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Irrigation Expansion and Rural Transformation in China: Evidence of Provincial Data in 1978–2018

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ABSTRACT

The role of irrigation expansion in facilitating rural transformation has been widely documented, yet quantitative studies remain rather limited. Based on the statistical data from 27 provinces in China, this paper analyses the correlation between irrigation expansion and rural transformation over the period of 1978–2018. The econometric results indicate a positive relationship between irrigation expansion and high-value agriculture. However, from a dynamic perspective, for each percentage point increase in the share of cultivated land with irrigation, the share of high-value agriculture decreases by 0.09 percentage points in the early stage, but increases by 0.07 and 0.12 percentage points in the subsequent middle and later stages, respectively. Likewise, the relationship between irrigation expansion and non-farm employment of rural labourers is not always negative. Specifically, an additional one percentage point increase in the share of cultivated land with irrigation is associated with a 0.09 percentage points decline in the share of rural labour non-farm employment in the early stage. This reduction moderates to a 0.05 percentage points in the middle stage, but there is a 0.08 percentage points increase in the later stage. This paper further concludes with several implications for policymakers and academic research.

1 | Introduction

Irrigation investment is a critical driving force for rural development in developing countries (IFAD 2016; FAO 2017; Higgins, Arslan, and Winters 2021). According to the existing literature, scholars have explored the link between irrigation expansion and crop yield (Hussain and Hanjra 2004; Burney, Naylor, and Postel 2013; Boris, Daniel, and Aslihan 2020) and have found the expansion of irrigation serves as a vital instrument for boosting crop yield and ensuring yield stability through the provision of water supply, particularly in regions prone to drought or experiencing unpredictable rainfall (Y. Yang, Wang, and Huang 2016; Y. Wang et al. 2018). Irrigation expansion also enables the adoption of more intensive agriculture production practices (Q. Huang et al. 2006), thereby enhancing the efficiency of land and other resource utilisation. Furthermore, the roles of irrigation expansion in raising farmers' incomes and reducing rural poverty have been documented by other studies (Q. Huang et al. 2005; Ravallion and Chen 2007; Hanjra, Ferede, and Gutta 2009).

However, the broader contributions of irrigation expansion to promoting rural development, beyond agricultural growth, have largely been overlooked (Huang 2018, 2020; J. Huang and Rozelle 2018). While the expansion of irrigation can significantly raise the productivity of all agricultural commodities, empirical investigation into its impact on crop diversification is still insufficient (Dawe 2015; J. Li et al. 2020). Moreover, there is no consensus on whether irrigation expansion has facilitated the transformation of rural labour employment from farm to non-farm sectors. Some scholars consider the increased income from irrigated agriculture has stimulated demand for non-agricultural products and services, thereby driving the shift of rural labour to non-farm employment (Bustos, Caprettini, and Ponticelli 2016; Emberick 2018). In contrast, other researchers suggest that the enhanced agricultural productivity due to irrigation expansion may reduce the motivation of rural labour to pursue non-farm job opportunities (Marchiori, Maystadt, and Schumacher 2012; Zaveri, Wrenn, and Fisher-Vanden 2020).

Understanding the nuanced interactions between irrigation expansion and rural transformation is critically important. On the one hand, the structural change in agriculture moving from less labour-intensive grain production to more labour-intensive cash crop, livestock and aquaculture production, promoted by the expansion of irrigation, could have profound implications for rural labour employment within agriculture and across farm and non-farm sectors. On the other hand, the impact of irrigation expansion may vary across different stages of rural transformation (J. Huang 2018), a hypothesis that lacks empirical evidence. It is particularly noteworthy that China has witnessed a marked rise in irrigation expansion over the past few decades, a period that has also coincided with rapid rural transformation (J. Huang and Shi 2021; Shi and Huang 2023). This occurrence serves as a compelling case study for exploring the relationship between irrigation expansion and rural transformation. It also presents policymakers with valuable perspectives for shaping irrigation-introduced transformation, as well as determining the optimal scale of irrigation investments at different stages of rural transformation.

To bridge the research gaps, this paper adheres to the conceptual framework proposed by J. Huang (2018), and uses Chinese statistical data to identify the role of irrigation expansion throughout the distinct stages of rural transformation, with a focus on both agriculture production and rural labour employment. To our knowledge, this study is the first to quantitatively estimate the dynamic relationship between the expansion of irrigation and the evolution of rural transformation. The structure of this paper is organised as follows: Section 2 introduces the dataset used for the empirical analysis. Section 3 outlines the model specifications and presents the econometric results. Section 4 discusses the policy implications and provides guidance for future academic research.

2 | Data and Descriptive Analysis

2.1 | Data

Prior to examining the relationship between irrigation expansion and rural transformation, it is necessary to articulate a clear definition of rural transformation to underpin data collection. Among many dimensions of rural transformation (D. Wang et al. 2023), the literature within the field of agricultural economics and development economics (e.g., IFAD 2016; FAO 2017; Otsuka and Zhang 2021) has primarily focused on two key aspects: the transition in agriculture production moving from grain-based to non-grain or high-value commodities, and the shift in rural labour employment from farm to non-farm sectors. Indeed, China has witnessed rapid rural transformation since 1978 (J. Huang 2020), where the structural change in agriculture production is often measured by the increasing share of non-bulk (J. Huang and Shi 2021) or non-grain (Shi and Huang 2023) commodities in agricultural output values, and the structural change in rural labour employment is typically evaluated by the expanding share of rural labour employed in non-farm sectors (deBrauw et al. 2002; Zhang et al. 2018; S. Li et al. 2021).

In this paper, we use the share of non-grain commodities in agricultural output values and the share of rural labour non-farm employment as indicators of rural transformation in China (Shi and Huang 2023). The data on agriculture production and output values, as well as rural labour employment, come from the Statistical Yearbooks of each province for relevant years. The data on farm-gate prices of grain are sourced from the Data Compilation on Production Cost and Benefit of Nationwide Agricultural Commodities annually. This dataset includes 27 out of the 31 provinces in mainland China, covering the period from 1978 to2022.[1] However, our analysis is narrowed to the 4 decades following the initiation of rural reform (1978–2018), with the objective of addressing the potential variability in policy impacts across different provinces. This is because China has implemented a land use policy restricting the shift of agriculture production from grain to non-grain commodities since the 2020/2021.

Based on this dataset, we calculated the output values of grain production (VG) using the farm-gate price and total production of grain. Then, we computed RT_1, or the output value share of high-value commodities in the total agricultural output values (TAV), using the formula (1-VG/TAV)*100. Given that high-value (or non-grain) commodities generally yield a higher output value (or profit) per unit of land than grain production, we will henceforth use the term 'high-value agriculture', including cotton, oil crops, sugar crops, vegetables, fruits, livestock and aquatic products, to distinguish it from grain-based agriculture. Moreover, we estimated the share of rural labour non-farm employment (RT_2) by using the total number of rural labourers and the portion engaged in farm activities. Notably, rural labourers' non-farm employment includes their employment in non-farm sectors both in urban and rural areas.

2.2 | Descriptive Analysis

2.2.1 | Irrigation Expansion

Irrigation has been a top priority in rural investment since the establishment of the People's Republic of China in 1949 (Fan, Cho, and Rue 2018; J. Wang et al. 2020). As shown in Panel A of Figure 1, the share of cultivated land with irrigation has generally increased across all provinces except Guangdong, with an average increase from approximately 35% to about 53% between 1978 and 2018. A detailed examination of Panel B reveals a downward trend in the total area of irrigated land in Guangdong, decreasing from around 3 million hectares in 1978 to less than 2 million hectares by 2018. This is primarily attributed to

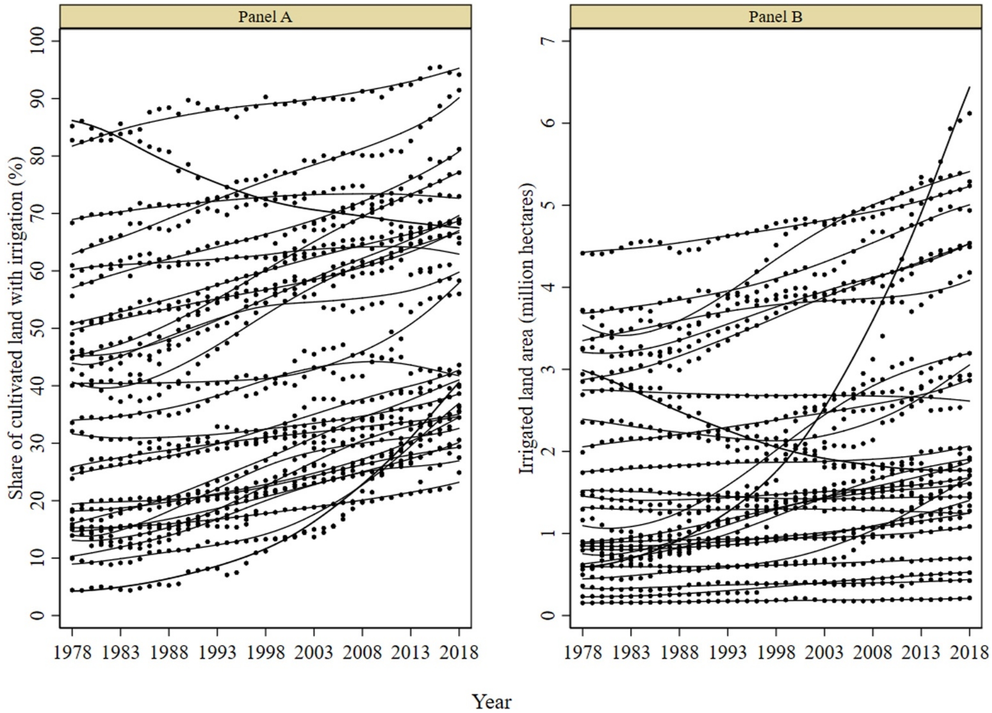

FIGURE 1 | Share of cultivated land with irrigation (Panel A) and irrigated land area (Panel B) by province in 1978–2018. We have utilised the Locally Weighted Scatterplot Smoothing (LOWESS) method to depict the expansion of irrigation at the provincial level. *Source:* Statistical Bureau of each province studied.

rapid urbanisation, which has encroached upon high-quality cultivated land equipped with irrigation facilities.

Over the same period, significant variation is observed in both the share of cultivated land with irrigation and the scale of irrigation coverage across provinces, as depicted in Figure 1. This variation is mainly due to China's vast size and the notable differences in rainfall and water availability from north to south and from west to east. The uneven distribution of precipitation across the country is predominantly influenced by the monsoon climate, resulting in abundant rainfall in the southeastern regions and arid conditions in the northwestern regions. These significant provincial disparities in the share of cultivated land with irrigation, coupled with its dynamic changes over time, provide a unique case study to explore the relationship between irrigation expansion and rural transformation.

2.2.2 | Path of Rural Transformation

As illustrated in Panel A of Figure 2, the average share of non-grain commodities in agricultural output values surged from roughly 50% in 1978 to about 86% by 2018. This upward trend has been nationwide, albeit to varying extents. A notable exception to this general pattern emerged only in one province, Jilin, in recent years. Here, a policy support programme aimed at raising maize and rice production was implemented by the local government (J. Huang and Shi 2021). The variation in the share of high-value agriculture among provinces is due to several factors. These include land scarcity or per capita cultivated land, water availability or share of cultivated land with irrigation, and market demand for both grain and non-grain commodities at a given time, as well as changes over time.

Panel B of Figure 2 shows the dynamic shift in the pattern of rural labour employed in non-farm sectors over the period of 1978–2018. On average, the share of rural labour non-farm employment has experienced a remarkable increase, expanding from a mere 7% in 1978 to almost 50% in 2018. However, this trend is marked by a considerable variation at the provincial level. For example, in 2018, the share of rural labour engaged in non-farm employment ranged from a low of 20% in Xinjiang to a high of 80% in Zhejiang. Such a wide-ranging disparity highlights the imbalance in economic growth and regional labour market development (Shi and Huang 2023).

2.2.3 | Stages of Rural Transformation

Numerous studies, including the seminal works by Weitz (1971) on the United States, Hayami (1985) on Japan, Timmer (2017) and J. Huang (2018) on Asian developing countries, have demonstrated that the evolution of rural transformation is marked by stage-specific characteristics. In a recent study, J. Huang (2020) categorised China's rural transformation into four distinct stages: the initial stage centres on the production of food grains; the second stage is characterised by substantial agricultural diversification; the third stage is notable for the rapid expansion of high-value agriculture and a significant increase in non-farm employment of rural labourers; the final stage aims for high-value and sustainable agriculture, as well as promoting integrated development between urban and rural areas.

Following Huang's segmentation, which closely ties to the growth of high-value agriculture and the expansion of non-farm employment of rural labourers, the evolutionary stages can be mapped against their corresponding time periods. The early stage extends

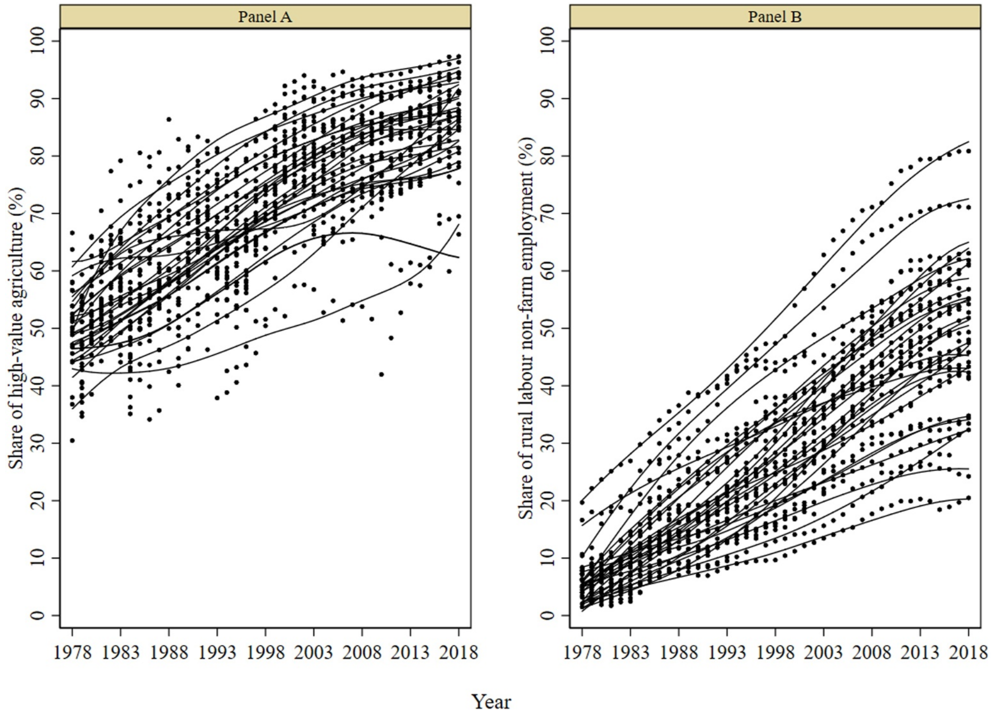

FIGURE 2 | Share of high-value agriculture (Panel A) and share of rural labour non-farm employment (Panel B) by province in 1978–2018. We have used the Locally Weighted Scatterplot Smoothing (LOWESS) method to illustrate the path of rural transformation at the provincial level. *Source:* Statistical Bureau of each province studied.

from 1978 to the late 1980s, which is marked by a dominance of food grain production and the majority of rural labour engaged in agricultural activities. During this stage, the share of high-value agriculture (RT_1) remained below 60% (Shi and Huang 2023), while the share of rural labour non-farm employment (RT_2) was less than 15% (X. Wang et al. 2011). The middle stage spans from the early 1990s to around 2005, where RT_1 increases to between 60% and 80% and RT_2 ranges from 15% to 40%. The later stage, roughly from 2005 to the present, is distinguished by RT_1 exceeding 80% and RT_2 surpassing 40% (Shi and Huang 2023). In this stage, the rural economy has shown a growing specialisation in either farming or non-farm employment.

In accordance with our classification (Figure 3), the majority of provinces were in the middle and later stages of rural transformation throughout most of the observation period, with only a few provinces in the early stage during certain years. Furthermore, there exists a pronounced distinction among the stages of rural transformation in terms of both RT_1 and RT_2. As shown in Table 1, the mean value for RT_1 is 52% in the early stage, increases to 71% in the middle stage, and achieves a high of 86% in the later stage. Similarly, RT_2 averages 9% in the early stage, rises to 27% in the middle stage, and reaches 51% in the later stage.

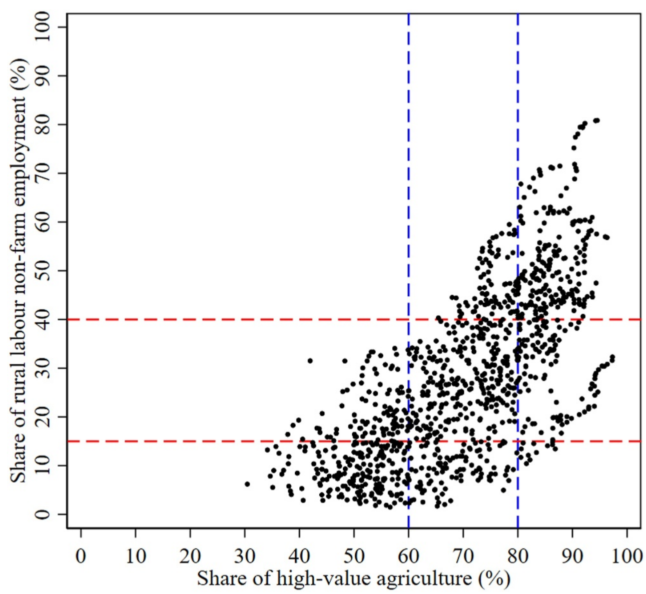

FIGURE 3 | Stages of rural transformation based on share of high-value agriculture and share of rural labour non-farm employment in 1978–2018. The horizontal axis, with 60% and 80% as the dividing lines, indicates the stages of RT_1. The vertical axis, with 15% and 40% as the dividing lines, indicates the stages of RT_2. *Source:* Statistical Bureau of each province studied.

3 | Empirical Models and Results

3.1 | Model Specification

We have employed provincial fixed-effects (FE) models to quantitatively investigate the relationship between irrigation expansion and rural transformation, as these models have the advantage of controlling for regional differences that remain constant over time. To reduce the endogeneity of our major concern variable, we have further introduced a 1-year lagged variable of *I* (the share of cultivated land with irrigation).[2] Although this approach does not fully solve the endogenous

TABLE 1 | Average level of rural transformation for each stage in 1978–2018.

Stage	RT_1 (%)	RT_2 (%)
Early stage	52	9
Middle stage	71	27
Later stage	86	51

Note: Authors' calculation.

problem, our aim is to examine the correlation between irrigation expansion and rural transformation, rather than the causal impact. Moreover, we have controlled for other major factors that may affect RT_1 and RT_2, including the relative prices of non-grain commodities or high-value agriculture to grain (P), as well as the wages for rural labour non-farm employment (W). Notably, the price variable influences farmers' choices between growing grain and non-grain commodities, and an increase in wages is expected to have a negative effect on RT_1 and a positive impact on RT_2. The model specifications have also included the per capita cultivated land (L), as grain production is more land-intensive than high-value agriculture. We anticipate that a higher per capita cultivated land will negatively affect RT_1 and positively influence RT_2. Based on the above discussions, the statistics results are summarised in Table 2, and we have formulated the econometric models as follows:

$$\mathrm{RT_{kit}} = \alpha_1 I_{i(t-1)} + \alpha_2 P_{i(t-1)} + \alpha_3 W_{i(t-1)} + \alpha_4 L_{it} + \nu_i + \varphi_t + \varepsilon_{it} \quad (1)$$

where, $\mathrm{RT_{kit}}$ donates RT_1 ($k = 1$) or RT_2 ($k = 2$) for province i in year t; the key explanatory variable $I_{i(t-1)}$ is measured by the share of cultivated land with irrigation for province i in year t−1; P is the producer price index for high-value commodities relative to grain[3]; W is the annual wages for rural labour engaged in non-farm employment,[4] both P and W are lagged 1 year; ν and ϕ are included to capture the unobservable but invariant factors within provinces and across different years, respectively.

To examine whether the dynamics between irrigation expansion and rural transformation evolve throughout rural transformation, Equation (2) has been augmented with an interaction term between $I_{i(t-1)}$ and the stage dummy variables ($R_k D_{ij}$). Here, $R_k D_{ij}$ indicates the stage of $\mathrm{RT_k}$, signifying whether province i is in the early stage ($j = 1$), middle stage ($j = 2$) or later stage ($j = 3$) of rural transformation. If the coefficients δ_2 corresponding to the interaction term is statistically significant, it would provide evidence in favour of the sequential hypothesis.

$$\mathrm{RT_{kit}} = \delta_1 I_{i(t-1)} + \delta_2 I_{i(t-1)} * R_k D_{ij} + \delta_3 P_{i(t-1)} + \delta_4 W_{i(t-1)} + \delta_5 L_{it} + \nu_i + \varphi_t + \eta_{it} \quad (2)$$

3.2 | Empirical Results

The estimation results are presented in Table 3 for high-value agriculture (RT_1) and in Table 4 for non-farm employment of rural labourers (RT_2). Column (1) reveals the overall relationship between irrigation expansion and rural transformation, while column (2) examines whether this relationship varies across different stages of rural transformation. In general, all model specifications show a strong fit with the dataset, with R-squared values ranging from 0.884 to 0.933 in Tables 3 and 4. The coefficients associated with the irrigation variable are predominantly statistically significant, and the signs of the coefficients for the control variables (e.g., price, wage, and land) are consistent with expectations.

Column (1) of Table 3 reveals a positive correlation between the expansion of irrigation and the growth of high-value agriculture throughout the period of rural transformation from 1978 to 2018. Specifically, the coefficient for I_{t-1} is 0.06 and statistically significant at the 10% level. This suggests a one percentage point increase in the share of cultivated land with irrigation is associated with a 0.06 percentage points increase in the share of non-grain commodities in agricultural output values.

Interestingly, the relationship between irrigation expansion and high-value agriculture varies among different stages of RT_1, as shown in Column (2) of Table 3. Notably, the coefficient for I_{t-1} is −0.09 and highly significant at the 1% level, suggesting that for a one percentage point increase in the share of cultivated land with irrigation in the early stage, there is a corresponding 0.09 percentage points decrease in the share of non-grain commodities in agricultural output values. This decline pattern can be attributed to the pre-1990s policy in China that emphasised intensifying grain production to eliminate hunger, where irrigation expansion was primarily aimed at boosting grain yields rather than promoting high-value agriculture (J. Huang 2020). While the coefficients for the interaction terms are positive, with values of 0.16 ($I_{t-1} * R_1 D_2$) and 0.21 ($I_{t-1} * R_1 D_3$), respectively, this implies that, after accounting for other major factors, each additional percentage point rise in the share of cultivated land with irrigation is associated with a 0.07 (0.16–0.09) percentage points increase in the middle stage and a 0.12 (0.21–0.09) percentage points increase in the later stage. The increasingly important role of irrigation expansion in facilitating the shift from grain-based agriculture to more high-value agriculture is due to the following two points: Firstly, the ongoing surge in grain productivity after the early stage of rural transformation enables the allocation of limited land and water resources to the production of high-value commodities as irrigation coverage expands. This shift has underpinned a more substantial growth of high-value agriculture in China (J. Huang and Shi 2021). Secondly, high-value commodities (e.g., horticulture, animal husbandry, and aquaculture), are more water-intensive and more profitable (ADB 2012; McCord et al. 2015), leading farmers to develop high-value agriculture in areas with advanced irrigation systems (Y. Li and Wang 2009; Qian, Rao, and Liu 2022).

In Table 3, the coefficients for the control variable P_{t-1} are positive and statistically significant at the 5% level across columns (1) and (2). This indicates that a rise in the relative price of high-value commodities over grain incentivises farmers to allocate more resources towards high-value agriculture. Additionally, the negative coefficient for W_{t-1} is consistent with expectations. This is because the production of high-value commodities typically demands greater labour input than grain production. As wages for non-farm employment increase, the opportunity cost for rural labour involved in labour-intensive high-value agriculture production rises, prompting a shift in

TABLE 2 | Variables definitions and statistical summaries.

Variables	Variable definitions	Mean	S.D.
RT_1	Share of non-grain commodities in agricultural output values (%)	70.2	14.3
RT_2	Share of rural labour non-farm employment (%)	28.2	17.1
I_{t-1}	Share of cultivated land with irrigation (%), lagged 1 year	43.3	22.3
R_1D_1	1 if early stage based on RT_1, 0 otherwise	0.27	0.45
R_1D_2	1 if middle stage based on RT_1, 0 otherwise	0.43	0.50
R_1D_3	1 if later stage based on RT_1, 0 otherwise	0.30	0.46
R_2D_1	1 if early stage based on RT_2, 0 otherwise	0.28	0.46
R_2D_2	1 if middle stage based on RT_2, 0 otherwise	0.45	0.50
R_2D_3	1 if later stage based on RT_2, 0 otherwise	0.26	0.44
P_{t-1}	Producer price index for non-grain commodities relative to grain, lagged 1 year	0.9	0.2
W_{t-1}	Annual wages for rural labour engaged in non-farm employment (1000 yuan at 2018 prices), lagged 1 year	18.2	13.9
L	Per capita cultivated land (hectare)	0.14	0.10

Note: Authors' calculation; There are a total of 1107 samples.

TABLE 3 | Estimation results for the relationship between irrigation expansion and high-value agriculture (RT_1).

	(1)	(2)
I_{t-1}	0.06*	−0.09***
	(0.03)	(0.03)
I_{t-1} * R_1D_2		0.16***
		(0.01)
I_{t-1} * R_1D_3		0.21***
		(0.01)
P_{t-1}	2.17**	1.89**
	(0.87)	(0.75)
W_{t-1}	−0.08*	−0.14***
	(0.04)	(0.04)
L	−28.51**	−32.80***
	(11.10)	(9.58)
Constant	48.02***	54.62***
	(2.55)	(2.28)
Province FE	Yes	Yes
Year FE	Yes	Yes
R-squared	0.884	0.915

Note: A total of 1080 samples were used in the regression model. Standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

TABLE 4 | Estimation results for the relationship between irrigation expansion and non-farm employment of rural labourers (RT_2).

	(1)	(2)
I_{t-1}	−0.09**	−0.09***
	(0.04)	(0.03)
I_{t-1} * R_2D_2		0.04***
		(0.01)
I_{t-1} * R_2D_3		0.17***
		(0.01)
P_{t-1}	−0.93	0.03
	(0.92)	(0.81)
W_{t-1}	0.41***	0.27***
	(0.05)	(0.04)
L	84.92***	60.88***
	(11.66)	(10.41)
Constant	−5.67**	−1.71
	(2.68)	(2.38)
Province FE	Yes	Yes
Year FE	Yes	Yes
R-squared	0.913	0.933

Note: A total of 1080 samples were used in the regression model. Standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

farm activities towards more grain production. Finally, the negative coefficient for L implies that farmers with larger land holdings or farm sizes are more inclined to produce land-intensive crops such as grain, whereas those with less land are more likely to transition to labour-intensive commodities such as vegetables, fruits, and livestock. Furthermore, as the amount of per capita cultivated land increases, labour-intensive high-value agriculture production may face greater household labour constraints, potentially motivating farmers to opt for land-intensive grain production instead.

Table 4 reports the empirical results concerning the relationship between irrigation expansion and non-farm employment of rural labourers. In parallel with the structure of Table 3, column (1) indicates that the share of rural labour non-farm employment is negatively correlated with the share of cultivated land with irrigation over the period of rural transformation from 1978 to 2018. The underlying cause of this correlation is the connection between the expansion of irrigation and the growth of high-value agriculture (Table 3). Therefore, as irrigation expands and the demand for agricultural labour intensifies, the supply of rural labour for non-farm sectors diminishes accordingly.

The results in column (2) of Table 4 reveal a significant change in the negative relationship between irrigation expansion and non-farm employment of rural labourers across the stages of rural transformation. In particular, the coefficient for I_{t-1} is −0.09, which is statistically significant at the 1% level. This indicates that in the early stage of rural transformation, for a one percentage point increase in the share of cultivated land with irrigation, there is a corresponding 0.09 percentage points decrease in the share of rural labour non-farm employment. As rural transformation progresses into the middle and later stages, the coefficients for the interaction terms of irrigation are 0.04 ($I_{t-1} * R_2D_2$) and 0.17 ($I_{t-1} * R_2D_3$), respectively, and both of which are statistically significant at the 1% level. These results imply that an additional percentage point increase in the share of cultivated land with irrigation is associated with a decrease of 0.05 (0.09–0.04) percentage points in the share of rural labour non-farm employment in the middle stage, but the negative relationship shifts to be positive, with an increase of 0.08 (0.17–0.09) percentage points in the later stage. Two possible explanations emerge for the evolving role of irrigation expansion in non-farm employment of rural labourers. Firstly, as rural transformation advances to the middle and later stages, the adoption rate of agricultural mechanisation significantly increases over time (X. Wang et al. 2016; Yi et al. 2019; J. Huang 2020), which helps to alleviate the labour demand pressure in irrigated agriculture. Secondly, because the expansion of irrigation has enhanced agricultural productivity, it may have released labour resources within the agricultural sector (Fan and Zhang 2004; J. Li et al. 2020; Luo, Luo, and Wang 2020), thereby promoting the transfer of rural labourers from farm to non-farm sectors.

The coefficients for the control variables in columns (1) and (2) of Table 4 are also as expected. Apart from P_{t-1}, all other control variables are statistically significant. For example, the coefficients for W_{t-1} are positive and reach the statistical significance of the 1% level, indicating that an increase in non-farm wages in the labour market has acted as a magnet, attracting more rural labour to seek non-farm employment (H. Li et al. 2012; J. Yang et al. 2016; M. Huang and Li 2019). Furthermore, the coefficients for L are positive and highly significant at the 1% level. As farm sizes expand, the shortage of labour becomes more pronounced, which the rise of agricultural mechanisation serves as an efficient solution to this challenge (Ji, Wang, and Zhong 2013) and simultaneously fosters the shift of rural labour towards non-farm sectors.

4 | Conclusions and Policy Implications

The existing literature has recognised the significant role of irrigation expansion in facilitating rapid and inclusive rural transformation in China (J. Huang 2022), but empirical research on this topic is relatively limited. Utilising statistical data from 27 provinces spanning 1978–2018, we have investigated the relationship between irrigation expansion and high-value agriculture, as well as non-farm employment of rural labourers, while accounting for other significant factors such as agricultural prices, non-farm wages for rural labour, and per capita cultivated land. Empirical findings demonstrate that the growth of high-value agriculture is positively associated with the increase in irrigation coverage. However, during the early stage of rural transformation (RT_1), irrigation expansion tends to boost grain production more than high-value agriculture. As RT_1 advances into its middle and later stages, and as rising grain production and rural hunger are largely eliminated in China, the sustained expansion of irrigation has facilitated a reallocation of water and land resources towards high-value agriculture production. This transformation within agriculture has led to increased income for farmers, given that high-value agriculture is both more labour-intensive and economically rewarding compared to traditional grain cultivation. Furthermore, our paper highlights a significant negative correlation between the expansion of irrigation and the shift of rural labour towards non-farm sectors. However, from a dynamic perspective, this inverse relationship progressively diminishes throughout the transition from the early to the middle stages of rural transformation (RT_2). Ultimately, the correlation turns positive in the later stage. The diminishing negative relationship between irrigation expansion and rural labour non-farm employment is largely attributed to the significant enhancement in agricultural productivity, which mitigates labour constraints. Additionally, the widespread adoption of agricultural mechanisation serves as an effective substitute for agricultural labour.

Several implications for both policymakers and researchers can be summarised as follows. Firstly, beyond the well-recognised roles of irrigation expansion in promoting grain production and agricultural productivity, this paper further emphasises the significant contribution of irrigation expansion to the shift from grain-based agriculture to high-value agriculture. Although irrigation may not favour the growth of high-value agriculture in the early stage of rural transformation, sustained investment in irrigation, in the long run, helps to enhance agricultural productivity, shorten the duration of stagnation in the early stage, and further promote high-value agriculture in the later stages. Therefore, the government should continue investing in irrigation. Secondly, the expansion of irrigation, especially for labour-intensive high-value agriculture, provides an effective strategy for addressing the prevalent issue of underemployment among agricultural labourers. Moreover, as rural transformation progresses, the increased demand for labour in high-value agriculture can be offset by advancements in agricultural mechanisation, which in turn releases rural labour for non-farm employment. Thirdly, further investigation into the causality between irrigation expansion and rural transformation, with a specific focus on high-value agriculture and non-farm employment of rural labourers, is needed. While this study has controlled for key factors to explore the correlation, a more detailed examination using household-level data is essential to understand the impacts of irrigation expansion on rural transformation and rural inclusion (e.g., identifying who benefits most). Finally, in addition to focusing on irrigation investment, it is crucial to evaluate the impacts of other major institutions, policies, and investments (or IPIs) on the speed of and outcomes (e.g., income, equity, and sustainability) of rural transformation. On the one hand, achieving successful rural development and the long-term goal of common prosperity through rural transformation requires a comprehensive understanding of which driving forces are effective. On the other hand, investigating the transformative roles of other IPIs throughout the process of rural transformation is equally important, not just for China but for many other developing countries as well.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Endnotes

[1] Our analysis excludes the three municipalities of Beijing, Tianjin and Shanghai, as the agricultural sector's economic contribution is relatively marginal. Tibet is also excluded owing to the unavailability of data for the estimation of all variables used in this study.

[2] We have also conducted econometric analyses with a 2- or 3-year lag for the share of cultivated land with irrigation (I), and the results remained robust and consistent.

[3] The producer price index (PPI)_of non-grain commodities is calculated by adjusting the PPI for all agricultural products, using the share of grain commodities in agricultural output values as the weighting factor.

[4] The annual wages for rural labour engaged in non-farm employment in different provinces are collected from China Population & Employment Statistical Yearbook each year and deflated by the consumer price index (CPI).

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