Inter-provincial Differences in Rice Multi-cropping Changes in Main Double-cropping Rice Area in China: Evidence from Provinces and Households

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Abstract: Since the early 1980s, the multi-cropping index for rice has decreased significantly in main double-cropping rice area in China, which is the primary double-cropping rice (DCR) production area. This decline may bring challenges to food security in China because rice is the staple food for more than 60% of the Chinese population. It has been generally recognized that rapidly rising labor costs due to economic growth and urbanization in China is the key driving force of the 'double-to-single' rice cropping system adaption. However, not all provinces have shown a dramatic decline in DCR area, and labor costs alone cannot explain this difference. To elucidate the reasons for these inter-provincial distinctions and the dynamics of rice cropping system adaption, we evaluated the influencing factors using provincial panel data from 1980 to 2015. We also used household survey data for empirical analysis to explore the mechanisms driving differences in rice multi-cropping changes. Our results indicated that the eight provinces in the study can be divided into three spatial groups based on the extent of DCR area decline, the rapidly-declining marginal, core, and stable zones. Increasing labor cost due to rapid urbanization was the key driving force of rice cropping system adaption, but the land use dynamic vary hugely among different provinces. These differences between zones were due to the interaction between labor price and accumulated temperature conditions. Therefore, increasing labor costs had the greatest impact in Zhejiang, Anhui, and Hubei, where the accumulated temperature is relatively low and rice multi-cropping index declined dramaticly. However, labor costs had little impact in Guangdong and Guangxi. Differences in accumulated temperature conditions resulted in spatially different labor demands and pressure on households during the busy season. As a result, there have been different profits and rice multi-cropping changes between provinces and zones. Because of these spatial differences, regionally appropriate policies that provide appropriate subsidies for early rice in rapidly-declining marginal zone such as Zhejiang and Hubei should be implemented. In addition, agricultural mechanization and the number of agricultural workers have facilitated double-cropping; therefore, small machinery and agricultural infrastructure construction should be further supported.

Keywords: multi-cropping change; inter-provincial differences; cropping system adaption; accumulated temperature; double-cropping rice area; China

1 Introduction

As the staple food for more than half of the world's population and 60% of the Chinese population, rice plays a critical role in China's food security (Verburg et al., 2013). Maintaining rice production and a certain self-sufficiency rate for staple food has been an important strategy of the Chinese government for decades.

Rice is double cropped, i.e., early and late rice being sequentially planted on the same plot within one year, mostly in southeastern China, along the final stretches of the Xun Xi River throughout most of Indochina, in the eastern half of India and Ganges floodplain, and on the island of Java (Leff et al., 2004). As an intensive agricultural practice and effective way to increase land productivity and ensure food security, double-cropping can nearly double the annual yield of single-cropping (Zhang et al., 2012; Huang et al., 2015). However, the sown area and multi-cropping rice index (ratio of harvested area to farmland area in one year) has decreased significantly in the main double-cropping rice (DCR) production area of China since the early 1980s. According to the database from Ministry of Agriculture of the People's Republic of China, the sown area of DCR has decreased 57.09% since 1980. In comparison, the sown area of single-cropping rice (SCR), mostly transferred from DCR (Xin and Li, 2009), has increased by 106.87% in the same time period. Planting SCR instead of DCR has become a common phenomenon in many provinces, a large change from previous decades. This 'double-to-single' trend might have a great impact on food production and will likely bring serious challenges to China's food security in the context of population and economic growth (Qiu et al., 2015).

Governments have already proposed several policies and regulations aimed at stabilizing and promoting DCR for reasons of food security, especially for early rice production in recent years. Researchers have also tried to estimate the scale of DCR sown area reduction and resulting rice yield loss due to the change in rice cropping. They have evaluated the dynamic characteristics of the land-use decision-making process of rice farmers, primarily based on local-level panel or household survey data. During the period of rapid DCR decline from 1998 to 2006, the area of DCR transferred to SCR reached at least 1.74×10^6 ha; consequently, total rice yield decreased by 5.4% (Xin and Li, 2009).

Like many developing economies, rural households in China have become increasingly integrated with urban markets. As a result, rural land use is affected by many factors across spatial scales, from local communities to regional and global markets (Liu et al., 2013; Verburg et al., 2013; Müller and Munroe, 2014). Most studies have argued that the impact of increasing labor costs on China's agriculture land use, due to urbaniza-

tion, has been much stronger in recent decades and has become a key driving factor in land-use change (Tian et al., 2010; 2015; Deng et al., 2015; Yi and Liu, 2016). Some researchers have explored the macroscopic scale: they have focused on the conflict between grain production and economic development, arguing that the development of secondary and tertiary industries, agricultural mechanization, and urbanization cause loss of rice farmers and arable land occupation (Huang and Dai, 2004; Chen and Du, 2006; Zheng et al., 2014; Shao and Qiao, 2016). Moreover, the relatively low prices of early rice and the increasing wages of migrant workers have aggravated DCR loss (Chen and Ma, 2011). Other researchers have tried to identify the mechanism of rice farmers' land-use decisions at the microscopic level by conducting household surveys (Weng and Wang, 2009; Chen et al., 2011; Liu et al., 2012; Huang et al., 2015). They found that technology conditions, farmer income structures, comparative benefits of rice, marginal return of production factors, and the opportunity cost of agricultural labor all contribute to farmers adjusting their rice cropping frequency. In summary, most assessments of the 'double-to-single' trend have shown that labor cost is the key driving factor of rice cropping frequency change. It is generally believed that the rising labor prices caused by rapid urbanization throughout China and increasing labor opportunity costs in rice cropping will drive the transfer of labor out of agriculture, leading to a continued decline in sown rice area and the multiple-cropping index.

While these general trends are observed, there have been spatial differences in declining DCR between provinces in the primary rice-producing area. Not all provinces have experienced such a dramatic decline in the rice multi-cropping index despite the increasing labor wages across all provinces in China. Therefore, although existing research has indicated that labor cost in rice cropping might be the key factor affecting paddy land use and cropping frequency, this hypothesis does not explain the variation in rice multi-cropping index change among different provinces where no distinct vartions been found but the latitude location, giving that the proportion of DCR area were above 80% in most of the eight provinces in DCR main prodction area before 1980s. Therefore, in this work, we explore the key factors that have contributed to these inter-provincial distinctions and the mechanisms for change. We first ana-

lyzed the characteristics of proportional DCR change in different provinces since 1980; after evaluating the commonalities and differences between provinces, we proposed a hypothesis for this spatial variability. Then we used the provincial panel for empirical analysis to verify the influencing factors and our hypothesis. Moreover, we estimated the profits of different rice farmers across the studied provinces and provided further evidence for household cropping system decisions using the household survey data we collected. Finally, based on this work, we propose modifying policies to stabilize rice production in main DCR area in China.

2　Material and Methods

2.1　Study area and evolving policy

The main DCR production area in China was analyzed in this study, including eight provinces: Zhejiang, Anhui, Hubei, Fujian, Jiangxi, Hunan, Guangdong, and Guangxi [①]. The region (104°26′–122°55′E, 20°13′–34°38′N) is primarily located in the subtropics and covers 1 343 700 km². According to agricultural census data from *China Statistical Yearbook* (National Statistical Bureau of China, 2016), the total rice-sown area here was 173 711 km² in 2015. The sown area of early rice (April–July), middle rice (May/June–August/September), and late rice (June/July–October) respectively accounts for 31.81%, 32.98%, and 35.21% of the total rice sown area.

Similar to other rural areas in China, the main DCR production area has been experiencing rapid and dramatic social-economic-political changes due to policy reform. In the late 1970s, the Chinese government began a series of policy reforms called the Household Responsibility System when rural-urban migration was initially permitted. Almost simultaneously, the proportion of DCR began to decline. The period from 1994 to 2003 marked the reintroduction of a government grain procurement system; maintaining grain production and securing affordable food supplies had become a priority for the Chinese government (Tian et al., 2015). Grain prices were inflated above world market prices to promote grain production, and the government subsidized grain procurement, export, and storage. The Governor's Grain Bag Responsibility System was implemented, giving provincial and local governments responsibility for agricultural production to ensure food self-sufficiency at the provincial level.

Nearly concurrently, industrial-sector growth, resulting from economic reforms, created labor demand in urban areas. Beginning in 1991, the government liberalized urban jobs and implemented housing policies that encouraged rural-to-urban migration. Public investment in rural infrastructure increased with rising labor wages and off-farm work opportunities were further stimulated. As a result, rice sown area decreased dramatically to its lowest in 2003; this trend continued until 2004 when a series of strong policies were applied. Agriculture taxes were eliminated and subsidies in the form of cash, high-quality grain seeds, and machinery were made to households to stimulate grain production. These policy reforms have significantly impacted land use and sown area changes in the paddies of the study area (Heerink et al., 2007; Jiang et al., 2008).

2.2　Data collection

We used two datasets in our analysis. First, for the empirical analysis of provincial differences, we obtained sown area and farming season data for early, middle, and late rice based on the crop dataset from the Ministry of Agriculture of the People's Republic of China. Pricing information for the three types of rice, wages for agricultural labor, agricultural mechanization data, and population urbanization data were retrieved from the Compilation of National Agricultural Products Cost-benefit Data, China Yearbook of Agricultural Price Survey, China Population and Employment Statistics Yearbook, and some provincial statistical yearbooks. This part of the dataset covered the eight provincial-level administrative units from 1980 to 2015.

Second, for further household-level validation analysis, we conducted household surveys in June 2016 and March 2017. Household samples were selected based on the stratified sampling and random sampling method (Wang et al., 2016). We chose one province from each group and one typical county in each province, which had similar rice-sown area changes to that of the province. Then, in each county we randomly selected 15 to

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①The DCR region in China primarily covers ten provincial-level administrative units, including Zhejiang, Anhui, Hubei, Fujian, Jiangxi, Hunan, Guangdong, Guangxi, Yunnan, and Hainan. We selected the first eight (seven provinces plus the Guangxi Zhuang Autonomous Region) for analysis because some required statistics were missing for Yunnan and Hainan and the DCR area in these provinces only accounts for ~0.6% of the total DCR planting area

20 villages where rice cropping was the traditional agriculture practice. Finally, we randomly selected ~10 households as respondents in each village. Questionnaires were completed through semi-structured one-on-one interviews with the household heads or household members responsible for the farm. The questionnaire contained six sections including family demographic characteristics, labor allocations, household income, plot features, input-output crop information, and climate conditions for 2015 and 2016. In total, 441 households were interviewed and 410 were considered to be valid, a 93% effective rate.

2.3   Methodology

2.3.1   Provincial panel analysis

We used the provincial panel for analysis, which contained detailed statistics on agriculture, labor, market conditions, and socioeconomic development. We assumed that accumulated temperature conditions in each province had remained relatively stable for the past decades and changes in climate and soil quality would not affect the multi-cropping potential of a paddy field. The unit of analysis was province and the dependent variable was the proportion of DCR sown area in each province during the period 1980–2015. Labor cost has been proved to be a key factor, so we use the agriculture labor wages of each province as an explanatory variable. However, the effect of labor price changes on DCR proportion varies from province to province so we interacted labor price with a dummy variable and set the interaction as the explanatory variable to test the various effects of labor cost on rice cropping frequency of different locations. As argued previously, there is no clear difference between the eight provinces but the latitude to explain their varying DCR decline. Due to differences in latitude, the groups have different incident radiation and thermal regimes and one of the most important variables that could explain the difference is active accumulated temperture condition. Therefore, the dummy variable represents different thermal zones or accumulated temperature conditions of these eight provinces. We also considered other possible influencing factors based on previous studies. First was price cost; the price of early rice has usually been lower than middle or late rice, and it has been regarded as an important reason for rice farmers switching from double-cropping to single-cropping (Yi and Liu, 2016). Second is the propor-

tion of cash crop area to all crops' area. This variable characterizes the transfer of labor and farmland resources from the rice industry to the non-grain industry (Tian et al., 2015). Third is the total power of agricultural machinery per unit area, representing the agricultural mechanization development. With some manual work replaced by agricultural machinery, labor intensity and costs should drop, which should lead to an increase in double-cropping (Luo et al., 2017). Fourth is the proportion of the total population that are agricultural workers, which represents the labor force one region can use for rice production. This proportion also represents the level of urbanization in the context of the nationwide migration of the rural labor force. Last but not least, the development of secondary and tertiary industry, relative to primary industry, could also influence DCR-cropping because agricultural income is less important to a household in developed regions than in less developed regions. The low comparative gain of rice cropping could also promote laborers out of rice-planting and influence the input intensity and cropping system adaption; therefore, we use the proportion of agriculture GDP to total GDP to describe local economic development. The primary equation relating DRC area and potential factors is as follows:

$$y_{it} = \alpha_0 + \sum_{j=1}^{3} \alpha_{1j} labor_{it} d_j + \alpha_2 early_{it} + \alpha_3 cashcrop_{it} + \\ \alpha_4 mech_{it} + \alpha_5 apop_{it} + \alpha_6 agdp_{it} + \varepsilon_{it} \tag{1}$$

where y_{it} is the proportion of DCR sown area in province i in year t which can represent the multi-cropping index of rice. α_{1j}, α_2, α_3, α_4, α_5 and α_6 are the parameters for each variable. d_j is the dummy variable and $d_1{=}1$ while $d_2{=}0 \cap d_3{=}0$ for high-latitude region, Zhejiang, Anhui, and Hubei; dummy variables are defined similarly for mid-latitude region, Fujian, Jiangxi, and Hunan, and low-latitude region, Guangdong and Guangxi. *labor*, *early*, *cashcrop*, *mech*, *apop*, and *agdp* are the vectors for agricultural labor price, relative price of early rice, proportion of cash crop area to all crops' area, total power of agricultural machinery per unit area, proportion of agricultural workers, and proportion of agriculture GDP to total GDP, respectively. The relative price of early rice was measured by multiplying the price of early rice by two and then dividing it by the sum of middle and late rice. We used the annual agricultural labor wage per day in rice cropping to estimate

labor cost. This study used the fixed-effect model for estimations because it takes into account region or district-specific characteristics, thus, regional dummy variables can be included. In addition, the random effects model would require assuming no correlation between the unobserved time-invariant characteristics and explanatory variables. Therefore, the fixed-effect model was selected, which was supported by the Hausman test and is consistent with its use in past studies (Kim and Pang, 2009; Barnwal and Kotani, 2010; Cabas et al., 2010).

2.3.2 Empirical study on household level

We used the 'labor pressure index (LPI)' to measure the labor intensity required during the time window for early rice harvest and transplanting late rice. The LPI is calculated as follows:

$$LPI = \frac{L_r \times A}{L_h \times A} \tag{2}$$

where L_r is the amount of labor required per unit area, A is the area of paddy field owned by each household, L_h is the number of agricultural laborers one household can provide, T is the busy season time window in each province, $L_r \times A$ represents the total amount of labor required during the busy season for DCR production, and $L_h \times T$ represents the total amount of labor that one family can provide during the same time. An $LPI < 1$ indicates that the family labor can meet the demand during the busy season while an $LPI > 1$ indicates that the family labor cannot meet demand. The whole equation is used to describe labor input only during the time window when early rice is harvested and late rice is transplanted. Therefore, labor required here mainly refers to harvesting early rice, plowing land, raising seedlings, and transplanting late rice. The households with land circulation cannot represent average cases and were not included in the calculation because these households can change the labor pressure index by leasing land and modifying their labor hiring at the same time. The labor required in rice production depends largely on the paddy field area and production technology. Greater areas have larger labor requirements, which can be reduced with agricultural machinery. Labor required in transplanting late rice varied from household to household; for example, some households used the labor-saving throw-planting method when transplanting late rice while others did not. Therefore, we calculated the LPI of each household

based on their situation and then averaged them within each province to produce the provincial LPI.

To develop a comprehensive understanding of the household decision-making process for changing their rice cropping system, and the spatial variability in DCR sown area, we conducted a comparative analysis of household survey data from three selected provinces. Household ration demands are no longer the most important objective of rice farmers and the labor market has been working better in the past three decades. Therefore, economic benefits and the trade-off between agricultural and non-agricultural work are more likely to affect the rice cropping system. An important consideration for households is availability of agricultural labor to meet the needs for 'rush-harvesting and rush-transplanting' during that time window. With enough household agricultural labor to meet the demand, they are more likely to choose double-cropping because it is usually hard for them to find other jobs and they can only do farm work. Households that cannot meet the labor demands have two options: hire labor to maintain the double-cropping system or switch to single-cropping without additional labor hiring. Then profits are considered; lower profits from double-cropping due to labor hiring than single-cropping will likely cause farmers to choose the latter. The basic assumption here is that households will choose the more profitable cropping system mainly by adjusting their labor input in a relatively perfect commodity and factor market.

The net profit of rice can be calculated using cost-benefit analysis as follows:

$$\pi = p \times Y - C_{material} - C_{machinery} - C_{labor} - C_{other} \tag{3}$$

where p is the price of rice (yuan (RMB)/kg); Y is crop yield (kg/ha); $C_{material}$, $C_{machinery}$ and C_{labor} are respectively the vectors for material, machinery, and labor input (yuan/ha); and C_{other} is other capital input, such as irrigation and transportation cost (yuan/ha). In the household survey we found that few farmers had large agricultural machinery and most chose to hire machinery, and operators, during harvest. This input is incorporated in $C_{machinery}$. For labor cost, we investigated the agricultural employee wage during both slow and busy seasons and estimated the price of family labor based on the ratio between family labor price and agricultural employee price for the most recent five years[①].

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① This information can be found in the Compilation of National Agricultural Products Cost-benefit Data

3   Results and Analysis

3.1   Inter-provincial differences in rice multi-cropping change

According to different extends in the proportional change in DCR and the remain proportion in recent years, we divided the eight provinces into three groups (Fig. 1).

Group 1: The 'rapidly-declining marginal zone' including Zhejiang, Anhui, Hubei, and Fujian. The proportion of DCR area dropped from >50%–90% to <30%, and single-cropping has been the dominant rice cultivation system since 1980.

Group 2: The 'core zone' including Jiangxi and Hunan provinces, which are the most important rice-produ-

cing areas in China. In these two provinces, the proportion of DCR area has slightly decreased, from >80% to 60%–70%, and double-cropping is still the primary cropping system.

Group 3: The 'stable zone' including Guangdong and Guangxi, in which the proportion of DCR area has remained stable at >90% since 1980.

As discussed before, differences between these three groups include physical conditions, economic development, and demographics; however, we found the most significant difference between them was latitude. Due to differences in latitude, the groups have different incident radiation and thermal regimes; there was a strong relationship between rice cropping system and thermal regime. The active accumulated temperature (≥10℃
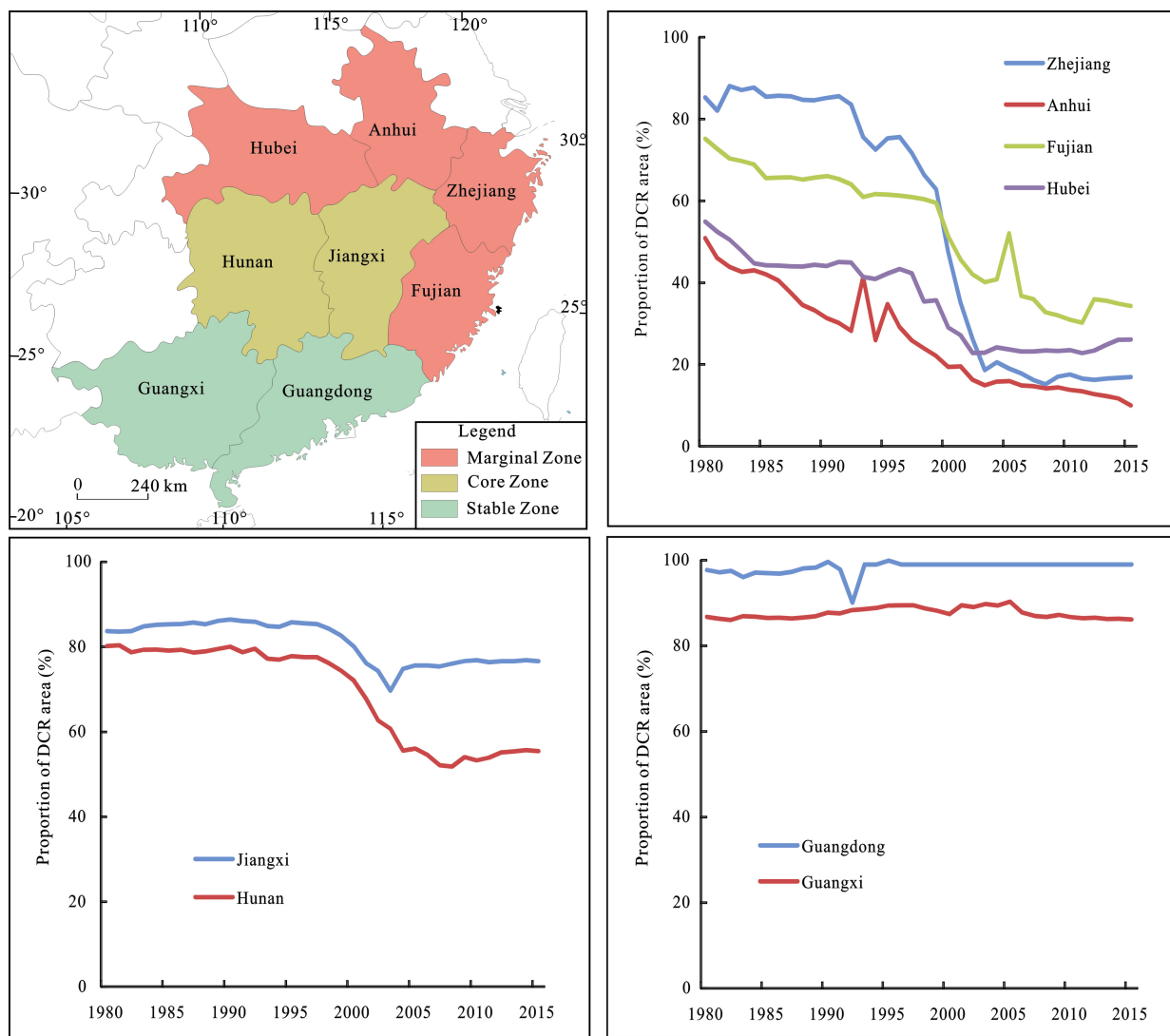

Fig. 1   Different trends in the proportion of double-cropping rice (DCR) planting areas for the three groups of provinces since 1980

accumulated temperature) required for rice growth plays a pivotal role in determining the appropriateness of rice double-cropping in a single year on the same plot. The mechanism for accumulated temperature leading to variation in rice multi-cropping needs to be evaluated. To characterize this mechanism, we identified a correspondence (Zou, 2011) between thermal zones and duration of average daily temperatures >10℃. We found that provinces with higher active accumulated temperature had more time for DCR planting (Table 1).

Double-cropping rice requires an extraordinary amount of work (Talhelm et al., 2014), especially during the harvesting of early rice and transplanting of late rice. Most of the work needs to be done in a short time window (called 'shuang qiang' or 'rush-harvesting and rush-planting'), creating an urgent need for labor. Generally, the average growing period for DCR was about 240 days, so a shorter duration of average daily temperature over 10℃ results in a shorter time window for 'rush-harvesting and rush-planting' and higher labor demands. We further calculated the average time window for each province based on farming season data from 1980 to 2015; the results show that Hubei, Anhui, and Zhejiang had only 3–7 days, while Guangdong and Guangxi had ample time to transfer from early rice to late rice (Table 2).

Based on the analysis above, we inferred that active accumulated temperature at high latitudes has been rela-

tively low, which shortened the entire DCR growing period and the time window for 'rush-harvesting and rush-transplanting'. Shorter time windows required more intensive labor input. As labor prices continue to rise in China, the labor costs for paddy rice will continue to increase drastically, and the cropping system is likely to transfer from double-cropping to single-cropping in regions with higher labor intensity during the time window for 'rush-harvesting and rush-transplanting'.

3.2 Effect of active accumulated temperature on rice multiple-cropping change

Estimates from Equation (1) using the provincial panel are presented in Table 3. The basic result is insensitive to a variety of robustness checks using the stepwise regression method which produced 6 columns of regression results. In general, labor price and proportion of DCR area in the three groups are negatively correlated and the relationship is significant at 10% level, proving that the increase in labor cost has an impact on the transformation from double-cropping to single-cropping. However, there is an additional clear distinction between these groups. In Table 3, column 6, the interaction of *labor* and d_1 ($labor \times d_1$) has the largest significance level (1%) and coefficient, which indicates that compared with other provinces, increasing labor price has the greatest influence on the decrease in proportion of

Table 1 Active accumulated temperature conditions in different thermal zones

Thermal zones	Active accumulated temperature (℃)	Duration (d)	Provinces included
Northern subtropics	4500–5000	220–240	Anhui, Hubei, and Northern Zhejiang
Middle subtropics	5000–6500	240–300	Jiangxi, Hunan, Northern Fujian, and Southern Zhejiang
Southern subtropics	6500–8000	300–350	Guangdong, Guangxi, and Southern Fujian

Table 2 DCR farming season and time window for transplanting rice in each province

Province	Harvesting date of early rice	Transplanting date of late rice	Window of time (d)
Zhejiang	7/21	7/28	7
Anhui	7/25	7/29	4
Fujian	7/17	7/28	11
Hubei	7/22	7/25	3
Hunan	7/16	7/26	10
Jiangxi	7/16	7/26	10
Guangdong	7/11	7/30	19
Guangxi	7/11	7/29	18

Note: Harvesting and transplanting dates were average values based on farming season data from 1980 to 2015

DCR area in high-latitude region, including Zhejiang, Anhui, Hubei. Interaction of *labor* and d_2 (*labor*×d_2) and proportion of DCR area are negatively correlated, which is statistically significant at the 10% level, indicating that labor price in Jiangxi, Hunan and Fujian still have a negative impact on DCR proportion. However, this impact is much weaker than in high-latitude region. In low-latitude region, the correlation between labor price and proportion of DCR area is not statistically significant, implying that the proportional change in DCR area is insensitive to labor price in Guangdong and Guangxi.

We also evaluated the control variables. The relative price of early rice has a positive effect on proportion of DCR area but the correlation is not strong. Agricultural mechanization is significantly positive at the 10% level, indicating that it had played a positive role in DCR planting due to labor savings. The proportion of cash crops has a negative impact on rice multi-cropping, this is reasonable because planting cash crops usually means

more profits and farmers would transfer the rice double-cropping system into one season rice plus one other crops. This has been proven in many villages we surveyed where farmers planted oilseed rape or lotus instead of early rice. The proportion of agricultural workers strongly correlates with the proportion of DCR area, indicating that a more abundant agricultural labor force will likely increase the rice multi-cropping index. Additionally, the effect of GDP per capita on DCR proportion has not been as great as presumed.

3.3 Further evidence from household scale data

3.3.1 Labor pressure based on LPI from three provinces

Agricultural machinery was commonly applied for harvesting and plowing in most surveyed villages. However, transplanting late rice still relied on manpower, which was the main labor input during the busy season time window. The number of days spent on all produc-

Table 3 Results of the provincial panel regression

Variables	(1)	(2)	(3)	(4)	(5)	(6)
labor	−0.001*	−0.001	−0.001	−0.001*	−0.001*	−0.001*
	(−1.49)	(−2.51)	(−1.47)	(−1.59)	(−1.73)	(−1.66)
labor×d_1	−0.005***	−0.003***	−0.013***	−0.014***	−0.013***	0.013***
	(−3.33)	(−3.01)	(−5.45)	(−7.34)	(−6.57)	(−4.62)
labor×d_2	−0.001***	−0.001*	−0.001	−0.002**	−0.001**	−0.001*
	(−1.57)	(−1.35)	(−0.61)	(−1.76)	(−1.67)	(−1.55)
labor×d_3	−0.000	−0.000	−0.000	−0.001	−0.001	−0.001
	(−0.28)	(−0.24)	(−0.67)	(−0.67)	(−0.77)	(−0.71)
early		0.064	0.046	0.031	0.025	0.011
		(1.69)	(1.55)	(1.14)	(1.03)	(0.64)
cashcrop			−0.006*	−0.005*	−0.005*	−0.001*
			(−6.73)	(−5.45)	(−5.18)	(−2.01)
mech				0.004*	0.003*	0.003*
				(1.71)	(1.64)	(1.63)
apop					0.007***	0.005***
					(8.73)	(7.62)
agdp						−0.034
						(−0.73)
Constant	0.425***	0.583***	0.612***	0.745***	0.579***	0.531***
	(13.53)	(14.23)	(15.02)	(17.28)	(14.11)	(13.87)
R^2_w	0.4947	0.5095	0.5152	0.5236	0.5432	0.5501

Notes: *labor*, *early*, *cashcrop*, *mech*, *apop*, and *agdp* are the vectors for agricultural labor price, relative price of early rice, proportion of cash crop area to all crops' area, total power of agricultural machinery per unit area, proportion of agricultural workers, and proportion of agriculture GDP to total GDP, respectively. *labor*×d_1, *labor*×d_2 and *labor*×d_3 are agriculture labor wages and the interaction with dummies which represent three thermal zones, respectively. $^*P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$; values in parentheses are *t*-values. The value of *labor* and *mech* were calculated in logarithmic form

tion processes during the busy season was estimated from survey data; labor input was calculated only for transportation time when machinery was employed for farming tasks. The labor required per unit area (1 ha) was quite similar for each of the three provinces according to our survey. Harvesting early rice usually needed two workdays[①] and plowing needed one workday of manual labor. In comparison, once agricultural machinery was employed, plowing using a small tractor took 0.5 workdays. Using the survey data from Zhejiang, Jiangxi, and Guangxi, we calculated the LPI values shown in Table 4.

The average LPI for Zhejiang is 1.54, which is the largest among the three provinces, indicating that rice farmers in Zhejiang faced the most labor pressure due to the short time window during the busy season. The LPI for Jiangxi is close to one, indicating that family labor in Jiangxi barely met the demand. The LPI for Guangxi is 0.54, indicating that the labor force in most households was sufficient during the 'busy season', which may not have been that busy in Guangxi because farmers had plenty of time to harvest early rice, plough fields, and transplant late rice. The LPI rankings for the three provinces correlated with their changing trends in proportion of DCR area.

3.3.2 Cost-benefit analysis: double-cropping versus single-cropping

Families with large LPIs have a choice to plant DCR using hired agricultural workers to meet their labor requirements. However, this would increase a lot costs giving that labor is the main cost in rice-cropping (Chen et al., 2011; Deng et al., 2015), so it is necessary to compare the benefits of double-cropping and single-cropping to identify the land use decision mechanism of the households with higher LPI. Notably, agri cultural

labor wages usually increased during the busy season (Table 5); Zhejiang had the biggest increase, while the increase in Guangxi was minor. The wage increases directly lead to the difference in benefits between DCR and SCR. Due to the lack of household data for planted SCR in Guangxi, we only compared Zhejiang and Jiangxi (Fig. 2).

The net DCR profit (973.8 yuan/ha) was much lower than from SCR (1813.95 yuan/ha) in Zhejiang than in Jiangxi when labor costs for both family and hired workers were considered. This large difference in profit explains the greater decline in proportion of DCR area in Zhejiang than in Jiangxi.

Generally, both the provincial panel analysis and household survey supported our hypothesis that a difference in accumulated temperature leads to different time window lengths for 'rush-harvesting and rush-transplanting'. This results in regions such as Guangxi and Guangdong having longer time windows for work in fields during the busy season. In comparison, farmers in areas such as Zhejiang have faced labor shortages when planting DCR due to the short time window. Families that can meet the labor demand during this time will likely choose double-cropping. In comparison, families that cannot meet the DCR labor demands can hire labor to maintain the double-cropping system or switch to single-cropping without hiring extra labor. Finally, given the lower profits from DCR with hired labor than SCR without hired labor, farmers will choose the latter.

4 Discussion

Labor cost in rice cropping is widely believed to be the key factor affecting paddy land use and cropping frequency in China, however this alone cannot explain the variation in rice multi-cropping index change among

**Table 4** LPI values for three surveyed provinces

Province	Paddy field area per household (ha)	Agricultural laborers per household	Time window (d)	Labor pressure index (LPI)
Zhejiang	0.28	1.25	7	1.54
Jiangxi	0.34	2.07	10	0.91
Guangxi	0.33	1.88	18	0.54

Notes: the average paddy field area and number of agricultural laborers in each province is for reference. Labor required in each process of DCR-cropping during the busy season is not shown here because households varied significantly. The LPI values were calculated based on the information from each household surveyed. Labor input in the calculation only included work in the paddy fields; labor for supporting the household was not included. For example, during the busy season a family usually needed 1–2 people to prepare food for the laborers

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① Here one workday is an 8-h working period for one laborer

Table 5 Average wages for hired agricultural labor during the slow and busy seasons in 2016 (yuan/d)

Season	Zhejiang	Jiangxi	Guangxi
Slow season	153.96	149.71	89.24
Busy season	186.15	170.57	102.13
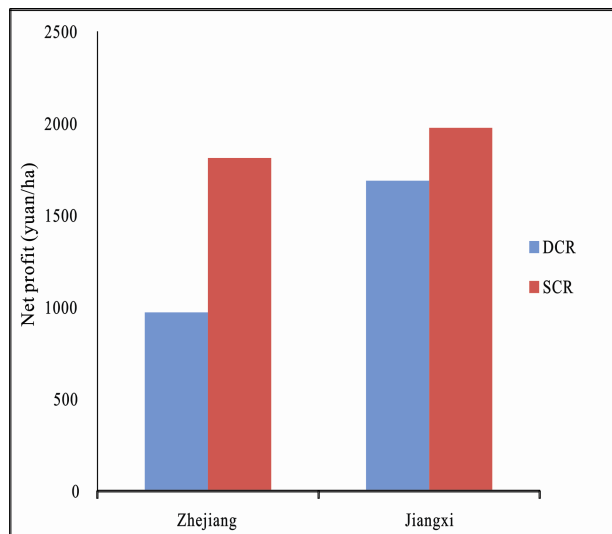
Fig. 2 Net profits from double-cropping rice (DCR) and single-cropping rice (SCR) in Zhejiang and Jiangxi (2016)

different provinces. In our study we found that accumulated temperature conditions caused by latitude and location, besides the labor cost, were also an important background in rice multi-cropping changes and their inter-provincial distinctions. Our study has proposed an explanation on the spatial variability in declining DCR proportion on the basis of previous researches.

Among the eight provinces in our study, Fujian is a special case. Although located at a similar latitude and thermal zone to Hunan and Jiangxi, Fujian shows significantly different trends; the proportion of DCR area has declined much faster in Fujian than in Hunan or Jiangxi. The limitations of labor substitution may provide an explanation for this anomaly. Due to the large proportion of mountainous area in Fujian, it is technically challenging for agricultural machinery to substitute for labor. In other words, it is much harder for the labor to be replaced by agricultural machinery in Fujian. With labor costs continue to increase, more and more rice farmers are likely to adjust double-cropping to single for economic consideration. As a result, Fujian has shown a similar variation pattern to those provinces in higher latitudes.

In this study we mainly focused on the inter-provincial

differences in rice multi-cropping changes and mechanism of these differences, to interpret that we use data at household and average level for empirical analysis. Land use decision-making is a multi-level progress and differences in household or plot characteristics may lead to different land uses (in this case, opportunity cost of rice-planting of each family member would probably be an important factor in household land use decisions). Further analysis at fine level is necessary.

Weather fluctuations and climate risks, partly caused by latitudinal and thermal differences, have proven to be highly related to agricultural land-use change (Chalise and Naranpanawa, 2016). These factors were not considered in our study and the dynamics of rice cropping system changes in the context of climate risks and hazards need further research. Thermal conditions determine the geographical differentiation of rice multi-cropping and the rising labor cost further impact the multi-cropping changes, but the impact of thermal changes on multi-cropping changes in a long term is also an interesting subject.

5   Conclusions and Policy Implication

(1) The multi-cropping index of rice in main DCR area in China has shown a clear downward trend since the early 1980s. However, this trend has varied between provinces. The provinces were divided into three groups based on the extent of DCR decline. Group 1 is the 'rapidly declining marginal zone', including Zhejiang, Anhui, Hubei, and Fujian; here, the proportion of DCR area has decreased dramatically and single-cropping has become the dominant rice cultivation system instead of double-cropping. Group 2 is the 'core zone', including Jiangxi and Hunan province, where the proportion of DCR area has slightly fallen but DCR has remained the primary cropping system. Group 3 is the 'stable zone', including Guangdong and Guangxi, where the proportion of DCR area has remained > 90% and stable since 1980.

(2) The sensitivity of DCR area to labor costs varied between provinces. Increasing labor costs had the greatest impact in Zhejiang, Anhui, and Hubei, dramatically decreasing the proportion of DCR area. However, labor costs had little impact in Guangdong and Guangxi.

(3) The difference in the accumulated temperature conditions resulted in varying labor demands and pres-

sure on farmers during the busy season. This led to varying labor costs and benefits during the busy season. In the context of overall wage increases in China, the eight provinces had varied trends in rice multi-cropping changes. In the provinces with short time windows for the busy season, families with higher LPI have more urgent labor shortage problems and hiring labor has not been cost-effective due to increasing wages during the busy season. As a result, rice farmers in those provinces have changed from double-cropping to single-cropping.

(4) Increasing labor cost due to rapid urbanization indeed is the key driving force of the rice cropping system adaption, but the land use dynamics vary hugely among different provinces located in different thermal zones. In province where accumulated temperature is relatively low like Zhejiang, farmers face more serious labor shortage (or higher LPI) than those who lived in provinces like Guangxi. As a result, rice farmers with higher LPI have two options: hiring labor to keep double-cropping or changing two-season to one-season. However, agriculture labor prices are very high and usually rise more sharply during the busy season of rice in the places where time window is short, that makes hiring labor uneconomical for most households there. As a result, although at the similar starting point before 1980s, the multi-cropping indexes vary hugely among these provinces in recent years.

(5) The extent of agricultural mechanization and number of agricultural workers had a positive effect, increasing the proportion of DCR area. Proportion of cash crops has a negative impact on multi-cropping index of rice.

(6) To address the 'double-to-single' phenomenon in rice cropping, stabilize rice-sown areas and ensure food security, it is necessary to apply different policies appropriate for each region. In 'rapidly declining marginal zone' such as Zhejiang and Hubei, more subsidies can be further implemented for early rice because its price is usually lower than other crops. Moreover, as the labor cost continues to rise, labor substitution technology especially small machinery and agricultural infrastructure construction should be further supported.

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