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Increasing Wages, Factor Substitution, and Cropping Pattern Changes in China

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Abstract

This article analyzed the influence of increasing wages on cropping patterns from theoretical and empirical perspectives. The results showed that the increasing labor cost provided a significant incentive to adjust the grain cropping pattern, which increased the production of the three major cereal grains but reduced the production of other grain crops. Increasing wages had a significant negative impact on cash crops. More labor-intensive cash crops experienced a larger negative impact in the context of increasing wages. The increase in labor costs also had a negative impact on the proportion of vegetables produced, which was more evident in northern China. A further mechanism test indicated that factor substitution was a significant reason for cropping pattern changes; this illustrated the substitution of labor by machinery not only between grain crops and cash crops but also among different cash crops.

Keywords: cropping pattern changes, factor substitution, increasing wages, production transformation
JEL codes: J31, Q10, Q16

I. Introduction

China has enhanced its capacity to ensure a sufficient food supply, owing to advancements in agricultural production conditions and adjustments in relevant policies (Gong, 2018a). However, the rise in income among both urban and rural populations has catalyzed a shift towards a more diversified consumption structure of agricultural products. There

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has been a significant mismatch between supply of and demand for agricultural products. In particular, the acceleration of industrialization and urbanization in China has led to the transfer of rural labor to the urban industrial sector, resulting in a continuous decline in rural surplus labor and an increasing rural labor cost (Wang et al., 2011; Zhang et al., 2011), which has increased production cost, leading to the transformation of agricultural production methods to save labor (Wang et al., 2016; Zhang et al., 2020). On this basis, the structural contradiction between the supply and demand of agricultural products is becoming increasingly prominent, necessitating urgent further adjustments.

As shown in Table 1, in 2017, the total supply and demand of China's rice and wheat were slightly in surplus, while the supply and demand gap of soybeans, cotton, sugar crop, and oil crop remained high. The change in agricultural structure is incompatible with the change in consumer demand, which negatively impacts the efficiency of resource allocation and the competitiveness of agricultural products (Wei, 2017). Furthermore, from 2005 to 2017, the proportion of the sown area of the three major grains in the total area increased by 7.92 percent. Even though the Chinese government reduced the sown area of grains in the non-major grain production areas (about 3 percent of the total cultivated land area) in 2016, the sown area of the three major grains still increased substantially. On the other hand, the proportion of the sown area of cash crops such as soybean, cotton, oil crop, and sugar crop decreased by 1.21, 1.34, 1.26, and 0.08 percent, respectively, and showed apparent stagnation or even shrinkage. These changes make the contradiction of agricultural supply and demand imbalance even more severe. It is thus urgent to clarify the logic of agricultural cropping patterns under the current situation.

Table 1. Supply and demand of China's major agricultural products in 2017

	Category	Output (10,000 tons)	Import (10,000 tons)	Consumption (10,000 tons)	Export (10,000 tons)	Output/ consumption (%)	(Output + import)/ consumption (%)
Supply > demand	Rice	21,268	403	18,651	171	114.0	116.2
	Wheat	13,433	442	12,349	1	108.8	112.4
Balance of supply and demand	Maize	25,907	283	26,790	2	96.7	97.8
	Vegetable	69,193	49	68,113	1,125	101.6	101.7
	Fruit	27,937	480	27,624	473	101.1	102.9
Supply < demand	Soybean	1,528	9,553	10,705	14	14.3	103.5
	Cotton	565	116	849	4	66.5	80.2
	Sugar	1,031	229	1,510	18	68.3	83.4
	Oil	2,715	577	3,336	29	81.4	98.7

Sources: The data are from US Department of Agriculture (USDA) and *China Rural Statistical Yearbook* (NBS, 2018a).

Policy support may reduce the cost or increase the income of grain production to improve the comparative advantages of expanding the sown area of grains and thus occupying the production space of other crops. However, as shown in Table 2, the three major grains had lower cost returns than cash crops in most years. Obviously, the above support policies have not changed the basic pattern of higher costs and lower profits for grains relative to other cash crops. From the demand side, the increasing income level has fundamentally changed the food consumption structure in China. That is, the consumption of non-grain products with high protein and high value is expanding (Sheng et al., 2020), which is also inconsistent with the trend of agricultural cropping pattern change. To summarize, neither policies nor demand can reasonably explain the causes of changes in cropping patterns. As a result, it is worth studying the paradox of lower demand/returns and a higher share in the production of major grain crops.

Table 2. The cost return rate of China's major agricultural products (%)

Period	Cereal grains	Soybean	Peanut	Cotton	Sugar cane	Sugar beet
2003–2007	32.18	41.92	66.80	48.65	26.66	36.49
2008–2012	29.73	32.58	62.99	39.68	33.58	42.98
2013–2017	2.42	–13.21	10.06	–2.69	7.83	14.75

Source: The data are from *The Compiled Materials of Costs and Profits of Agricultural Products of China* (NBS, 2018b).

China's agricultural production mode is dominated by a labor-intensive and small-scale peasant economy (Gathala et al., 2021), and labor-intensive crops face significant impacts when labor wages continue to increase, so such high labor-intensive production mode may be unsustainable (Wang et al., 2016). From the supply side, existing literature presents two controversial opinions on interpreting how large-scale flow of rural labor migration and rapidly increasing wages have influenced the agricultural production structure in China. One view suggests that, increasing wages has had a negative impact on grain. Wang et al. (2013) pointed out that increasing wages has increased the cost of agricultural production, leading to a decrease in the index of grain replanting. When off-farm wages are high, some farmers tend to prefer the single-season planting mode, allowing them to allocate more labor to the off-farm sector (Chen et al., 2013). Other farmers tend to shift from diversified planting to specialized production (Omamo, 1998), and they prefer to grow cash crops, which will bring more profits to compensate for the impact of rising labor costs (Su et al., 2016; Binswanger and Singh, 2018). Changes in the aforementioned two farming patterns will increase the probability of farmers' exit from grain production (Miluka et al., 2010). The other opinion proposes that, increasing wages has enhanced the comparative advantage of grain production. Ji et al. (2017)

pointed out that the choice of cropping pattern depended largely on the level of agricultural mechanization services. If machines can be rented at a relatively low price, even small-scale farmers can save labor costs effectively through the rental market (Yamauchi, 2016), thus leading to the adjustment of cropping patterns. Compared with cash crops, grain production is easier to achieve mechanization, leading to a more comparative advantage in the process of mechanization.

Previous studies have made many contributions to grain production, but more research is needed on the stagnation or even shrinkage of cash crop production. On this basis, this article focuses on the main aspects of the contradiction between the supply of and demand for agricultural products in China and establishes an analytical framework for the changes in the above agricultural production structure to answer the following questions. What are the effects of increasing wages due to labor shortages on cropping pattern? What role does mechanical substitution play in this process? What causes different crops to have varied responses to wage increases? These are important issues that scholars and policymakers should consider, especially in this critical period of China's agricultural transformation. Although international trade is an alternative to fix the mismatch between domestic supply and demand, it is still necessary to understand the logic and dilemma of China's cropping pattern changes and reduce the imbalance, especially in the context of the US–China trade conflict (Zhang et al., 2020; Gong et al., 2021).

This article aims to analyze the impact of increasing wages on cropping pattern adjustment and the role of mechanical substitution and to determine the shock response to increasing wages of different crops in China.[1] More important, a mechanism analysis is established to investigate and identify the reasons behind the cropping pattern changes. The empirical results show that increasing wages led to the expansion of grain cultivation, which is consistent with the findings of Huang et al. (2010), and Zhong et al. (2016). Moreover, the cash crop varieties that used a greater labor input witnessed a larger reduction. Factor substitution was a significant reason for the cropping pattern changes. The higher the degree of substitution between machines and labor was for a crop, the greater competitiveness it achieved in the context of increasing wages.

The main contributions of this article are as follows. First, it incorporates the stagnation and shrinkage of crop production into the scope of the research, thereby

[1]Because of the diversity of crops, it is difficult to analyze each kind of crop. This article selects five representative crops: grain, cotton, oil crop, sugar crop, and vegetables. Considering the special status of grain production, this article further divides grain crops into the three major cereal grains and other grain crops. These crop varieties mainly reflect the current contradictions in the total agricultural cropping pattern in China, whereas the agronomic characteristics of crop production are also representative, which is helpful to summarize the general logic of crop production changes.

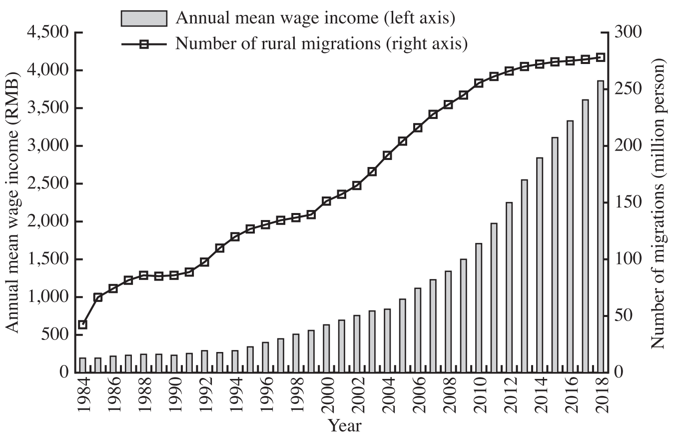
providing a more comprehensive perspective to observe the adjustment of China's cropping pattern. Second, it introduces a mechanism analysis and finds evidence to support the argument that the impact of increasing wages on the cropping pattern depends on the magnitude of any machinery–labor ratio adjustment, which can illustrate cropping pattern changes among grain crops and different cash crops.

The remainder of this article is structured as follows. Section II establishes a theoretical framework for cropping pattern changes due to increasing wages. Section III builds an econometric model and describes empirical data. Section IV provides the empirical results. Section V concludes the major findings and discusses policy implications.

II. Mechanism analysis of cropping pattern changes

The migration of the rural labor force has made outstanding contributions to China's industrialization and urbanization during the whole reform period. As shown in Figure 1, in the 21st century, the scale of rural labor mobility in China has continued to expand. As economic growth accelerates the consumption of population dividends, the speed of rural labor migration has shown a trend of increasing first and then decreasing, which means that the supply of rural labor gradually changed from abundant to scarce, leading to an increase in rural labor wages. From 2000 to 2018, the mean annual wage

Figure 1. Rural migration in China (1984–2018)



Sources: The data are from *Compilation of Agricultural Statistics during the 30 Years of Reform and Opening-up* (NBS, 2009) and *China Rural Statistical Yearbook* (NBS, 2018a).

Notes: The wage income is calculated at constant 2000 prices. The number of rural migrations is equal to the rural labor force minus the rural labor force engaged in agriculture, forestry, animal husbandry, and fishery.

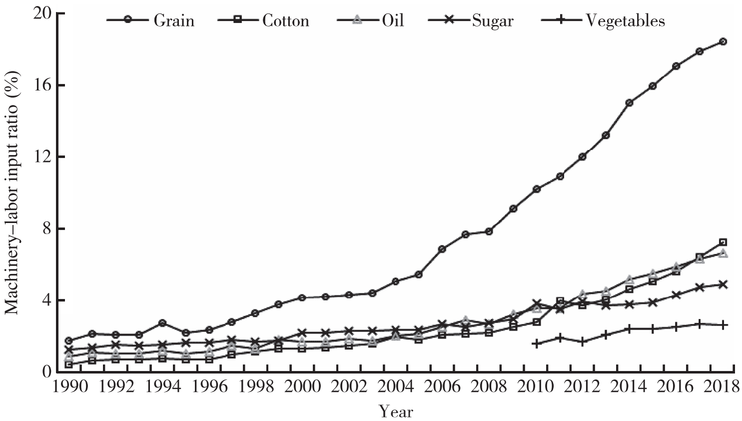
income of rural residents increased by 5.81 times from RMB667.14 to RMB3,874.63 (at constant prices in 2000). The mean daily wage of rural labor increased by 5.49 times from RMB10 to RMB54.86. Rural labor wages are increasing due to the exodus of rural migration, making this labor-intensive and small-scale agricultural system more expensive than ever (Otsuka et al., 2016).

With concerns about food security, existing studies have focused on the impact of rigid labor constraints on the transformation of grain production. Some studies show that, with the outflow of youth labor, as well as aging and feminization issues, the actual rural labor input continues to decline (Chang et al., 2011), leading to a decrease in agricultural output (Rozelle et al., 1999; Qian and Zheng, 2010; Shi, 2018). Agricultural mechanization has been an important way to improve agriculture's competitiveness and farmers' income levels, especially in recent years when the increasing wage has greatly increased the cost of grain production (Huang and Yang, 2017). During the 21st century, although China's real agricultural wages have increased substantially, the price of agricultural machinery has remained relatively stable, resulting in an accelerated decline in the price ratio between agricultural machinery and labor (Wang et al., 2016). Based on the increasing constraints of labor cost and migration, farmers can adjust their input portfolio through the market mechanism. For example, they can replace labor input with relatively cheap mechanical input, which mitigates the impact of increasing wages and labor shortages (Van den Berg et al., 2007; Ji et al., 2012; Otsuka et al., 2013). Moreover, developing social services for agricultural mechanization also helps to replace labor in agricultural production (Yang et al., 2013). The development of mechanization has played a positive role in agricultural economic growth (Abay et al., 2019; Chen and Gong, 2021).

The above changes are consistent with the induced innovation theory, which suggests transferring from a traditional mode to modern production by adopting agricultural technology with higher productivity (Schultz, 1964; Hayami and Ruttan, 1971; Gong, 2020). As a result, advanced inputs and higher productivity can compensate for the negative impact of increasing wages. However, the process of modernization transformation among different crops varies a lot. On the one hand, cash crops are more labor-intensive, while the relative "standardization" of grain cultivation is more suitable for mechanical operations. On the other hand, compared with cash crops, grain crops have a more adequate supply of mechanical factors. Figure 2 shows the changes in the machinery and labor input ratios for six major crops. In the early 1990s, the input ratio of machinery and labor in various crop production was low, and the demand for labor in crop production was large. Nevertheless, as labor wages increase, the process of replacing labor with machinery is accelerating. By the end of 2018, the machinery–

labor input ratios of grain, oil crop, cotton, sugar crop, and vegetable rose to 18.43, 6.67, 7.26, 4.52, and 2.63, respectively. It is worth noting that grain production is gradually getting rid of the traditional production highly dependent on labor input, while cash crop production still maintains high labor input. Grain production gives more attention to the adjustment of input structure, while cash crop production is more likely to adjust output selection (Li et al., 2017). With the continuous increase in rural labor costs, the improvement of mechanization level may further induce the use of cultivated land resources for grain production with a higher degree of mechanization and less labor input, leading to the stagnation of other crops (Qiao, 2017).

Figure 2. The input structure of crop production: Machinery–labor input ratio



Source: The data are from *The Compiled Materials of Costs and Profits of Agricultural Products of China* (NBS, 2018b).

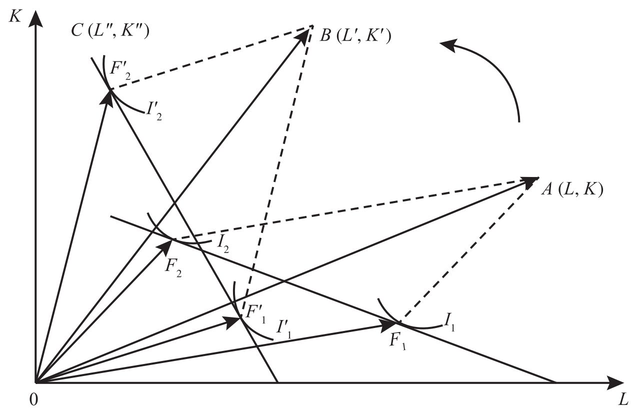
Note: The machinery input is calculated at constant 2000 prices.

The above analysis suggests that increasing labor wages may affect cropping patterns, so this article next considers the mechanism determining the increasing labor wages and the adjustment of the cropping pattern. Assume that an agricultural system produces two products, Crop 1 and Crop 2. Compared with Crop 1, Crop 2 has a greater substitution between capital and labor. Figure 3 illustrates the dynamic impact of increasing wages on the cropping pattern. Points *A*, *B*, and *C* represent the state of factor endowment. Lines *FF*, including F_1F_2 and $F_1'F_2'$, refer to the iso-cost lines, and the slope of *FF* measures the ratio of labor to capital prices and the relative demand for factors. Curves *I*, including I_1, I_2, I_1', and I_2', are the iso-output lines, and the tangent point of *I* and *FF* is the optimal input point, where the production cost is minimum. The ratio of capital to labor used in production depends on the relative prices of labor and capital.

Thus Crop 2 uses a higher capital–labor ratio than Crop 1 for any given relative price of labor and capital.

At first, labor is in infinite supply, and the labor–capital price ratio (w/r) is low. In a competitive market economy, when the iso-cost line is a tangent to the two iso-output lines, the negative slope of this iso-cost line is equal to the relative price of labor and capital, resulting in cost minimization. In this case, the optimal production point for Crop 1 is F_1, the optimal production point for Crop 2 is F_2, and the product combination is (F_1, F_2).

Figure 3. Factor price changes, factor density, and cropping pattern change



Source: Drawn by the author based on the Rybczynski theorem.
Notes: The slope of F_1F_2 is $-(w/r)$, and the slope of $F'_1F'_2$ is $-(w/r)'$.

Then, with the decreasing labor supply and increasing labor costs, the labor–capital price ratio measured by (w/r) rises to $(w/r)'$. Meanwhile, increasing wages (increasing labor–capital price ratio) induce farmers to use more capital and less labor to mitigate the negative impact of labor shortage on agricultural production. For Crop 1, due to the low substitution of capital and labor, the rapid increase in the labor–capital price ratio leads to a significant decline in labor input but a slight increase in capital input. Meanwhile, the amount of capital per labor is still limited, so less can be produced for the same cost. In order to control costs, rational producers choose to produce at F_1', and the corresponding iso-output line moves inward. The new equilibrium yield goes down from F_1 to F_1'.

Crop 2, for which it is easy to implement labor–capital replacement, will absorb more capital elements to mitigate the impact of a increasing cost curve. Thus the iso-output line of Crop 2 will gradually increase from I_2 to I_2' to satisfy the tangent of the iso-output line and iso-cost line at the same time. When the output curve is adjusted from I_2 to I_2', under the technical conditions measured by I_2', the output of Crop 2 will be increased with less labor input. As a result, the status of agricultural supply is gradually adjusted from (F_1, F_2) to (F_1', F_2').

Due to the continuous increase in labor costs, the comparative advantage of Crop 1 is constantly weakened compared with Crop 2. The output share of Crop 2 keeps increasing, while that of Crop 1 keeps decreasing. The cropping pattern gradually tends to focus on crops with low labor intensity that are easily replaced by machinery. Under the current technological and output price levels, more and more labor-intensive agricultural products will therefore be impacted by the increasing cost of labor, thus having a more profound impact on the cropping pattern.

III. Empirical specification and data

1. Model

The previous section showed that cropping pattern changes resulted from changes in the input portfolio induced by increasing wages. First, this article establishes the following regression model to investigate the effects of increasing wages due to labor shortages on the adjustment of cropping patterns:

$$Y_{it} = \alpha_0 + \alpha_1 Wage_{it} + \alpha_2 \boldsymbol{X}_{it} + \varepsilon_{it}, \quad (1)$$

where i and t represent province and time, respectively. Y_{it} represents the proportion of a particular crop to the total crop sowing area of the crop. $Wage_{it}$ refers to the labor cost, measured by the per capita wage income of rural residents. As discussed above, the wage income of rural residents has been shown to follow nearly the same trend as the daily wage of rural labor and can also reflect the opportunity cost of agricultural production of rural residents. $\boldsymbol{X}_{it}$ is a series of control variables. α_0, α_1, and α_2 are estimated parameters. α_1 is the coefficient of interest. If α_1 is significantly greater than 0, the increased labor cost promotes the expansion of the proportion of crop production; otherwise, it shows the reduction of the proportion of crop production.

Second, this article investigates the channels through which labor cost changes affected cropping pattern changes. The increasing labor cost induces the adjustment of the input portfolio; that is, it promotes the improvement of labor-saving technology by replacing expensive labor factors with cheaper mechanical factors to accelerate the adjustment of the cropping patterns. This article follows Jiang (2022) and uses the mediating effect to construct the following regression model:

$$MC_{it} = \beta_0 + \beta_1 Wage_{it} + \beta_2 \boldsymbol{X}_{it} + \mu_{it}, \quad (2)$$

where MC_{it} represents the ratio of machinery–labor per unit of a particular crop, which reflects the input portfolio of these two factors.

Third, due to the high labor input in cash crop production, the transformation of the input portfolio is relatively slow. Following Zheng and Xu (2016), this article constructs the following regression model to investigate whether the change in the machinery–labor ratio can help to mitigate the negative impact of the labor cost change on cash crop production:

$$Y_{it} = \lambda_0 + \lambda_1 Wage_{it} + \lambda_2 Wage_{it} \times MC_{it} + \lambda_3 \boldsymbol{X}_{it} + \xi_{it}, \tag{3}$$

where $Wage_{it} \times MC_{it}$ is the interaction term of labor cost and machinery–labor ratio. If the labor cost coefficient λ_1 and the interaction term coefficient λ_2 have opposite signs, it means that the machinery–labor ratio will offset the effect of labor cost on cash crop production. The higher the machinery–labor ratio, the greater the offset effect is.

Three groups of control variables are considered in Equations (1)–(3). The first group includes the output price index and product demand for agricultural products, which reflects the agricultural market characteristics. A price increase for some farm commodities may induce the farmers to produce more for higher profits. At the same time, an increase in market demand, measured with urbanization level, may also induce cropping pattern changes.

The second group is agricultural production conditions, including the cultivated land area per capita, the degree of population aging, and the average years of schooling. Population aging does not reduce the agricultural labor force directly. However, it may reduce the actual amount of labor input (Zhong et al., 2016), thus resulting in a supply constraints for the agricultural workforce. The overall impact of education level on the actual supply of agricultural labor remains unknown and must be estimated. On the one hand, improving the education level may promote productivity (Gong, 2018b) and increase the actual labor supply. On the other hand, labor with higher human capital tends to choose off-farm employment, which will reduce the input of agricultural labor.

The third group consists of policy variables, including fiscal expenditure on agriculture and agricultural tax. Fiscal expenditure on agriculture mainly contains policy-based subsidies for agricultural production, which help to increase farmers' income and stimulate enthusiasm for grain planting.[2] Since 2004, the central government has increased the intensity of agricultural tax exemption for major grain-producing areas and has completely abolished any agricultural tax in 2006. On this basis, this article introduces the variable of agricultural tax to measure the impact of agricultural tax policy on crop production.

[2]Before 2004, policy subsidies were mainly indirect subsidies. Specifically, indirect subsidies were provided to farmers through tax reductions for enterprises engaged in agricultural production. Since 2004, policy subsidies have turned to direct subsidies, which include direct grain subsidies, grain seed subsidies, agricultural machinery subsidies, and subsidies for increasing production means (Chen et al., 2010).

2. Data

This article attempts to summarize the general logic of crop production changes from a more comprehensive perspective, and estimate the impact of increasing wages on grain, vegetables, cotton, oil crop, and sugar crop. Given the importance of crop production and sample representativeness, grain and vegetable are inspected nationwide, and representative provinces are selected for this study based on the production scale of cotton, oil crop, and sugar crop among different regions. For cotton, oil crop, and sugar crop, to ensure abundant research samples and overcome the influence of small scale in some regions on the regression results, the sown area of a particular crop in each province from 1990 to 2017 is first accumulated and then the proportion of the accumulated regional value in the whole country is ranked from high to low, and selects the corresponding sample provinces into the study. The sample selection is shown in Table 3.

Table 3. The sample selection of cotton, oil crop, and sugar crop

	Sample selection
Oil crop	Anhui, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hebei, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Qinghai, Shaanxi, Shandong, Shanghai, Sichuan, Xinjiang, Yunnan, Zhejiang, a total of 24 provinces (98.7%)
Cotton	Anhui, Gansu, Guangdong, Hebei, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Shaanxi, Shandong, Shanxi, Sichuan, Tianjin, Xinjiang, Zhejiang, a total of 16 provinces (98.8%)
Sugar crop	Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangxi, Jilin, Liaoning, Ningxia, Shanxi, Sichuan, Xinjiang, Yunnan, Zhejiang, a total of 20 provinces (98.9%)

Notes: Chongqing was established in 1997 as a municipality, so the data on oil crop in Chongqing from 1990 to 1997 were based on the corresponding production scale ratio between Chongqing and its nearest province, Sichuan, in 1998. The provinces listed in the table are sorted from large to small in proportion to the sowing area of cash crops. The figures in parentheses are the proportion of the cumulative value of the sowing area in the sample provinces of the whole country.

This article uses province-level panel data from 1990 to 2017. The data were mainly collected from *China Rural Statistical Yearbook* (NBS, 2018a), the *Compiled Materials of Costs and Profits of Agricultural Products of China* (NBS, 2018b), the *China Statistical Yearbook* (NBS, 2018c), the *China Population and Employment Statistical Yearbook* (NBS, 2018d), the *China Yearbook of Household Survey* (NBS, 2018e), the Wind Economic Database, and the Bric Agricultural Database.

The relevant variables were calculated as follows: (i) The mechanical input of machinery–labor ratio is obtained by adding the five parts of each machine's operating cost, irrigation cost, storage cost, fuel cost, and depreciation cost, and data sourced from the *Compiled Materials of Costs and Profits of Agricultural Products of China* (NBS, 2018b). (ii) Cultivated area per labor is measured by the ratio of total cultivated area to agricultural labor force, and data sourced from *China Rural Statistical*

Yearbook (NBS, 2018a). (iii) Due to the frequent fluctuation in agricultural prices, the 5-year moving average was adopted to eliminate the influence of short-term contingent factors to avoid the influence of atypical years and indicate the long-term trend in market price changes. (iv) There were significant gaps in agricultural consumption data, and further calculation was needed to fill these missing observations. The *China Yearbook of Household Survey* (NBS, 2018e) provided the provincial per capita consumption data for oil crop, sugar crop, and vegetable, and the *China Statistical Yearbook* (NBS, 2018c) provided the provincial population data. Using these two datasets, we could obtain data on total consumption, which measured the market demand for oil crop, sugar crop, and vegetables. The same method could be applied to derive data on total grain consumption in each province. Combined with the data on industrial grain and feed grain provided by the Wind Database and Bric Agricultural Database, the total grain consumption of each province could be calculated. Consumption data for cotton can be collected from the Bric Agricultural Database. (v) The degree of the aging population, measured as proportion of aged population, refers to the share of the rural population aged 65 and above. (vi) Education level is measured by years of schooling. (vii) Considering that grain subsidies mainly depend on the sowing area in the current year but have a lag impact, this article employs the lag value of public expenditures. (viii) Due to the difficulty in obtaining accurate data for agricultural tax, dummy variables are introduced to represent changes in agricultural tax policy. If there is an agricultural tax, the variable of agricultural tax is set as 1; otherwise, it is 0.[3] Table 4 includes descriptive statistics for the variables.

Table 4. Summary statistics

Variables	Unit	Mean	Standard deviation	Min.	Max.
Proportion of grain sowing area	%	68.82	11.52	32.81	97.45
Proportion of cereal grain sowing area	%	51.12	11.30	18.02	82.79
Proportion of other grain sowing area	%	17.71	11.95	0.81	68.61
Proportion of cotton sowing area	%	4.55	6.83	0.35	42.40
Proportion of oil sowing area	%	8.02	5.81	0.23	33.50
Proportion of sugar sowing area	%	2.68	3.50	0.41	20.10

(Continued on the next page)

[3]Due to the differences in agricultural tax reduction and cancellation processes among provinces, there are some differences in the setting of agricultural tax variables. Specifically, the provinces with a value of 0 from 2004 include Beijing, Heilongjiang, Jilin, and Shanghai. The provinces with a value of 0 from 2005 are Anhui, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Liaoning, Ningxia, Qinghai, Shaanxi, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, and Zhejiang, and the provinces with a value of 0 from 2006 are Hebei and Shandong (Chen et al., 2010).

(Table 4 continued)

Variables	Unit	Mean	Standard deviation	Min.	Max.
Proportion of vegetable sowing area	%	10.90	6.97	1.19	35.65
Grain machinery–labor ratio	–	4.43	4.44	0.36	26.69
Cereal grain machinery–labor ratio	–	5.79	6.22	0.43	46.13
Cotton machinery–labor ratio	–	0.94	1.66	0.02	14.49
Oil machinery–labor ratio	–	1.50	1.17	0.07	6.07
Sugar machinery–labor ratio	–	1.88	1.24	0.42	5.32
Annual wage	RMB thousand	0.71	0.85	0.0	5.55
Grain price	RMB	0.97	0.22	0.51	1.73
Cereal grain price	RMB	0.82	0.21	0.43	1.51
Cotton price	RMB	6.86	2.16	2.35	17.34
Oil price	RMB	2.05	0.63	0.98	4.33
Sugar price	RMB	0.17	0.05	0.05	0.30
Grain consumption	million tons	15.75	9.98	1.38	54.35
Cotton consumption	million tons	0.25	0.37	0.01	2.16
Oil consumption	million tons	0.30	0.22	0.01	1.07
Sugar consumption	million tons	0.05	0.04	0.01	0.54
Vegetable consumption	million tons	4.49	3.35	0.06	15.69
Cultivated area per labor	hectare	0.32	0.22	0.08	1.40
Proportion of aged population	%	8.27	2.97	1.31	20.61
Education year	year	6.67	1.15	1.93	9.43
Agricultural tax	–	0.54	0.50	0	1
Fiscal expenditure on agriculture	RMB billion	16.22	21.59	0.19	102.31

IV. Results

1. Basic regression results

Table 5 reports the estimated results of Equation (1) for different crops. The estimated coefficient of wages on the share of grain crops is 0.045 and significantly positive, indicating that increasing wages increased the share of grain planting. The increasing labor cost therefore encouraged the expansion of grain production. Within grain crops, the increasing wages showed a significant positive effect on the production of the three major cereal grains but a significant negative effect on the other grain crops. This was in line with the different production modes among grain crops; that is, the standardized production level of the three main grain crops was much higher than that of other grain crops (Yan et al., 2021). The coefficients of wage in the regressions of cash crops (cotton, oil crop, and sugar crop) were all significantly negative (the coefficients are –0.746, –0.190, and –0.274, respectively), which implies that increasing wages reduced the production of cash crops.

Table 5. The effect of increasing labor costs on crop sowing area

	The proportion of crop sowing area						
	Grain	Cereal grain	Other grain	Cotton	Oil	Sugar	Vegetable
Labor wage	0.045* (0.022)	0.076* (0.039)	–0.367** (0.138)	–0.746*** (0.198)	–0.190* (0.102)	–0.274** (0.116)	–0.123 (0.113)
Output price	0.105* (0.059)	0.186 (0.181)	– –	0.177* (0.102)	0.024 (0.083)	1.724 (2.191)	– –
Crop consumption	–0.002 (0.003)	–0.004 (0.007)	0.017 (0.086)	0.060 (0.214)	0.341* (0.167)	–0.243 (0.412)	0.036* (0.020)
Cultivated area	0.149** (0.056)	0.209** (0.076)	–0.258 (0.249)	0.234 (0.443)	0.247 (0.249)	–1.381*** (0.449)	–0.187 (0.196)
Proportion of aged population	0.001 (0.002)	–0.003 (0.006)	0.010 (0.015)	0.024 (0.033)	–0.002 (0.019)	–0.010 (0.017)	0.020* (0.010)
Education	–0.060*** (0.018)	–0.076** (0.036)	–0.010 (0.085)	0.358 (0.296)	–0.213 (0.143)	0.034 (0.087)	0.243* (0.122)
Agricultural tax	–0.035* (0.020)	0.012 (0.036)	–0.118* (0.059)	0.137 (0.235)	–0.073 (0.076)	0.182*** (0.053)	0.084* (0.049)
Fiscal expense	0.002** (0.001)	0.003** (0.001)	0.001 (0.003)	–0.003 (0.011)	–0.004 (0.004)	0.007* (0.004)	–0.002 (0.003)
Year and region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	840	840	839	387	644	528	840
R^2	0.559	0.363	0.389	0.554	0.363	0.399	0.736

Notes: ***, **, and * represent significance at the 1, 5, and 10 percent levels, respectively. Standard errors listed in parentheses are adjusted for spatial correlation and are clustered at the provincial level. Due to the lack of other grain and vegetable prices, the other grain and vegetable equations do not include vegetable price variables. See Table 4 and Section III. 2 for the definitions of all variables. FE, fixed effects.

To summarize, increasing wages might not have constituted the constraint condition on grain production but they decreased the production of cash crops, especially for more labor-intensive cash crops. The impact of increasing wages on vegetables was investigated, and no significant effects were found. Increasing wages led to higher production costs and higher income, which helps to expand the market demand for vegetables. Therefore, the overall impact of increasing wages on vegetable production was the mixture of the two factors discussed above – that is, the expansion of market demand helped to mitigate the negative impact of the increase in production costs.

As for the fluctuations in the product market, the change in output price had a significantly positive effect on grain and cotton production but no significant effect on oil crop and sugar crop. In general, higher output prices increased the overall return from crop production and thus mitigated the negative impact of increasing labor costs. However, the prices of cotton, oil crop, and crop sugar rose by 0.42, 1.45, and 1.62 times, respectively (the current price), whereas labor wages increased by 6.83 times (the current price) from 2000 to 2017. As the increase in the labor cost far exceeded that of the agricultural output price, the increasing crop price failed to offset the negative impact of increasing labor cost fully. Product demand had a significant positive impact on the production of oil crop and vegetable, which confirmed that the change in market capacity was conducive to the adjustment of cropping patterns (Zhong et al., 2016).

As for the agricultural production conditions, the result shows that the cultivated area per labor had a significant positive effect on the share of grain production, which is consistent with Zhong et al. (2016). However, it had a significant negative effect on sugar crop and insignificant effects on cotton, oil crop, and vegetables. In general, areas with more arable land per capita tend to increase capital investment, resulting in a substitution effect on the labor force and a greater possibility to expand grain production. However, in comparison with grain crops that tended to realize mechanical substitution, it was difficult for machinery to replace labor among cash crops, and the production process still followed the traditional labor-intensive approach. As labor and land are complementary production factors, the improvement of cultivated land resources increased the demand for labor, which naturally increased the production cost of cash crops in the context of increasing wages, and thus may adversely affected the proportion of cash crops production.

From the regression results of policy variables, policy implementation also played a specific role in the adjustment of the cropping patterns. On the one hand, as agricultural tax is linked to the scale of the cultivated area, the abolition of agricultural tax significantly promoted the increase of the proportion of grain production and had a negative impact on the proportion of sugar crop and vegetable cultivation.[4] On the other hand, the increase in fiscal support for agriculture may lead to the expansion of grain cultivation, which is in line with China's grain production-oriented fiscal policies.

2. Mechanism test

This subsection investigates the mechanism of labor cost change on cropping pattern adjustment. Due to the severe lack of input and output data for other grains and vegetables, the analysis in this section mainly focuses on grain, cotton, oil crop, and sugar crop.

Table 6 reports the estimation results for Equation (2). In terms of grain and cereal grain crops, the labor cost increase significantly induced the machinery–labor ratio

[4]Before agricultural tax was abolished, a certain proportion of agricultural tax was required to be paid on the income obtained by increasing one unit of cultivated area. The specific tax rates are: Anhui 15 percent, Beijing 15 percent, Fujian 15 percent, Gansu 13.5 percent, Guangdong 15.5 percent, Guangxi 14 percent, Guizhou 14 percent, Hebei 15 percent, Heilongjiang 19 percent, Henan 15 percent, Hubei 16 percent, Hunan 16 percent, Inner Mongolia 16 percent, Jiangsu 16 percent, Jiangxi 15.5 percent, Jilin 18.5 percent, Liaoning 18 percent, Ningxia 13.5 percent, Qinghai 13.5 percent, Shandong 15 percent, Shanghai 15 percent, Shaanxi 14 percent, Shanxi 15 percent, Sichuan 16 percent, Xinjiang 13 percent, Yunnan 14 percent, and Zhejiang 16 percent. The measures for expropriation in the Xizang Autonomous Region will be formulated independently, so a specific tax rate for this area is not available.

increase. Moreover, the labor cost had a more prominent effect on the machinery–labor ratio of cereal grain. The labor–land ratio for grain production has been controlled at a low level (the average labor input per hectare was 5.04 working days in 2017) due to incremental machinery utilization. The adoption of mechanical technologies has alleviated effectively the negative impacts of labor shortage and increasing wages, which constitute the driving force of grain growth. Such transformation in grain production further explains why labor shortage is not the constraint condition for grain production.

However, the results are rather different for cash crops. As for oil crop and sugar crop, the labor cost coefficients are significantly positive, indicating that the increase in labor cost induced an increase in the machinery–labor ratio. This is in line with the logic of induced technological change mitigating the impact of increasing labor costs by replacing expensive labor factors with cheaper mechanical factors. There are certain differences in the ratio of labor cost increase to machinery use of different cash crops. Among them, when labor costs increase, the oil crop has the highest rate of labor substitution by machinery, followed by sugar crop and cotton. These findings are consistent with the impact of labor cost on the cropping pattern in Table 5, indicating that the impact of increasing the labor cost on agricultural production depends on the adjustment of the machinery–labor ratio. By 2017, the number of laborers per mu (one mu equals 1/15 hectare) of land for cotton, oil crop, and sugar crop production was 15.62, 7.53, and 10.99 working days, which was 3.10, 1.49, and 2.18 times that of grain, respectively. If the current production of cash crops cannot be transformed successfully into labor-saving modes that use more machinery input instead of labor input, it will inevitably suffer from fewer profits due to increasing labor costs, which explains why the production of cash crops such as cotton, oil crop, and sugar crop is stagnant or even shrinking. Nevertheless, it is still a rational choice to mitigate the negative impact of increasing labor costs by increasing machinery input.

Table 6. The mechanism for the effect of labor cost on the cropping pattern

	Machinery–labor ratio				
	Grain	Cereal grain	Cotton	Oil	Sugar
Labor wage	2.189*** (0.782)	2.927*** (0.993)	0.215 (0.487)	0.763*** (0.162)	0.518* (0.264)
Control variables	Yes	Yes	Yes	Yes	Yes
Year and region FE	Yes	Yes	Yes	Yes	Yes
Observations	840	840	448	644	532
R^2	0.769	0.760	0.240	0.829	0.897

Notes: *** and * represent significance at the 1 and 10 percent levels, respectively. Standard errors listed in parentheses are adjusted for spatial correlation and are clustered at the provincial level. All regressions are controlled for relevant characteristic variables and fixed effects of region and year. Due to space limitations, the estimation results of other control variables and constant terms are retained. See Table 4 and Section III. 2 for the definitions of all variables. FE, fixed effects.

This study further considered how the change in the machinery–labor ratio mitigated the negative impact of labor cost increases on crop production. Table 7 reports the estimation results for Equation (3). In terms of grain production, the promotion effect of labor cost increase on the proportion of grain planting was strengthened with the increase in the machinery–labor ratio, resulting in the expansion of grain production. As for cash crops, the coefficients of the interaction terms between labor wage and machinery–labor ratio among the three cash crops are all significant, indicating that, when facing a labor cost rise, the improvement in the machinery–labor ratio helps alleviate the negative impact of labor cost rise on cropping pattern adjustment. However, since the absolute values of the above interaction terms are all smaller than the coefficients of labor wage, this indicates that the increase in the machinery–labor ratio is not enough to offset the negative impact of labor cost increase on the proportion of cash crops. The more intensive the use of labor factors in crop varieties, the greater the negative impact of labor cost increases. As the labor cost in China has increased dramatically, accelerating the supply of machinery factors is of great importance for the cash crops discussed above.

Table 7. The interactive effects of labor cost on cash crops

	Proportion of sowing area				
	Grain	Cereal grain	Cotton	Oil	Sugar
Labor wage	0.005 (0.017)	0.012 (0.025)	–0.864*** (0.220)	–0.384* (0.187)	–0.462** (0.198)
Labor wage × Machinery–labor ratio	0.008** (0.003)	0.021*** (0.005)	0.157** (0.063)	0.0590* (0.0292)	0.055** (0.026)
Control variables	Yes	Yes	Yes	Yes	Yes
Year and region FE	Yes	Yes	Yes	Yes	Yes
Observations	840	840	390	644	532
R^2	0.551	0.456	0.575	0.241	0.350

Notes: ***, **, and * represent significance at the 1, 5, and 10 percent levels, respectively. Standard errors listed in parentheses are adjusted for spatial correlation and are clustered at the provincial level. See Table 4 and Section III. 2 for the definitions of all variables. FE, fixed effects.

3. Region differences

Hayami and Ruttan (1971) hypothesized that the selection of appropriate production technology following the "induced development mode," with relative changes in factor prices is an important process to eliminate the constraints imposed on production by inelastic factors (i.e., labor force). Whether additional mechanical factors can replace the labor force is related to the agronomic characteristics of crop varieties themselves and closely related to the terrain conditions. Compared with plain areas, hilly and mountainous areas pose significant obstacles to mechanical operations. As China is a country with significant differences in geographical environment, the degree of mechanization is often higher in the plain areas but lower in the hilly and mountainous areas. Differences in mechanization will further affect cropping pattern changes. In areas with higher mechanization, allocating more agricultural resources to grain production is a rational choice. However, in areas with less mechanization, it is preferred to expand the planting proportion of high-value-added cash crops in the face of the same density of labor input. It can therefore be concluded that the effect of labor cost increase on grain production in regions with higher mechanization is greater than that with lower mechanization. In contrast, the negative impact on cash crop production in areas with lower mechanization will be smaller with higher mechanization.

This study divided the samples into two groups, high degree of mechanization and low degree of mechanization, for group regression based on the median mechanization level of the current year. Table 8 reports the impact of increasing labor costs on the proportion of crop cultivation in different regions. In terms of grain crops, increasing wages significantly promoted the increase of the grain crops as well as the three major cereal grains, and this positive effect on the three major cereal grains was stronger than

Table 8. The effect of increasing labor costs on crop sowing area among regions

Panel A: The effects of labor cost on cropping pattern (higher mechanization regions)

	Proportion of sowing area						
	Grain	Cereal grain	Other grain	Cotton	Oil	Sugar	Vegetable
Labor wage	0.101*** (0.031)	0.166** (0.057)	–0.435** (0.175)	–0.333* (0.163)	–0.343* (0.170)	–0.207* (0.107)	–0.325* (0.178)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year and region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	420	420	420	272	406	342	420
R^2	0.635	0.486	0.620	0.488	0.273	0.630	0.698

Panel B: The effects of labor cost on cropping pattern (lower mechanization regions)

	Proportion of sowing area						
	Grain	Cereal grain	Other grain	Cotton	Oil	Sugar	Vegetable
Labor wage	0.053* (0.028)	0.067* (0.0366)	–0.048 (0.117)	–0.900** (0.305)	–0.181** (0.0773)	–0.010 (0.103)	–0.105 (0.111)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year and region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	420	420	419	186	420	397	420
R^2	0.588	0.584	0.255	0.693	0.398	0.110	0.891

Notes: ***, **, and * represent significance at the 1, 5, and 10 percent levels, respectively. Standard errors listed in parentheses are adjusted for spatial correlation and are clustered at the provincial level. The observations are divided into two groups based on the median mechanization level: higher and lower. Areas with higher degrees of mechanization include: Anhui, Hebei, Heilongjiang, Henan, Inner Mongolia, Jiangsu, Jilin, Liaoning, Ningxia, Qinghai, Shandong, Shanghai, Shanxi, Tianjin, and Xinjiang; Areas with lower degrees of mechanization include: Beijing, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hubei, Hunan, Jiangxi, Shaanxi, Sichuan, Xizang, Yunnan, and Zhejiang. See Table 4 and Section III. 2 for the definitions of all variables. FE, fixed effects.

that of total grain in both higher and lower mechanization regions, which is consistent with the regression results in Table 5. Meanwhile, the increase in labor cost had a more substantial promoting effect on grain production in higher mechanization regions than in lower mechanization regions. In recent years, China's grain production center has been moving northward and tends to be concentrated in the main grain-producing areas. On the one hand, the northern regions with more plain areas and higher mechanization have more cultivated land resources for the large-scale management of grain production. On the other hand, most of the land resources in southern China are mountainous and hilly, which is not conducive to the adoption of mechanical technology, leading to the decline of its comparative advantage in grain production (Zheng and Xu, 2016). Although the northward movement of grain production is very important for ensuring national food security, this situation might exacerbate the water crisis in the northern regions. Moreover, the "South-to-North Water Diversion" and "North-to-South Grain Transport" led to invisible repeated transport, which not only failed to take advantage of the resource endowment but also caused a waste of resources.

In terms of cash crops, increasing wages had a significant negative impact on the planting proportion of cotton, oil crop, sugar crop, and vegetables in different regions but, compared with the lower mechanization regions, the three cash crops (oil crop, sugar crop, and vegetables) were more significantly negatively impacted by labor cost increases in the highly mechanized regions. On the one hand, cash crop production is facing stricter growth conditions. With the increasing constraint of labor cost, the production of cash crops tended to shift to regions with more natural endowment advantages. For example, oil crop tended to move to the central and southern regions, and sugar crop to the southwest. Vegetable production tended to spread across the country but was more pronounced in the southern provinces, which were not conducive to mechanized operations. On the other hand, in the process of regional adjustment of cash crops, it was also faced with competition from grain production. Due to the rich land resources and higher mechanization in northern China, it is a rational choice to increase mechanical input for grain production, thus resulting in the crowding-out effects on cash crops. On the other hand, it is more suitable to increase the planting proportion of cash crops in these hilly and mountainous areas where it is difficult to conduct mechanical operations.

The negative impact of the labor cost increase on cotton production in regions with a higher degree of mechanization was weaker than in those regions with a lower degree of mechanization, which may be related to the fact that cotton production is mainly concentrated in the north of China. As mentioned above, areas with higher mechanization tend to be in the north, where cotton production has scale advantages and can somewhat mitigate the impact of increasing labor costs. There are apparent differences in the impact of labor cost increases on cropping pattern changes in various regions, which is consistent with the theoretical logic of the "induced development model." The substitution relationship between machinery and labor therefore constituted an essential factor in the adjustment of cropping patterns for various crop varieties in different regions.

V. Conclusion and policy implications

This article analyzed the influence of increasing wages on cropping patterns from theoretical and empirical perspectives. The empirical results indicate the following. (i) Increasing wages promoted the development of the cropping pattern towards the expansion of grain cultivation, the main reason for this change being that it was easier to replace labor with machinery for grain production. (ii) Compared with grain production, increasing wages had a negative impact on cash crops – the more intensive the crop varieties that used labor factors, the more developed the negative impact of the increasing wages was. (iii) The rise in product prices and yield may also have mitigated the negative impact of increasing wages on cash crop production; however, the degree of increase in output price and yield level is very limited in the current market environment, which is not enough to completely offset these negative impacts, resulting in some stagnation and contraction in the production of cash crops. (iv) Increasing wages also had a significant negative impact on vegetable production, which was more obvious in northern China.

In terms of the impact mechanism, this study found that factor substitution was the main reason for cropping pattern changes. More specifically, it found that cotton had the lowest degree of substitution between machines and labor, which suffered from the largest decrease with increasing wages. Sugar crop had a higher degree of substitution between machines and labor than cotton, and sugar crop cultivation experienced less reduction than cotton. Oil crop had the highest degree of substitution between machines and labor among all the cash crops, and the loss due to increasing wages was also the smallest. Finally, the magnitude of substitution between machines and labor for grain crops was much higher than all these cash crops, and increasing wages lead to grain expansion. To summarize, crops for which it was more challenging to replace labor with machines experienced a higher labor cost increase due to increasing wages, which reduced the incentive for farmers to plant these crops and therefore change the cropping pattern.

These empirical findings may stimulate policy discussions about the adjustment of the cropping pattern in China. First, the continuous expansion of grain production is of great significance for ensuring China's food security. However, as China is facing land scarcity, considering its large population, the continuous expansion of grain production comes at the expense of reducing cash crop production, hence deepening the contradiction between the supply and demand structures of agricultural products. This study suggests reducing the grain acreage with low yields and increasing research and development investment in high-quality grain seeds to promote grain production capacity by higher productivity instead of increasing sown area, thus providing more space for structural adjustment. This article also suggests that more technological support should be applied to improving crop varieties. As the total saline-alkali wasteland in China is nearly 35 million hectares, more than 10 percent of the total has potential for agricultural development. Culturing new grain varieties that can adapt to various growing environments, such as saline-alkali and drought land, will help broaden the adjustment space of agricultural cropping patterns and ensure food security.

Second, based on the production endowments of different regions, food security and ecological security should be considered simultaneously to avoid wasting resources. Against a background of increasing labor costs, the endowment advantage of grain crops in northern China is inducing the focus of grain production to shift to northern China, which will aggravate the water crisis in northern China. On the one hand, existing policies for irrigation water distribution and food transportation lead to invisible repeated transport, fail to take advantage of the resource endowment, and cause a waste of resources. On the other hand, it is necessary to improve the level of agricultural machinery in southern China, which is characterized by mountainous and hilly terrain, to enhance the comparative advantage of grain production in the southern areas.

Third, to balance the supply and demand structure of crops and promote cash crop production, it is necessary to understand the logic and constraints of the adjustment of farmers' input portfolio and the change in the cropping pattern. The backward development of mechanical technology has seriously restricted the production of cash crops, so mechanical innovation and the supply of labor-intensive crops deserve attention. The impact of increasing labor costs can be mitigated by enhancing the development of labor-saving technologies and increasing the supply of small and medium-sized agricultural machinery and tools for labor-intensive crops.

The government should also reconsider the impact of increasing wages when creating policies to promote grain production. The deregulation of the agricultural price system in China is necessary to fill the gap between demand and supply. When increasing wages lead to more grain crops and fewer cash crops, the market-oriented price will fall for grain and increase for cash crops, which will induce more technological innovation for cash crops and provide incentives for farmers to expand their cash crop production. When optimizing the cropping patterns, it is also necessary to consider the impact of market risk, especially the regulating role of prices and the futures market.

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