mather *et al*., 1998). In fact, the intensive use of cultivated land is an agricultural development trend (Foley *et al*., 2005), and increasing land use intensity produces higher grain yields. In the context of growing global grain demands, advances in agricultural technology contribute to the shrink of cultivated area and the subsequent abandonment of former farmland.

In addition to socioeconomic factors, inappropriate agricultural practices can lead to severe soil erosion and land degradation, thereby contributing to the abandonment of agricultural land (Benayas *et al*., 2007), though the area impacted by land degradation is usually localized. In addition, climate change may also increase or decrease the risk of land abandonment (EC, 2009; Keenleyside *et al*., 2010).

3.2 Farmland marginalization is the fundamental cause of farmland abandonment

Neoclassical economics argues that land resources tend to be used in the most profitable way in a market economy (Barlowe, 1989), so land-use changes result from changes in the possibilities for various uses and from comparative benefits (Li, 2002). When only one land-use type is feasible, if the profit from farmland use is reduced to zero or is even negative (not viable for farming) due to price changes for inputs and outputs, that is, farmland is beyond the margin of zero rent, and no matter how the farmer adjusts the input proportions the farmland always exceeds this margin, then rational farmers have no motivation to farm the land, so the land will be abandoned (MacDonald *et al*., 2000). The processes of urbanization and industrialization create very large numbers of non-agricultural employment opportunities, which pull rural people off the farms and lead them to migrate to urban areas (Li *et al*., 2011a; Liu *et al*., 2005). Next, the relatively larger incomes and opportunities associated with non-farm jobs' increase the opportunity costs of agricultural production, and lead to a rapid rise in the cost of agricultural labor. The increasing cost of farming, coupled with re-

ductions in the profits of agricultural production, eventually generates marginalization and leads to the abandonment of poor cultivated land (Strijker, 2005; Xie *et al*., 2014). Large-scale farmland abandonment is a response to the process of urbanization and industrialization in developed countries, mainly due to the marginalization of farmland that has occurred as a result of the rising opportunity cost of farming. Fundamentally, the drivers of farmland abandonment—including changing demands (Lieskovský *et al*., 2015), the development of international trade (Hecht *et al.*, 2007), rising agricultural prices (Rudel *et al*., 1996), cuts to agricultural subsidies (Prishchepov *et al.*, 2013), advances in agricultural technologies (Shively *et al.*, 2001), and policies that promote ecological conservation (Ding *et al.*, 2009)—all resulted in rents decreasing and farmland marginalization. We can conclude that marginalization is a necessary cause for farmland abandonment, however, in the process of becoming marginalized, if the rent for another feasible type of land use (such as forest land) increases, this type of land use will be undertaken, and the land will not necessarily be abandoned (Liu *et al*., 2005). For example, farmers in southern China are more likely to plant eucalyptus, walnut, or fruit trees on marginal land, than to abandon it.

Some studies allege that China reached Lewis' turning point in 2003 (Zhang *et al*., 2011b). Although this allegation is still being debated, we note that the wages for labor in China have shown a dramatic upward trend. Since 2003, the wages for China's migrant workers have risen at an annual rate of about 10% (Fang *et al.*, 2009; Lu, 2012). This has led to a rapid increase in the labor costs for agricultural production (Figure 2). From 2003 to 2013, the labor costs for agricultural laborers rose by 6.1 times, while the prices of seeds, fertilizers, pesticides, agricultural films and products increased by 2.9, 2.5, 2.9, 1.8 and 2.1 times respectively. In other words, labor costs per mu for agricultural production were growing at a rate higher than the costs of materials and services. In 2013, labor costs per mu reached 430 yuan, and for the first time exceeded the costs of materials and services.

A rapid rise in labor costs, coupled with slow growth in agricultural revenues, substantially lowered the profits of agricultural production (Tian *et al*., 2009). In response to their loss of profits caused by rising labor costs, farmers usually adopted large-scale operations, such as using labor-saving machinery instead of expensive agricultural labor (Xin *et al*., 2011; Zhu *et al*., 2007), or planting more high-labor-productivity crops to maximize labor's productivity (Tian *et al*., 2009). These responses can reduce the agricultural labor costs caused by rising labor prices. However, in some areas with unfavorable terrain that prevents famers from achieving rapid increases in labor productivity, when labor costs increase, farmlands in these areas will gradually be marginalized

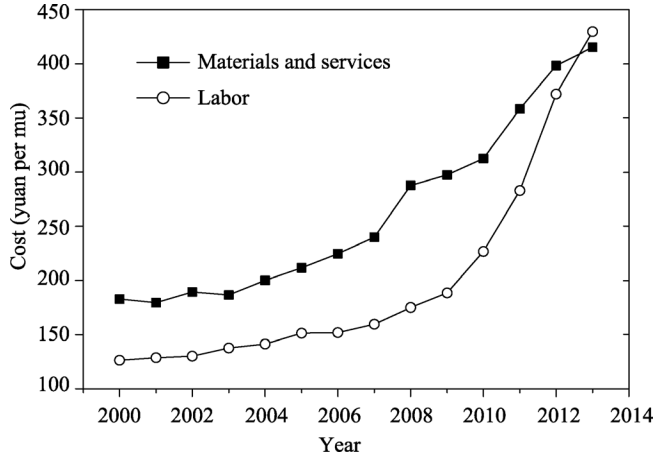

Figure 2 The labor, materials and service costs for China's three main grain crops since 2000
Data source: National Agricultural Costs and Benefit Compilation

and then abandoned (Strijker, 2005; Li *et al*., 2011a).

3.3 Shrinking agricultural labor forces are the direct cause of farmland abandonment

Shrinking rural populations and a declining agricultural labor force are the corollary of urbanization. As the size of the agricultural labor force declines, farmers must improve their labor productivity to enable them to farm all of their land. In the context of rapid increases in farming opportunity costs, substituting human labor with machinery is the most effective way to improve productivity. Nonetheless, on marginal farmland, such as hilly and mountainous areas, because of the difficulties associated with adopting agricultural machinery, farmers choose to plant only crops with high-level labor productivity, and to reduce the areal extent of labor-intensive crops, resulting in larger area of monocultural cropping (MacDonald *et al*., 2000; Tian *et al*., 2009; Yan *et al*., 2016b). Certainly, adjustment of farming practices through structural change cannot improve labor productivity as efficiently as using machinery will, so with shrinking agricultural labor forces, rural households do not have enough time to farm all their land, so some of the land will be abandoned. Since land quality is not homogeneous in hilly and mountainous areas, farmers usually invest more in high quality farmland than in low quality farmland, so with a decrease in labor inputs, the marginal revenues from low quality land will decline at a faster rate, and low quality land will be abandoned first (Ding *et al*., 2009).

In Europe, the reduction of agricultural labor force is often synchronized with population decline, therefore, rural depopulation has been considered to be a very important driving force of farmland abandonment (Table 1), but it is not the case in China (Yan *et al*., 2016). The household registration system and land system reduce the possibility of settling down in cities for migrant workers (Sheng, 2014). Hence, outmigration of rural labor does not necessarily lead to depopulation, as the elderly parents and often also wife and children of the migrated laborer remain stay in the home village (Yan *et al*., 2016). According to the report of National Migrant Workers Survey 2015, male migrant workers accounted for 68.8% of the total (NBS, 2016).

The agricultural labor force is not only shrinking, it is also aging (Romero-Calcerrada *et al*., 2004; DGL, 2005). In some less-developed areas, given the developing economy and changes to traditional concepts, rural households are giving more attention to their children's education, thereby further reducing the agricultural labor force and promoting farmland abandonment. For example, in the south of the Himalayas in Nepal, children aged 5 to 14 accounted for more than 1/5 of the total local population; these children have to date been directly or indirectly involved in agricultural production, so they are an important part of the agricultural labor force. Therefore, with an increase in the rate at which children are being enrolled in schools, farmland abandonment has become more serious (Khanal *et al*., 2006). In conclusion, given the declining size of the labor force, if farmers cannot improve labor productivity, some farmland will inevitably be taken out of production. In addition, rather than the ageing itself, the absence of a successor may more often lead to farmland abandonment in Europe (Schnicke, 2010; Terres *et al*., 2015).

3.4 Farmland abandonment is the result of multiple driving forces

Any land-use activity is integral to the country's interrelated environmental, economic, and

institutional systems (Barlowe, 1989). A change to one system can precipitate land-use changes, together with changes in other elements of other systems; but changes to other systems' elements may promote or inhibit land-use changes, since there are positive and negative feedbacks loops in the composite systems. For example, after farmland has been abandoned, reforesting promotes the more frequent appearance of wild animals (e.g., wild boar and buffalo), which increases the risk of crop failures (depredated by wild animals). This increase in wildlife not only increases the costs of risks associated with agricultural production, but also the labor costs, because farmers have to spend more time preventing crops from being destroyed by wild animals. Cost increases thus accelerate the marginalization of farmland, and damage caused by wildlife has become a significant cause for farmland abandonment in China's mountainous areas (Pointereau *et al*., 2008; Li *et al*., 2014b). In addition, the soil erosion that follows farmland abandonment (Harden, 1996; Khanal *et al*., 2006) and seed rains after forest restoration (Gellrich *et al*., 2007a) also have negative impacts on agricultural yields, which in turn increase the risk of farmland abandonment. Farmland marginalization and abandonment could be slowed by the implementation of government policies that support marginal regions, food prices rising induced by increasing demands or labor costs, and promoting new technologies and the development of energy crops (Campbell *et al*., 2008; Min, 2010; Li *et al*., 2011a; Campbell *et al*., 2013; Zumkehr *et al*., 2013). Therefore, the abandonment of arable land is a result of the combined effects of economic development, government policies, natural factors, and technological advances.

4 Factors that influence land distribution

Farmers will make the necessary adjustments to their land utilization in order to adapt to cost increases or output reductions brought about by the driving force of abandonment. There are, however, some factors that limit opportunities for making effective adjustments; these factors determine the spatial distribution of farmland abandonment (Pointereau *et al*., 2008; Terres, 2013; Zhang *et al*., 2014). Identifying the factors that influence abandonment enables us to understand the mechanisms of farmland abandonment, and provides the scientific references needed to simulate regional land-use changes and conduct a spatial evaluation of abandonment risk.

4.1 Farmland abandonment occurs mainly in mountainous areas

From the macro-scale point of view, in a region with comparable socioeconomic development levels and policies, farmland abandonment is more prone to occur in mountainous and hilly regions (Mather, 1998; Shao *et al*., 2015). For instance, survey data from the MAFF show that even if there is a direct subsidy policy for agriculture in mountainous or semi-mountainous areas (Hu, 2007), farmland abandonment rates in mountainous agricultural areas are 3 times as high as on the plains, and 2.5 times as high as in semi-mountainous areas (MAFF, 2011). The reason mountainous areas have a higher risk of agricultural abandonment is that they have some features that hinder agricultural mechanization and large-scale production, such as farmland fragmentation, steep slopes, long farming distances, and poor transportation (Baldock *et al*., 1996). Compared to flatlands, sloping lands in mountainous areas require more labor inputs, and these additional costs reduce marginal

profits (Khanal *et al*., 2006). Because of their access to good transportation and farming conditions, cultivated lands around the metropolises in China were rarely abandoned, whereas farmland in the hills, mountains, and remote countryside has largely been abandoned because of its low soil fertility, weak agricultural infrastructure, and remoteness (Xu, 2010a).

Outdated management styles and ingrained traditional views also contribute to a higher probability of farmland abandonment in mountainous areas. Mountainous agricultural systems in Europe are small-scale and extensive (Baldock *et al*., 1996). These systems severely hamper making technological and structural adjustments, and in addition, mountain farmers' traditional attitudes make it more difficult for them to adopt new agricultural technologies, thereby entailing a higher risk of farmland abandonment (Campagne *et al*., 1990). According to published case studies, farmland abandonment has only occurred in the plains in Eastern Europe—suggesting no significant relationship between abandonment and terrain (Prishchepov *et al*., 2012)—while elsewhere hilly and mountainous areas have been abandoned (Table 1). The reason for agricultural abandonment in Eastern Europe is distinct from the reasons for abandonment in other regions, and is closely related to its land system and agricultural policy reforms. Therefore, farmland marginalization in plain areas may be reversed. Recent research shows that from 2000 to 2012, areas of abandoned farmland in Eastern Europe that have been reused are much larger than the areas that have been newly abandoned (Estel *et al*., 2015). In short, the possibility of farmland abandonment is higher due to the presence of various conditions in mountainous areas that are adverse to farmland production (Khanal *et al*., 2006), and the probability of their reuse after abandonment is lower.

4.2 The distribution of abandonment is influenced by multilevel factors

Some researchers have summarized the spatial distribution of farmland abandonment. Within the same landform unit, different villages, different types of rural households, and different plots were found to have different risks and extents of farmland abandonment. Baumann *et al.* summarized the spatial distribution of abandoned land in Ukraine as basically being affected by the natural environment, land, location, population changes, and regional agricultural development levels (Baumann *et al*., 2011). Gellrich *et al*. (2007) argued that farmland abandonment and reforestation occur in areas where farm costs are high but outputs are low, and thus factors affecting farmland abandonment and reforestation are classified as being farming costs and benefits. The EU's Joint Research Centre (JRC) reported that the influencing factors of farmland abandonment in Europe can be classified into three categories: poor environmental/biophysical suitability for agricultural activity, low farm stability and viability, and negative regional drivers (Terres *et al*., 2013). This summary indicates that natural conditions, labor attributes, the level of agricultural development, plot location, the economic situation, and agricultural policy affect the spatial distribution of land abandonment. As mentioned earlier, changing socioeconomic factors (urbanization and industrialization) are the leading drivers of land abandonment; declining rents are the fundamental cause of land abandonment; and the shortage of rural laborers is the direct cause. Consequently, in terms of these three aspects, we can classify the influencing factors into three types: labor attributes, farming conditions, and socioeconomic conditions (Table 2).

Table 2 Determinants of farmland abandonment at different levels

Levels	Labor attributes	Agricultural production conditions	Socioeconomic situations
Regional/village scale	No. of agricultural laborers (–) Labor participation (–) Land area per agricultural laborer (+) Percentage of off-farm laborers (+) Percentage of full-time farms/farmers (–)	Mechanization (–) Average elevation (+) Average slope (+) Temperature (~) Precipitation (~) Degree days (~) Fragmentation (+) Parcels per household (+) Agricultural infrastructure (–) Soil quality (–) Average farming distance (+) Average nearest distance from land parcel to road (±) Average nearest distance from land parcel to forest edge (–) Wild animal influence (+) Average yield (–)	Farming opportunity cost (+) Off-farm income (+) Proportion of non-agricultural employment (+) Percentage of non-agricultural GDP (+) Per capita GDP (+) % change of rural labor force and population (+) Urbanization rate (+) Distance to administrative center (±) Road density (+) Land rental rate (–) Agricultural subsidy (–)
Household/ farm level	No. of agricultural laborers by household (–) Household size (–) Land area per agricultural laborer (+) Average age of agricultural laborer in the household or farm (+) Percentage of elderly agricultural laborers (+) Percentage of male agricultural laborers (–) Age of head of a household or farm (+) Age of farm holder/head of household (+) Dependency ratio (+) Percentage of part-time farmers (+) Education (±) Household type	No. of pieces of agricultural machinery (–) Farm size/No. of parcels (+) Average area per parcel (–) Average farming distance (+) Soil quality (–) Average yield of the household or farm (–)	Per capita income (+) Agricultural income (–) Non-farm income (+) Percentage of non-farm income (+)
Parcel level		Parcel size (–) Shape index of the parcel (+) Slope (+) Elevation (+) Soil quality (–) Potential productivity (–) Farm distance (+) Distance from land parcel to nearest road (±) Distance from land parcel to forest edge (–)	

Note: (+), (–), (±), (~) represent the positive, negative, uncertain, and non-linear correlations between the influencing factors and abandonment respectively.

Comprised of the number of individuals in an economy who are either working or available for work, a labor force is characterized by age structures, sex ratios, and educational levels. Other descriptors of the labor force are dependency ratios, and the average farmland area per farmer, and we classify our data accordingly. Total agricultural labor capacity is

comprised of the quantity and quality of the agricultural labor available. Generally, the smaller the labor force, the older the farmer, the lower the proportion of male farmers, the higher the dependency ratio, the fewer the number of full-time farms/farmers, and the higher the probability of land abandonment (Zhang *et al*., 2011a; Li *et al*., 2014b). The cultivated land per farmer and the number of farmers per mu reflect the relative abundance of labor resources, so the larger the cultivated area per farmer the greater the shortage of laborers, and the higher the risk of land abandonment (Li *et al*., 2014a; Xie *et al*., 2014; Zhang *et al*., 2014). In different types of rural households, labor force participants' levels of education have different effects on land abandonment (Zhang *et al*., 2011a; Li *et al*., 2014a).

Agricultural production conditions affect the associated benefits and costs. Benefit-related factors include climate, soil, irrigation facilities, and distance to the forest edge. Cost-related factors include the land's elevation, slope, fragmentation, commuting/tillage distance (accessibility), and level of mechanization. The higher the altitude, the steeper the slope, the more fragmented the land holding, the longer the commuting distance, the thinner the soil layer, the poorer the soil quality, the fewer the degree days, the more labor inputs required, the lower the productivity, and so the higher the risk of abandonment (Baldock *et al.*, 1996; Doorn *et al*., 2007; Gellrich *et al*., 2007a; Gellrich *et al*., 2007b; Sklenicka *et al*., 2014; Xie *et al*., 2014). Improvements to agricultural infrastructure and mechanization are conducive to improving agricultural revenues and reducing labor inputs, thus helping to reduce farmland abandonment. Agricultural land that is closer to the edge of the forest and exposed to shade and seed rains is likely to have lower crop yields, implying higher probabilities of abandonment (Gellrich *et al*., 2007a; Xie *et al*., 2014). Crop yield is a more direct factor that is integral to agricultural revenues, and it is the most important factor in relation to the spatial distribution of land abandonment in flat western Russia (Prishchepov *et al*., 2113).

Socioeconomic situations are proxies for land abandonment drivers, and they are associated with increasing farming opportunity costs in relation to urbanization and industrialization, land rental rates, and agricultural subsidies. Farming opportunity costs are difficult to measure, especially in the absence of household survey data, so proxies that represent opportunities and wages of off-farm employment are used instead. At the regional level, they include the proportion of non-agricultural employment (or agricultural employment), reduction ratios of the rural labor force or rural population, the proportion of non-agricultural income, the urbanization rate, and per capita GDP (Gellrich *et al*., 2007a; Baumann *et al*., 2011; Xie *et al*., 2014). Distance to the nearest administrative center and road density to an extent, are used as proxies to reflect the total migrant labor cost, but their correlation is quite low (Prishchepov *et al*., 2013). The land rental rate used reflects both perfect land markets and the price of the land, so the higher the rental rate is, the lower the likelihood of abandonment (Zhang *et al*., 2014a; Terres *et al*., 2013; Shao *et al*., 2016).

The influencing factors of labor attributes, agricultural production conditions, and socioeconomic conditions perform differently at different levels. The spatial distribution of abandoned land can be explained by factors at the village and parcel levels, and it conforms to Von Thünen-Ricardo's Rent Theory (Lambin *et al*., 2010; Prishchepov *et al*., 2013). The household is the basic decision-making unit of agricultural land use, and farmland abandonment is a result of the allocation of the household labor force. Hence, a household-level study is important to understanding the mechanisms of abandonment (Tian *et al*., 2009).

Facing the rising opportunity cost of farming, farmers will optimize the allocation of their households' labor and land resources, so different types of rural households have different ways of dealing with marginal land, and they abandon farmland for different reasons (Doorn *et al*., 2007; Zhang *et al*., 2011a; Li *et al*., 2014b). Besides, the influencing factors of different levels have different powers to explain the variance in probability of farmland abandonment. Zhang *et al.* analyzed the influencing factors on multi-scale farmland abandonment using multilevel regression analysis, which revealed that of the variances in the occurrence of land parcel abandonment, 80% can be explained by the attributes of individual land parcels, while only 7% and 13% can be explained by household and village level factors, respectively (Zhang *et al*., 2014).

4.3 The effects of influencing factors vary by region

Farmland abandonment is the outcome of interactions between multilevel factors. The complexities of the influencing factors lead to different results in different regions. Thus, some good indicators may fail to reveal land abandonment in some areas. For example, extensive land fragmentation is considered a crucial determinant of agricultural abandonment. Small parcel size not only impedes the efficient substitution of human labor with machinery, but also increases commuting costs, which in turn increase production costs and reduce labor productivity (Lusho *et al*., 1998; Vranken *et al*., 2004). Thus, the more extensive the fragmentation is, the greater the risk of farmland abandonment (Baudry *et al*., 2004; Bielsa *et al*., 2005). However, land fragmentation does not always lead to low productivity; it may be the result of diversification strategies adopted by farmers to reduce production risks associated with economic crises and social instability (Deininger *et al*., 2012). In this context, in some areas the higher the fragmentation is, the lower the rate of land abandonment (Sikor *et al*., 2009). As another example, the probability of land abandonment may increase with the distance from the parcel to the road, but it may also decrease with increasing distance. This positive correlation can be explained by noting that being near a road can reduce transportation costs and time (Alix-Garcia *et al*., 2012), so the further the travel distance is, the higher the likelihood of abandonment (Li *et al*., 2014b; Zhang *et al*., 2014). With regard to the negative correlation, farmers who are close to the road have more opportunities to access off-farm jobs, so the further the distance is, the less likelihood there is of abandonment (Hatna *et al*., 2011). Fundamentally, the distance from the land parcel to the road cannot be used as a direct indicator of the spatial distribution of abandoned farmland, since it does not reflect the real commuting distance, nor the farm's opportunity cost, particularly given that dependence on transportation carries different weights in different types of agricultural land uses (Gellrich *et al*., 2007a). In the Carpathians of western Ukraine, for example, the abandonment rate in plain areas is higher than in mountainous areas, because the quality of farmland is better in the mountains (Baumann *et al*., 2011). In addition, regional agricultural policies may also undermine the explanatory power of primary influencing factors such as topography (Pointereau *et al*., 2008). In short, when selecting the factors that would be used to conduct the regional risk evaluation of abandonment or the spatial pattern simulation, the complexities and regional differences of the influencing factors required us to choose those that are closely related to the driving forces and reasons for abandonment in the study area.

5 Consequences of land abandonment

5.1 Regional variations of environmental consequences

After farmland has been abandoned, semi-natural artificial ecosystems without management gradually evolve into natural ecosystems, thereby changing the entire traditional agricultural landscape, and also having substantial ecological and environmental effects (MacDonald *et al*., 2000; Benayas *et al*., 2007; Zaragozí; *et al*., 2012). Existing research on the ecological and environmental effects of land abandonment have focused mainly on biodiversity and landscape diversity, the carbon sink function, soil erosion and restoration, and forest fires (Benayas *et al*., 2007). Among these, the study of biodiversity is the richest (Benayas *et al*., 2007; Zaragozí *et al*., 2012). Case studies have illustrated that there are obvious regional differences between the ecological and environmental consequences of land abandonment, though which are more positive than negative is still being debated. Some scholars have argued that land abandonment threatens some semi-natural habitats with a high ecological value, so this agricultural practice should be maintained (Fischer *et al*., 2012). Others have advocated that abandonment is a good opportunity to restore natural ecosystems and conserve biodiversity (Aide *et al*., 2004; Chazdon, 2008; Aide *et al*., 2012).

The most controversial argument that has been raised concerns the impact of land abandonment on landscape diversity and biodiversity (Queiroz *et al*., 2014). Since global agriculture has a long history, extensive farming has generated important ecological communities and ecosystems, where species diversity is even greater than in natural ecosystems (MacDonald *et al*., 2000). Previous studies indicate that more than 50% of the important biomes in Europe live on extensively managed farmland (Bignal *et al*., 1996), which is considered to be High Natural Value Farming that contributes to biodiversity (Doxa *et al*., 2010). Therefore, farmland abandonment and the natural ecological succession that follows can lead to the loss of species-rich habitats and the degradation of traditional agricultural landscapes with high conservation values (Fischer *et al*., 2012). Meanwhile the species that rely on these farmland ecosystems will disappear gradually, and among them, birds and arthropods are most susceptible to land abandonment (Anthelme *et al*., 2001; Doxa *et al*., 2010). Consequently, land abandonment can initiate a decline of currently abundant wild species (Stoate *et al*., 2001), as well as a decline in ecological and aesthetic values (Bignal *et al*., 1996). Most case studies in Europe provide evidence of the negative effects land abandonment has on ecological systems (MacDonald *et al*., 2000; Pointereau *et al*., 2008). Studies in Japan (Katoh *et al*., 2009) and Mexico (Garcia-Frapolli *et al*., 2007) have also found that the maintenance of traditional agricultural production and landscapes is conducive to the protection of endangered species. In addition, natural succession on abandoned land promotes the homogenization of vegetation, which in turn increases the fire risk (Vega-Garcıa *et al*., 2006; Benayas *et al*., 2007), and thus further reduces biodiversity because of the now-flourishing pyrophyte (Benayas *et al*., 2007).

Many scholars have also argued that land abandonment has more positive than negative effects on biodiversity. Navarro *et al*. (2012) questioned the environmental friendliness of extensive traditional agricultural practices, noting that rewilding an extensive farming landscape is conducive to promoting biodiversity and enhancing ecosystem services such as carbon sequestration and recreation. Therefore, they recommended rewilding as a possible

land management option for marginal land in Europe. Queiroz *et al*. (2014) reviewed 276 papers and found that studies supporting the opinion that land abandonment had negative impacts on biodiversity are predominantly concentrated in Europe and Asia, whereas American studies have produced contrary results. Their further analyses concluded that the differences found are mainly determined by the measures, species, and time periods used by researchers. In terms of species diversity, the abandonment of farmland may lead to the reduction of a species adapted to the open habitat, and an increase in a species adapted to the closed forest landscape (Dunn, 2004). Moreover, the diversity of a revegetation community will increase with time after land abandonment (Bai *et al*., 2006).

Land-use change plays a key role in the terrestrial ecosystem's carbon cycle. It is generally believed that the restoration of natural vegetation following land abandonment is a carbon sequestration process (Houghton *et al*., 1999; Ma *et al*., 2015), and the transition from cropland to secondary forest can increase soil carbon storage (Batlle-Bayer *et al*., 2010). Therefore, reforestation after land abandonment has greater carbon-sink effects, which will benefit eco-environments and mitigate the greenhouse effect. Kuemmerle *et al*. (2011) evaluated the carbon sequestration potential of large-scale farmland abandonment and the subsequent forest recovery in Ukraine after the collapse of the Soviet Union, and showed that this land-use change had a potential for carbon sequestration of 150 TcC from 1988 to 2007. Vuichard *et al*. (2008) found similar results in their assessment of the carbon sequestration potential in the Soviet Union from 1991 to 2000. From 2001 to 2008, China's annual carbon sequestration increased by 5.87 Mt due to the Cropland Conversion Programme (Li, 2011b).

The natural restoration time varies considerably between regions with different climates, and it has different effects on the soil of abandoned land. Following farmland abandonment, revegetation will increase the soil infiltration rate, reduce surface flows, and enhance its water-holding capacity (Bruijnzeel, 2004), so it effectively reduces water loss and soil erosion (García-Ruiz *et al*., 1995; Molinillo *et al*., 1997; Bakker *et al*., 2008) and increases soil fertility (Robinson *et al*., 2003). However, in semiarid areas, slow revegetation increases the development of soil crusts that reduce infiltration and increase overland flows and soil erosion (Inbar *et al*., 2000; García-Ruiz *et al*., 2011). After the abandonment of slope farmlands and terraced fields, the lack of maintenance and followed by overgrazing increases surface roughness and surface and underground flows, so in the early stage abandonment in this area will increase the risk of natural hazards such as soil erosion, floods, and landslides (Harden, 1996; Khanal *et al*., 2006). In addition, land abandonment will affect the soil's microbial community structure and biomass (Zeller *et al*., 2001).

5.2 Socio-economic effects

Compared with studies of ecological and environmental effects, there have been relatively few studies of the socio-economic effects of land abandonment, and even fewer have been based on good quantitative assessments. Different people have different opinions regarding the socio-economic impacts of cultivated land abandonment. Abandonment is, after all, a rational behavior by farmers (Cao *et al*., 2008; Xu, 2010b) in terms of economic usability. While in Europe rural residents generally have negative perceptions of the abandonment of farmland—which is mainly associated with inefficient use of the land (Ruskulea *et al*.,

2013)—and the economic and aesthetic values of the abandoned land here are the lowest among different land-use types (Benjamin *et al*., 2007). Meanwhile, the characteristic wilderness of landscapes that is induced by land abandonment makes the farmers of this wild environment feel confused and out-of-control (Ruskulea *et al*., 2013).

Farmland abandonment causes a direct decline in grain acreage—which may lead to considerable reductions in local food production (Han *et al*., 2008)—and contributes to food shortages in areas where land has been abandoned (Feng *et al*., 2005; Khanal *et al*., 2006). However, the issue of food security only makes sense at a country level, so whether the abandonment of farmland has negative impacts on the food security issue needs a deeper discussion (Luo, 2012). Previous studies have indicated that the giant Grain for Green Programme (GGP), which aimed to turn slope cropland into forest, had a modest negative influence on food security (Xu *et al*., 2006), with overall grain reduction estimated at only 2% to 3% (Feng *et al.,* 2005). The main reason for this small effect is that most of the farmland returned to the forest by the GGP, or abandoned by farmers, is poor, and has low productivity, so the real impact on grain yield reductions was less than the proportionate reduction of the sown area. In addition, we should note that abandonment is only an extreme result of land marginalization, which also includes seasonal abandonment and "recessive abandonment" such as transitioning from "two cropping rice to one cropping," "paddy field turn into dry land," and "intensive farming to extensive" (Liu *et al*., 2005; Wang, 2014). Hence, when discussing the impacts of land abandonment on food security, it is more reasonable to take into account the holistic aspects of land marginalization.

With the socio-economic development, the function of farmland also changes after its land-use transition (Song *et al*., 2015). In addition to its function as a source of food production, farmland also has social functions that include landscape aesthetics, leisure activities, entertainment, tourism, and farming's cultural inheritance, the importance of which has been increasing dramatically (Buijs *et al*., 2013; Peng *et al*., 2014; Peng *et al*., 2015). Thus, one of the significant negative social effects of land abandonment is landscape degradation and rural decay, which leads to a loss of the traditional farming culture and its aesthetic values (Benjamin *et al*., 2007), as well as its decline as a tourism attraction (EU, 2004; Sayadi *et al*., 2009). Worse, however, is that farmland and rural marginalization interact to create a positive feedback loop, in which farmland abandonment occurs due to a rural exodus, which, in turn, further promotes rural marginalization (Brouwer *et al*., 2008; Pointereau *et al*., 2008), restricts the sustainable development of rural areas, and exacerbates the poverty of low-income rural households (Khanal *et al*., 2006).

6 Policies and instruments for land abandonment

Farmland abandonment first occurred in Europe quite early, and has developed rapidly, thereby arousing the concerns of governments and the EU. To reduce land abandonment, many European countries have introduced pointed policies. The measure with the widest scope is the Less Favoured Areas (LFAs) Scheme, which was updated as the Areas of Natural Constraint (ANCs) Scheme in 2015. LFAs were first launched in France in 1970, and initially applied only to marginal mountainous areas. They were later gradually extended to non-mountainous marginal areas that included disadvantaged rural areas with difficult cli-

matic conditions, low soil productivity, and low population densities. Fifty-seven percent of the EU's Utilized Agricultural Area has been classified as a less-favored area. The LFAs Scheme aimed to improve agricultural viability in constrained areas by issuing direct payments, and ensuring continued agricultural land use in order to maintain and promote sustainable farming systems and viable rural communities in these areas (EC, 2015). Implementation of the LFAs contributed to averting the abandonment of previously managed lands, but the effects varied among member states because of their unequal support for farmers in LFAs (Perrier-Cornet, 2010).

Coupled with rural depopulation, reductions to the agricultural labor force and an aging population, land abandonment has become a prominent problem for Japanese agriculture, especially in mountainous and semi-mountainous areas. To promote agricultural development and prevent the abandonment of agriculture and forestry in mountainous areas, the Japanese government introduced a direct subsidy policy for these areas in 2000 (Hu, 2007). Under that policy, each mountain farmer can receive an average subsidy of up to 80,000 yen per hectare (equivalent to more than twice the EU average area subsidy), and the government has also developed a policy that subsidizes rice production to stabilize rice farmers' incomes (Gao *et al*., 2005). Since the implementation of these policies, the rate of land abandonment has begun to slow, and from 2000 to 2005, the rate of land abandonment in Japan's mountainous areas was comparable to that in plain areas (MAFF, 2011).

In Asia and Latin America, a sharp decline in forest area owing to population growth and agricultural expansion has precipitated various natural eco-environmental problems and natural disasters, which in turn have aroused people's desires for the ecosystem services provided by forests. Their land-use policies, therefore, tend to accelerate forest transition, and prevent farmland encroachments on forestland. New labor-intensive and yield-increasing technologies have improved the intensity and profitability of high-quality cultivated land, which has reduced farmers' dependence on sloping farmland, and thus promoted marginal land abandonment and forest regeneration (Tachibana *et al*., 2001; Aide *et al*., 2004). In China, increasing yields and cropping indexes in the plain areas have contributed to a return of farmland to forests and grasslands, as well as improvements in the environment—all without compromising food security (Huang *et al.*, 2009). However, due to the small extent of cultivated land per capita and the large proportion of sloping land, it is necessary that China strikes a balance between food security and ecological conservation (Shao *et al*., 2014). China abolished its agricultural tax in 2004, and increased its agricultural subsidies to enhance the motivation of farmers to grow grain (Gale *et al*., 2005). However, there are no priorities in the subsidies' targets and no accommodation has been made for regional disparities in the subsidies' standards, so the policies intended to benefit farmers have been ineffective in halting farmland abandonment in mountainous China (Zhang *et al*., 2014).

Experiences in Europe and Japan have indicated that agricultural subsidies in mountainous areas can alleviate land marginalization and slow land abandonment. Nonetheless, due to noteworthy regional variations in the environmental effects of land abandonment, policies designed to address land abandonment should not focus only on maintaining production on marginal land (van Berkel *et al*., 2011; Shao *et al*., 2015). They should also address the perceived negative effects of land abandonment (Renwick *et al*., 2013). The FAO has proposed tackling farmland abandonment by categorizing different abandonment situations (FAO,

2006b), and Renwick *et al*. (2013) concluded that policy designs for land abandonment should consider both the land's capability and population density: areas with a low land capability and high population density should adopt multifunctional development (e.g., rural tourism); areas with a high land capability and low population density should promote agricultural development; areas with a low land capability and low population density should focus on nature conservation.

In addition to agricultural subsidies and supporting policies for marginal areas, measures to prevent land abandonment also include the following: (1) enhancing the efficiency of the allocation of land resources by improving the marketing of land, in order to prevent the abandonment of farmland with high-grade farming conditions (Shao *et al.*, 2016); (2) improving farming conditions through land consolidation, road and infrastructure construction (Shao *et al.*, 2015); (3) promoting the plantations of green organic products with higher economic values, as people's desires for higher food quality increase their demands for these products (Baldock *et al*., 1996; Strijker, 2005); and (4) planting other viable crops such as biocrops (Campbell *et al*., 2008; 2013).

Research findings on the effects of abandonment will influence policymaking for regional ecological conservation and management (Queiroz *et al*., 2014), whereas the consequences of land abandonment due to regional differences require the policymaker to consider the comprehensive effects of abandonment in specific regions, and draft measures that will address the negative impacts of land abandonment. Meanwhile, as typical mountain farming systems or mountain villages with high nature and cultural services values require protection, policymakers should introduce special agricultural subsidies or support the development of tourism to maintain an environment-friendly farming culture and landscape, and to promote the sustainable development of mountainous rural areas.

7 Prospects for farmland abandonment

7.1 Regional and national monitoring of abandonment dynamics

Remote sensing and household surveys are two methods for obtaining information on land abandonment. Remote sensing technology has a great advantage for mapping large-scale agricultural abandonment, as it provides the whole spatiotemporal picture of land abandonment (Spera *et al*., 2014; Estel *et al*., 2015) as well as references for regional land-use simulations and policymaking (Renwick *et al*., 2013). Although a household survey can be used to explain the mechanisms behind abandoned agriculture (Li *et al*., 2014b; Zhang *et al*., 2014), it is time-consuming and cannot provide an overview of the total extent and pattern of land abandonment quickly. The survey population, the sampling method, and the survey technique influenced the abandonment rate obtained using this household survey, so it may not reflect the overall situation accurately. Given the sensitivity of the land abandonment topic (farmland cannot legally be abandoned), farmers may not report their own land abandonments accurately, and consequently the abandonment rate calculated using survey data might underestimate the actual abandonment rate (Hu *et al*., 2013). Most studies conducted in China use household survey methods to estimate abandonment data (Yang *et al*., 2015), while only a few studies have used remote sensing (Dong *et al*., 2011; Xie *et al*., 2014), because of the difficulties involved in mapping highly-fragmented and scattered farmland with

this technology. Therefore, to fully understand the extent and pattern of abandoned land, a large-scale survey using multi-source remote sensing imagery of abandoned land is needed.

7.2 Trend and risk assessment

The global trend toward farmland abandonment has aroused the concerns of scholars and governments. Many researchers have used CAPRI, CLUE-S and Dyna-CLUE to simulate and forecast the spatiotemporal changes of land abandonment likely to occur in Europe (Verburg *et al*., 2009; Keenleyside *et al*., 2010; Terres *et al*., 2013; Terres *et al*., 2015), and thereby provide references for agricultural policymaking in Europe. China is still in the stage of rapid urbanization, and the rapid migration of the rural labor force is likely to be a long-term trend (Lu *et al*., 2012). How will this continuing rural exodus from China's mountainous regions impact land abandonment? Which regions will experience the greatest impacts? These are some of the questions we need to address. It is therefore necessary to create statistical and spatially explicit models that can be used to predict the extent of abandonment. These models will allow the simulation of the evolving spatiotemporal process, and the evaluation of the risk of abandonment, by exploring the dynamic mechanisms of abandonment and identifying the factors that influence farmland abandonment. Because China's mountainous regions cross several climate, agricultural, and economic zones, the causes of farmland abandonment in different zones may carry different weights. Therefore, when modeling the trend or risk of land abandonment, we should take into account regional factors such as climate, cropping systems, agricultural development, land rental markets, and socioeconomic development. Meanwhile, it is necessary that key factors of abandonment for different regions be identified using a substantial field survey.

7.3 Evaluation of the consequences and informed policymaking

Farmland abandonment is the main trend of land-use change in mountainous China. The objective of conducting research on land abandonment is to learn how this practice influences society and the environment. The effects of farmland abandonment largely determine what policies are adopted and which measures are taken to precipitate farmland abandonment and natural ecosystem restoration, or to prevent abandonment and maintain farming on marginal land. Therefore, the focus of land abandonment research is to evaluate the eco-environment and socio-economic effects of abandonment and their regional differences. Furthermore, given different regional effects, it is suggested that policies should be more specific and elaborated in greater detail. Land abandonment policies are not needed to maintain extensive farming on marginal land, or to leave it in a laissez-faire state. For example, in the Loess Plateau, where the eco-environment is fragile and soil erosion is serious, the land use policy should not only promote land abandonment, but also accelerate the process of ecological restoration through early-stage interventions that will reduce the negative effects caused by abandoned farmland.

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