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Farmland Leasing, misallocation Reduction, and agricultural total factor Productivity: Insights from rice production in China

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ABSTRACT

Reducing factor misallocation is crucial for enhancing agricultural aggregate total factor productivity (TFP) and narrowing the income gap between urban and rural areas in China. This paper presents a theoretical framework illustrating how farmland leasing affects aggregated TFP via the reduction of misallocation. Utilizing a comprehensive dataset of cost and benefit survey for Jiangsu rice farmers, monthly surface climatological data, and soil characteristic information from FAO, this study finds that efficient factor reallocation could theoretically result in a 23.6% increase in aggregate TFP. In practice, a 1% increase in farmland leasing leads to a 1.087% gain in aggregate TFP and a 0.267% reduction in misallocation using IV regression. These effects become larger after the Three Rights Separation (TRS) reform compared to prior conditions. The mediation effects of farmland leasing on TFP through misallocation reduction are only observed in Southern Jiangsu, possibly due to farmland concentration.

1. Introduction

Input misallocation offers new perspectives for understanding the substantial disparities in agricultural labor productivity across countries. The gaps in labor productivity between developing and developed countries are considerably more pronounced in agriculture than in non-agriculture sectors (Restuccia et al., 2008; Lagakos and Waugh, 2013; Gollin et al., 2014; Gollin and Udry, 2021). A critical question arises: Why is agricultural labor productivity so low in developing countries? Numerous studies have focused on differences in technology, technical efficiency, and aggregate inputs (Schultz, 1953; Restuccia et al., 2008; Gollin et al., 2021; Sun et al., 2021). Adamopoulos and Restuccia (2014) offered an alternative view, emphasizing that input misallocation across farmers accounts for three-quarter of international agricultural labor productivity disparities. This input misallocation among producers significantly reduces labor productivity by lowering aggregate total factor productivity (TFP) (Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009; Gollin and Udry, 2021).

Rural institutions are among the most significant contributors to input misallocation in developing countries (Adamopoulos and Restuccia, 2014). Growing evidence suggests that mobility barriers, pro-small land policies, and insecure property rights for land are more common in developing countries, distorting the allocation of inputs to more productive farmers (Adamopoulos and Restuccia, 2014; de Janvry et al., 2015; Chen, 2017; Gottlieb and Grobovšek, 2019; Ngai et al., 2019; Gollin et al., 2021; Sun et al., 2021). Similar institution-induced input misallocation has been observed in China, with distortions arising from the farmland system receiving the most attention (Adamopoulos et al., 2022; Chari et al., 2021; Gai et al., 2017, 2020; Gao et al., 2021; Yang, 1997; Zhang et al., 2019b).

China is implementing the Three Rights Separation (TRS) reform to promote market-oriented farmland leasing and reduce misallocation stemming from the Household Responsibility System (HRS). Although the HRS fostered agricultural growth, it led to misallocation between farm size and farmers' managerial ability due to the egalitarian farmland allocation. Since the 1980 s, the Chinese government has attempted to reduce misallocation through farmland leasing. However, communal farmland property only grants farmers usage rights without guaranteeing transfer rights (Chari et al., 2021; Adamopoulos et al., 2022). China's farmland rental markets remained limited until the 2014 TRS reform, which separated operational rights from contract rights while maintaining collective ownership rights. Farmers can now rent out operational rights while retaining contract rights during the contract period. The TRS reform both stabilizes contract rights for farmers and

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liberalizes operational rights over their farmland. Consequently, farmland rental activities have increased, and farmland has been redistributed from less productive to more productive farmers (Gao et al., 2021; Adamopoulos et al., 2022).

This study aims to determine the extent to which agricultural aggregate TFP could increase if the input misallocation were entirely eliminated, and whether farmland leasing enhances agricultural aggregate TFP through the mediation of input misallocation reduction. Additionally, this paper examines the differences in TFP gain and misallocation reduction from farmland leasing before and after the TRS reform in rural China. The paper first develops a theoretical framework to comprehend the relationship between farmland leasing, input misallocation, and agricultural aggregate TFP. Secondly, it utilizes an integrated dataset comprising cost and benefit surveys for rice farmers in Jiangsu, monthly surface climatological data, and soil characteristics data from the Food and Agriculture Organization (FAO) to explore the impact of farmland leasing on aggregate TFP and its underlying mechanism. Lastly, based on the empirical findings, the paper proposes policy implications to mitigate input misallocation in China's agricultural sector and narrow the income disparity between rural and urban areas, as well as with affluent countries.

Previous literature has shed light on the impact of farmland leasing on agricultural productivity and misallocation. Chari et al. (2021) observed that the implementing of the Rural Land Contracting Law led to farmland reallocation toward more productive farmers, resulting in 8% and 10% increase in agricultural output and aggregate productivity using national fixed-point survey data. Gao et al. (2021) reached a similar conclusion that farmland certification initiated in 2008 significantly reduced input misallocation across farmers and increased agricultural output in rural China, drawing from the Chinese Family Database. Zhang et al. (2020) focused on renting farmland rather than institution reform and found that it raised households' labor productivity by 43% using data from the China Family Panel Studies dataset. Adamopoulos et al. (2022) served as the closest antecedent to this paper in terms of theoretical modeling, revealing that reallocating farmland and labor within villages, across villages, and between sectors could enhance agricultural aggregate TFP by 24.2%, 53.2% and 1.7-fold, respectively. Their findings suggest that the scope of input reallocation considerably influences TFP gains and that labor reallocation yields greater TFP gains than that farmland reallocation.

This paper enhances the existing literature in three aspects. Firstly, while several studies have investigated the effects of the 2003 Rural Land Contracting Law and the 2008 farmland property certification program on input misallocation and agricultural productivity, limited knowledge exists regarding the impacts of farmland leasing, particularly after TRS reform, on TFP gain and misallocation reduction. The TRS reform signifies the establishment of a new farmland institution in rural China, and alleviates farmers' concerns over losing their farmland, and permits contracted farmers to retain contract rights and lease out operational rights. Encouraging farmland leasing is a primary objective of both the Rural Land Contracting Law and the farmland certification program. Consequently, this paper develops a theoretical framework to delineate the relationship between farmland leasing, input misallocation, and aggregate TFP. We calculate the aggregate TFP gain from factor-efficient reallocation theoretically and assess the impact of farmland leasing on aggregate TFP in practice.

Secondly, existing literature has not directly analyzed the potential mechanism through which farmland leasing affects agricultural productivity. This paper employs a mediation analysis model to study the pathway by which farmland leasing influences aggregate TFP via misallocation reduction. Thirdly, measurement error, production shock, and farmland characteristics may result in inaccurate estimations of farm-level TFP and distortion (Gollin and Udry, 2021; Gollin et al., 2021; Adamopoulos et al., 2022). This paper combines cost and benefits data for rice farmers in Jiangsu province from 2004 to 2016 with monthly surface climatological data and soil characteristics information from FAO, leveraging the panel structure of our integrated dataset to precisely estimate farm-level TFP and pure distortion.

The remainder of this paper is organized as follows: Section 2 provides an overview of China's farmland institution reform; Section 3 establishes the theoretical framework for farmland leasing, input misallocation and aggregate TFP; Section 4 presents the empirical models and summary statistics; Section 5 reports TFP gains from efficient factor reallocation and explores the impact of farmland leasing on aggregate TFP and the mediating pathway through misallocation reduction; and finally, Section 6 concludes and offers policy implications.

2. Background

The land institution plays a crucial role in rural China as it determines the allocation of land and its output among farmers. The HRS, established in the late 1970 s, significantly increased incentives for farmers to claim the residual and led to a substantial increase in output by extending contract rights from tenure rights over farmland to rural households for 15 years (Lin, 1992). However, the HRS reform resulted in the equal redistribution of farmland to farmers and led to misallocation between farm size and farmers' managerial ability (Yang, 1997; Fan and Chan-Kang, 2005; Adamopoulos et al., 2022). Since the 1980 s, the Chinese government has attempted to promote farmland leasing as a means of increasing agricultural productivity. In 1984, Document No.1 was introduced, which proposed to encourage farmers with strong managerial ability to expand their farm size by renting in farmland. Subsequently, the Rural Land Contracting Law came into effect in 2003, providing legal protection for the transfer of farmlands.

Despite government support for farmland leasing, farmland rental markets remained limited after the HRS. In practice, village officials frequently reallocated farmland in response to demographic changes within their villages (Benjamin and Brandt, 2002). If a household rented out their farmland, village officials may have interpreted this as a signal that the household did not require the farmland, resulting in the prior reallocation of the farmland to households whose family members had increased (Yang, 1997). Administrative reallocation involved 75% of households and the majority of farmlands between 1983 and 1995 (Benjamin and Brandt, 2002) . Consequently, instead of renting out their farmland through farmland rental markets, farmers often invited their family members or close relatives to operate their farmland to avoid losing it (Huang and Ding, 2016; Brandt et al., 2004). Under this context, the limited scope for farmland rental activity cannot effectively reallocate farmland to the most productive farmers, and even have a crowding-out effect as more capable farmers choose to work off the farm for higher incomes, leaving behind a large fraction of women and elderly people in rural China. This situation resulted in an inability to allocate farmland to the most productive farmers, contributing to low aggregate TFP and productivity (Chen, 2018; Liu and Li, 2017).

The No.1 Document of 2008[1] initially proposed implementing a farmland certification program to provide stable contract rights for farmers and to halt farmland administrative reallocation. Subsequently, the Central Rural Working Conference in December 2013 further advanced the idea of separating operational rights from contract rights. In 2016, the central government issued a policy on enhancing TRS reform. This new phase of farmland institutional innovation divided farmland property rights into three components: ownership right, contract right, and operational right. First, according to the Constitution of China, farmland ownership rights belong to the rural collective. All farmers who are collective members can be granted land through a

[1] The Communist Party of China often at the beginning of the year publishes an agricultural policy document laying out the main policies for the whole year. Hence it is often called the No.1 Document showing the Party places more emphasis on agriculture and food production.

contract between the farmers and the collective. The first round of farmland contracts commenced in 1983 and concluded around 1998. With some adjustment, the second round began immediately, extending contract rights to 30 years in 1993 and further extending them to 30 years in 2021. Second, farmers with contracted land possess contract rights. Finally, farmers who legally operate farmland hold operational rights.

Driven by TRS reform, the farmland rental market became more active, with rented farmland areas in China accounting for 41% of the total areas by the end of 2020. More specifically, numerous local farmland rental markets have emerged, and a substaintial amount of farmland has been transferred to new operators, such as family farms, farmers' professional cooperatives, and agricultural firms, rather than family members or close relatives (Huang and Ding, 2016; Zhang et al., 2019b). Additionally, fragmented farmland is often consolidated by the farmland rental market before being rented to new operators. Farmland operational rights leases driven by TRS reform not only direct farmland towards more productive operators but also improve farmland quality by addressing the long-standing issue of farmland fragmentation (Hong and Wang, 2019).

3. Theoretical framework

We develop a theoretical framework to briefly examine the relationship among farmland leasing, input misallocation and aggregate TFP based on the works of Hsieh and Klenow (2009) and Adamopoulos et al. (2022). We assume that a farmer i use the farmland l_{it} and labor c_{it} to produce grains in year t. Our theoretical model only considers the inputs of farmland and labor because the capital share (particularly the inputs of own purchased machinery) of China's grain production is very low (Pang et al., 2005) and decrease with the development of agricultural outsourcing services (Ji et al., 2012; Ji, 2018). We aim to study input misallocation across farmers with heterogeneous farming abilities; thus, we incorporate a parameter of individual farming ability s_{it} for farmer i in year t into the production function. The Cobb-Douglas function exhibits decreasing returns to scale and is given as follows,

$$y_{it} = (As_{it})^{1-\gamma}\left(l_{it}^{\alpha}c_{it}^{1-\alpha}\right)^{\gamma} \tag{1}$$

where y_{it}, l_{it} and c_{it} respectively denote the yield, farmland input and labor input of grain for farmer i in year t. The TFP of farmer i in year t consists of a common productivity term A and individual farming ability s_{it}. α captures the relative importance of land to labor in grain production, and γ denotes the extent of returns to scale at the household level. Both α and γ take values between 0 and 1.

Farmland institutions play a crucial role in farmland and labor allocation in rural China. Therefore, following the work of Hsieh and Klenow (2009), we define the distortions that raise the marginal products of farmland and labor by the same proportion as farmer i's output distortion τ_{it}^{y} in year t. For example, τ_{it}^{y} would be high for farmer i who is limited in expanding farm size in year t. The higher τ_{it}^{y} is, the lower output farmer i would harvest in year t. In turn, we denote distortions that increase the marginal product of farmland relative to labor as farmer i's farmland price tax τ_{it}^{l} in year t. For example, τ_{it}^{l} would be high if farmer i faces high transaction cost to rent in farmland, and thus the price of farmland relative to labor would increase. Both τ_{it}^{y} and τ_{it}^{l} take the value between 0 and 1, and 0 means no distortion. Farmer i uses farmland and labor inputs along with distortion to maximize their profit. Farmer i's profit function in year t is as follow,

$$\max_{l_{it},z_{it}}\left\{\pi_{it} = (1-\tau_{it}^{y})p_t y_{it} - \left(1+\tau_{it}^{l}\right)r_t l_{it} - w_t c_{it}\right\} \tag{2}$$

where π,p_t,r and w are farmer i's profit, grain price, rental price of farmland, and wage for labor, respectively. Equation (2) shows that output distortion would result in a decrease in grain output, and farmland price tax would increase the actual rental price of farmland. We can derive the analytical expression for farmer i's input demand of farmland and labor from the first-order conditions of profit maximization,

$$l_{it} = As_{it}(1-\tau_{it}^{y})^{\frac{1}{1-\gamma}}p_t\gamma^{\frac{1}{1-\gamma}}\left(1+\tau_{it}^{l}\right)^{\frac{\gamma(1-\alpha)-1}{1-\gamma}}\left(\frac{\alpha}{r_t}\right)^{\frac{\gamma(\alpha-1)+1}{1-\gamma}}\left(\frac{1-\alpha}{w_t}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}} \tag{3}$$

$$c_{it} = As_{it}(1-\tau_{it}^{y})^{\frac{1}{1-\gamma}}p_t\gamma^{\frac{1}{1-\gamma}}\left(1+\tau_{it}^{l}\right)^{\frac{-\alpha\gamma}{1-\gamma}}\left(\frac{\alpha}{r_t}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1-\alpha}{w_t}\right)^{\frac{1-\alpha\gamma}{1-\gamma}} \tag{4}$$

Equation (4) and (5) show that the allocation of farmland and labor is determined not only by individual farming ability s_{it}, but also affected by output distortion τ_{it}^{y} and farmland price tax τ_{it}^{l}. If distortions are entirely eliminated, a farmer with higher ability would command more inputs of farmland and labor. In other words, the inputs of farmland and labor would be strongly and positively correlated with individual ability in the absence of misallocation. However, farmlands were allocated among farmers on a highly egalitarian basis induced by HRS reform, resulting in no differences in farm size across farmers. Consequently, the distortion arising from the egalitarian-based allocation of farmland offsets the differences in farm size that would otherwise be determined by heterogeneous individual farming abilities. The TRS reform aims to reduce both the output distortion τ_{it}^{y} and farmland price tax τ_{it}^{l}, and will reassert the role of individual farming ability in farmland allocation. Specifically, unproductive farmers will lease out their farmland to more productive ones until the marginal product values of farmland and labor equalize across farmers. Therefore, farmland transfer induced by the TRS reform could reduce input misallocation across farmers.

In addition, following Hsieh and Klenow (2009) and Adamopoulos et al. (2022)'s works, this paper defines farmer i's distortion index in year t, induced by Chinese farmland institution, as the weighted average of marginal product values of farmland and labor,

$$D_{it} = \left[\frac{MRPl_{it}}{\alpha\gamma}\right]^{\alpha}\left[\frac{MRPc_{it}}{(1-\alpha)\gamma}\right]^{1-\alpha} = \frac{p_t y_{it}}{l_{it}^{\alpha}c_{it}^{1-\alpha}} \tag{5}$$

where $MRPl_{it} = \frac{r_t(1+\tau_{it}^{l})}{(1-\tau_{it}^{y})}$ and $MRPc_{it} = \frac{w_t}{(1-\tau_{it}^{y})}$ refer to the marginal product values of farmland and labor, respectively. The larger the marginal product value of farmland and labor, the larger the distortion index that farmer i faces indicating more substantial distortion. Furthermore, the expressions of $MRPl_{it}$ and $MRPc_{it}$ reveal that the marginal product values of farmland and labor do not equal the farmland rental price and wage due to output distortion τ_{it}^{y} and farmland price tax τ_{it}^{l}.[2]

Several studies have documented that input misallocation across producers can decrease aggregate TFP (Hsieh and Klenow, 2009; Restuccia and Rogerson, 2013; Adamopoulos and Restuccia, 2014; Adamopoulos et al., 2022). Therefore, this paper derives aggregate TFP at the township level by summing farm-level TFP while considering individual distortion as weight. The aggregate TFP is as follows,

$$TFP\_C_t = \left[A\sum_{i=1}^{N}s_{it}\left(\frac{\bar{D}_t}{D_{it}}\right)^{\frac{\gamma}{1-\gamma}}\right]^{1-\gamma} \tag{6}$$

where $\bar{D}_t$[3] is the weighted mean of farmers' distortion index at the township level in year t.[4] N denotes the number of farmers in the specific

[2] Here, we can get the inequality of $\alpha\gamma(1-\tau_i^{y}) < 1 < (1+\tau_i^{l})$ and $(1-\alpha)\gamma(1-\tau_i^{y}) < 1$ because the value of α , γ , τ_i^{y} and τ_i^{l} are all between 0 and 1. Distortion index reflects the extent to which the market price of input amplified by the distortion.

[3] $\bar{D}_t = \left[\sum_{i=1}^{M}\frac{y_{it}}{Y_t}\frac{r_t(1+\tau_{it}^{l})}{\alpha\gamma(1-\tau_{it}^{y})}\right]^{\alpha}\left[\sum_{i=1}^{M}\frac{y_{it}}{Y_t}\frac{w_t}{(1-\alpha)\gamma(1-\tau_{it}^{y})}\right]^{1-\alpha}$.

[4] we derives aggregate TFP on township level because we divided farming households into large, middle and small groups based on their sown areas on township level rather than village level and randomly select farmers from each group.

township. Equation (8) shows that the larger farmer i's distortion index, the smaller the weight. In general, more productive farmers face larger distortion; thus, they contribute a small part of aggregate TFP due to their reduced weight.

4. Empirical strategy and data

4.1. Measuring farmer's farming ability and distortion index

In order to accurately calculate aggregate TFP at township level and gains from input reallocation, we need to estimate farmer's farming ability and distortion index. The farm-level TFP and distortion index can be derived from equation (1) and equation (7), respectively.[5] However, the measured farm-level TFP and distortion index D_{it} may contain the effect of measurement errors and township-specific characteristics, which would amplify aggregate TFP gain from input reallocation and the actual distortions (Gollin and Udry, 2021; Adamopoulos et al., 2022). Therefore, we will extract farmer i's farming ability and pure distortion from farmer-level TFP and distortion index by partialing out the effects of measurement error and township-specific characteristics. We use a two-step process to estimate farming ability and pure distortion. First, we decompose the farm-level TFP to extract farmer fixed effect

$$\log TFP_{it} = \beta_0 + \beta_1 \log W_{it} + u_i^{TFP} + u_t^{TFP} + \varepsilon_{it} \tag{9}$$

where $\log TFP_{it}$ is the logarithm form of the measured farm-level TFP of farmer i in year t; $\log W_{it}$ is the vector of weather including temperature, precipitation, and sunshine duration; u_i^{TFP} is the farmer fixed effect;u_t^{TFP} is a year fixed effect that captures other time varying factors being common to all farmers; β_0 and β_1 are the parameters to be estimated;ε_{it} is the residual. We employ a fixed effect panel data model to estimate equation (9) and extract the farmer fixed effects. It is worth noting that the farmer fixed effects may encompass the effects of soil quality, elevation, and township-specific time-invariant factors, as they are collinear with the farmer fixed effect. In the second step, we regress the farmer fixed effect on soil quality, elevation and township dummies to isolate farming ability.

$$u_i^{TFP} = \psi_0 + \psi_1 \log Q_i + \psi_2 \log A_i + \lambda_j + s_i^{TFP} \tag{10}$$

where $\log Q_i$ and $\log A_i$ denote the logarithm form of soil quality and elevation; λ_j is the township dummies; s_i^{TFP} is the farming ability of farmer i; ψ_0, ψ_1 and ψ_2 are the parameters to be estimated. Following this procedure, we can also extract the pure individual distortion index u_i^D. We use the farmers' farming ability s_i^{TFP} to calculate aggregate TFP gains, and employ the pure individual distortion index to calculate aggregate TFP using equation (8).

4.2. Estimation strategy

The objective of this paper is to study the impact of farmland leasing on aggregate TFP and on the potential mechanism of input misallocation. Consequently, we need to estimate a mediation model in which farmland leasing influences input misallocation, which in turn affects aggregate TFP. Mediation analysis is widely used in various fields such as psychology, epidemiology, politics, and other social sciences (Jiang, 2022; MacKinnon et al., 2002). Baron and Kenny (1986) conducted seminal work, developing the causal steps approach to test the mediation effects. Additionally, MacKinnon et al. (2002) noted that the difference in coefficients approach and product of coefficients involving paths in path models have also been used in empirical studies. The difference in coefficients approach compares the coefficients of independent variable before and after adding the mediator into the regression, concluding there is a mediation effect if the coefficient of independent variable decreases after adding the mediator. MacKinnon et al. (2002) documented that the difference in coefficients approach suffered from high Type I error rates. Although the product of coefficients involving paths in path models has better statistical power, it holds an advantage in investigating correlation rather than causation (Jiang,

2022). Following Jiang (2022)'s recommendation, this paper employs an updated version of the causal steps approach to estimate the impact and mediating path of farmland leasing on aggregate TFP. The basic causal steps approach includes three equations and is shown as follows,

$$\log TFP\_C_{jt} = b_{10} + b_{11} LS\_C_{jt} + b_{12} \log W_{jt} + b_{13} \log M_{ijt} + \lambda_j + \lambda_t + \upsilon_{1jt} \tag{11}$$

$$\log D\_C_{jt} = b_{20} + b_{21} LS\_C_{jt} + b_{22} \log W_{jt} + b_{23} \log M_{jt} + \lambda_j + \lambda_t + \upsilon_{2jt} \tag{12}$$

$$\log TFP\_C_{jt} = b_{30} + b_{31} LS\_C_{jt} + b_{32} \log D\_C_{jt} + b_{33} \log W_{jt} + b_{34} \log M_{jt} + \lambda_j + \lambda_t + \upsilon_{3jt} \tag{13}$$

where $\log TFP\_C_{jt}$ refers to the logarithm form of aggregate TFP of township j in year t and is calculated by using equation (8); $\log D\_C_{jt}$ denotes the logarithm form of standard deviation of the pure individual distortion index for township j in year t; LS_C_{jt} is the variable of interest that measures farmland leasing, and is represented by the number share of farmers who rent in farmlands in township j in year t. $\log M_{jt}$ is the logarithm form of GDP per capital for township j in year t. $\log W_{jt}$,λ_j and λ_t are the same with the variables described previously. υ_{1jt},υ_{2jt} and υ_{3jt} are the random error terms;$b_{10} - -b_{13}$,$b_{20} - -b_{23}$ and $b_{30} - -b_{34}$ are the parameters to be estimated.

Jiang (2022) and MacKinnon et al. (2002) contended that the coefficients of $\log D\_C_{jt}$ and LS_C_{jt} in equation (13) might suffer from low statistical power due to their strong correlation. Consequently, Jiang (2002) proposed that applied economists should analyze mediation effects by estimating only equation (11) and (12), and paying more attentions to precisely estimating the casual effects of independent variable on dependent variable and mediators. Following this suggestion, the present paper focuses on estimating equation (11) and (12) to evaluate the impact and mediating path of farmland leasing on aggregate TFP.

LS_C_{jt} may be endogenous in equation (11) and (12) because farmer's decision on leasing in farmlands depends on some unobservable factors (e.g., the quality of the leased plots[6]), which affect the aggregate TFP and distortion. To address potential endogeneity issue, this paper employs a two-stage least square model (2SLS). In the first stage, the 2SLS model regresses farmland leasing on the instrumental variable (IV) and other exogenous variables, as shown in the following equation,

$$LS\_C_{jt} = c_0 + c_1 IV_{jt} + c_2 \log W_{jt} + c_3 \log M_{ijt} + \lambda_j + \lambda_t + \sigma_{jt} \tag{14}$$

where IV_{jt} is the IV for township j in year t. The county's grain commodity rate in the previous year, equivalent to the average proportion of grain for a farmer's own use in total production on county level, serves as the IV. A higher grain commodity rate indicates greater productivity for a farmer, who may then expand their farm size via farmlands leasing, thus increasing aggregate TFP. However, the average grain commodity rate in the previous year is unrelated to the quality of leased plots. The other variables retain their original meanings. Based on estimators in equation (14), we calculate the prediction of LS_C_{jt}, and replace LS_C_{jt} in

[5] Based on equation (1), we can derive that farmer level TFP equal to $(As_{it})^{1-\gamma} = \frac{y_{it}}{(l_{it}^{\alpha} c_{it}^{1-\alpha})^{\gamma}}$.

[6] Although we have farmland quality data on village level, we cannot observe the quality of each plot of leased farmland.

Table 1
Summary statistics of the selected variables.

Variable	Mean	Standard deviation	Minimum	Maximum
Yield per ha: tons	8.49	0.89	4.50	11.15
Land: ha	1.10	6.17	0.03	176.67
Labor: labor day	59.44	207.05	3.00	7020.00
Rice price: RMB per kilogram	1.67	0.16	1.24	2.16
Temperature: ℃	22.18	0.96	20.10	24.22
Precipitation: Millimeters	394.70	7602.94	21.60	166715.80
Sunshine duration: Hours	162.10	24.38	109.43	229.18
Soil quality [a]	1.47	0.66	1.00	4.00
Elevation: Meters	14.10	44.32	0.00	857.00
GDP per capital: RMB	36252.79	25322.56	4096.35	160663.20
Price indices for means of agricultural production	140.87	24.74	100.00	167.50

Notes: [a] Soil quality refers to the nutrient availability in soil, and it takes a value of 1 if there has no or slight limitations, a value of 2 if there has moderate limitation, a value of 3 if there has severe limitations, and a value of 4 if there has very severe limitations.

equation (11) and (12) with the prediction which is predicted on exogenous information.

4.3. Data

This paper combines cost and benefit data for Jiangsu rice farmers during 2004–2016 with the monthly surface climatological data and FAO soil characteristics data, using longitude and latitude for matching purposes. Jiangsu province ranks fourth in rice production in China, following Heilongjiang, Hunan and Jiangxi. In 2020, Jiangsu's rice production reached 19.7 million tons, accounting for 9.3% of China's total production. As one of the most developed provinces in both agriculture and non-agriculture sectors, Jiangsu exhibits a significant gap between its southern region and other areas. Consequently, the results and conclusions based on Jiangsu province offer valuable policy implications for other provinces.

The cost and benefit data for rice farms include farm size, yield, output value, pesticide cost, fertilizer quantity and cost, seed quantity and cost, irrigation cost, labor quantity and cost, and land cost on per unit area, as well as household head characteristics (e.g., age, education, and address). This dataset has been used to compile the China Agricultural Product Cost-Benefit Compilation and featured in several studies (Zhang and Yu, 2021; Hu et al., 2019; Zhang et al., 2019a; Zhang et al., 2019b). A stratified random sampling procedure ensures representativeness during the data collection process. More specifically, all rice planting counties from 13 cities are sorted by rice sown areas, and candidate counties are chosen by adding up each county's sown area in descending order until reaching 90% of total areas. Second, three to six townships in each sampling county are selected based on their rice sown areas and natural and economic conditions. Third, farming households in each township are divided into large, middle and small groups according to their sown areas, with at least one household chosen from each group to ensure a minimum of three townships and nine farming households per county. Selected households are surveyed for at least five consecutive years. Organizers annually replace unrepresentative households, but their share does not exceed 10% of the total surveyed households in that county. The final sample size comprises 4,317 observations, including 809 households from 171 townships in 39 counties.

There are 22 meteorological stations in Jiangsu from 2004 to 2016, we only match farming households with 17 stations based on distance. Soil characteristics data originates from the Harmonized World Soil Database, a collaboration 30 arc-second raster database created by FAO, IIASA, ISRIC-World Soil Information, Institute of Soil Science, Chinese Academy of Science, and the Joint Research Centre of the European Commission. We match soil characteristic with farming household using longitude and latitude information. Ultimately, we construct an integrated dataset encompassing cost and benefit data, monthly surface climatological data, and soil characteristics data.

Table 2
Aggregate TFP gains from eliminating misallocation.

Year	Within province	Within county	Within township
2004–2016	23.6%	12.4%	4.1%
Before TRS reform (2014)	27.3%	35.8%	7.4%
After TRS reform (2014)	11.1%	5.4%	3.0%

We deflate rice price and input price using the agricultural inputs price index, with 2004 as based year. Table 1 reports summary statistics for all variables. The average yield per ha for rice is 8.49 tons, and the mean farm size is 1.1 ha. Labor input averages 59.44 standard labor days, defined as a medium man aged 18–50 or a medium woman aged 18–45 working for 8 h. The average unit rice price is 1.67 RMB per kilogram. The temperature, precipitation, and sunshine duration represent mean values from May to November, which corresponds to Jiangsu's rice-growing season. Soil quality refers to nutrient availability, with value of 1, 2, 3, and 4 indicating no or slight limitations, moderate limitation, severe limitations, and very severe limitations, respectively. The mean soil quality value of 1.47 indicates favorable conditions for rice production in our sample. We also control for county-level GDP per capital in the regression analysis.

5. Empirical results

5.1. Distortion and aggregate TFP gains

To compute farm-level TFP—the residual of the production function in equation (1)—and distortion index using equation (7), we require values of the parameters γ and α. The values are $\gamma = 0.52$, implying a cost share of intermediate inputs of 0.48,[7] and $\alpha = 0.44$, reflecting the land cost share of 0.23, and labor cost share of 0.29. The low labor cost share in this paper compared to Adamopoulos et al. (2022) is due to the recent substitution of machinery outsourcing services for labor (Zhang et al., 2017). Factors like measurement error, land quality, weather condition, and unobserved township-specific factors may affect computed farm-level TFP and distortion index, as well as aggregate TFP gains. Hence, we extract permanent or pure farmer's TFP and distortion from farm-level TFP and distortion index using equation (9) and equation (10). Results show that precipitation has significantly impacts on measured farm-level TFP, while soil quality and elevation substantially influence farmer fixed effect. This underscores the necessity of accounting for measurement error. Estimation results can be found in Appendix A1.

[7] Intermediate input cost includes the cost of seed, fertilizer, pesticide, irrigation, machine outsourcing service, and some other costs. In addition, since intermediate inputs may also be distorted by farmland institution in rural China, we may underestimate the misallocation.

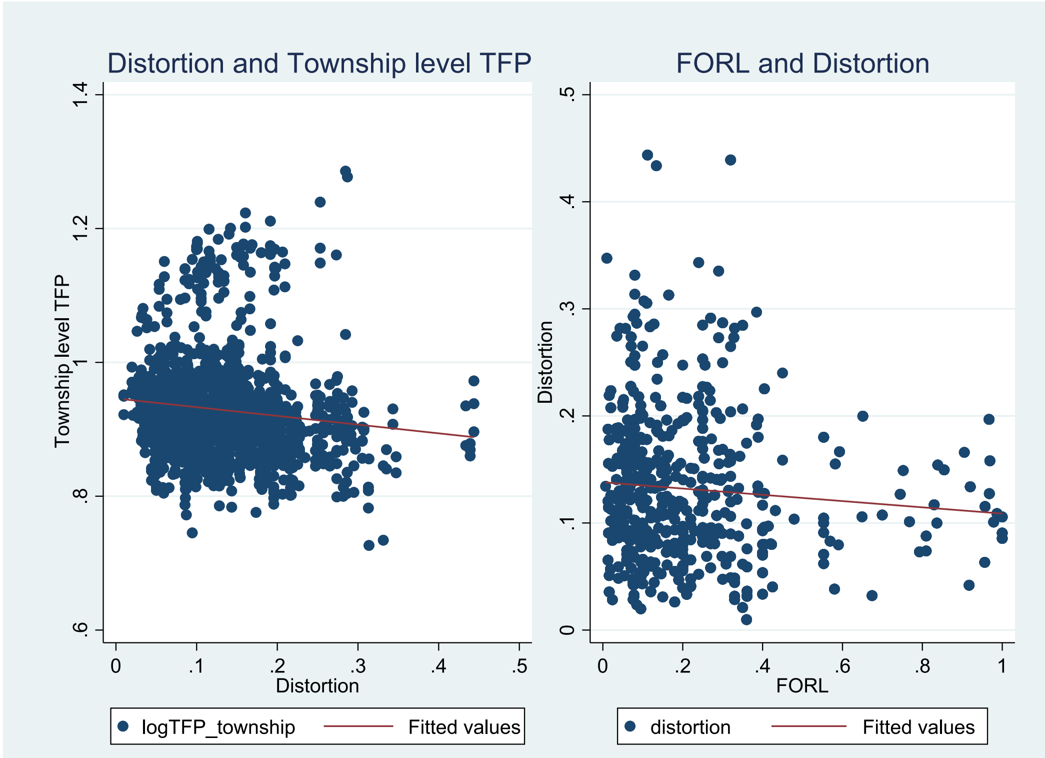

Fig. 1. Farmland leasing, Distortion and Township Level TFP.

Table 3
Impact of farmland leasing on aggregate TFP and the mediating path through distortion reduction on township level.

Variables	Aggregate TFP (Log)			Distortion (Log)		
	OLS	2SLS		OLS	2SLS	
	(1)	(2)	(3)	(4)	(5)	(6)
Farmland leasing	0.023***	0.837***	0.598**	−0.019*	−0.264**	−0.188*
	(0.006)	(0.238)	(0.288)	(0.010)	(0.122)	(0.111)
Farmland leasing × TRS reform			1.827*			−0.296*
			(0.950)			(0.168)
Temperature	−0.004*	−1.002*	−1.583*	0.207**	−0.258	0.376***
	(0.002)	(0.537)	(0.823)	(0.090)	(0.276)	(0.113)
Precipitation	0.096	0.011	0.015	0.004	0.004	−0.002
	(0.108)	(0.011)	(0.014)	(0.004)	(0.005)	(0.005)
Sunshine duration	−0.021	0.033	0.248*	−0.007	−0.035	0.012
	(0.016)	(0.067)	(0.148)	(0.014)	(0.034)	(0.029)
Per capital GDP	−0.038	−0.011	0.004	−0.044***	−0.052***	−0.063***
	(0.037)	(0.028)	(0.038)	(0.004)	(0.014)	(0.006)
Township fixed effects		Yes	Yes		Yes	Yes
Time fixed effects		Yes	Yes		Yes	Yes
Endogeneity test (P value)		0.000	0.000		0.014	0.000
Under identification		0.000	0.006		0.000	0.004
Weak identification test①		12.624②	5.729②		12.624②	5.729②
Observations	1400	1400	1400	1400	1400	1400

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses. ①It reports Cragg-Donald Wald F statistic. ②The value of the Stock-Yogo weak ID test critical value at 15% maximal IV size is 8.96 for Column (2) and (5), and is 4.58 for Column (3) and (6).

Using pure farmer's TFP, we calculate implied output gains or aggregate TFP gains[8] when misallocation is completely eliminated. We employ $Y^e = (A\bar{S})^{1-\gamma}(L^{\alpha}C^{1-\alpha})^{\gamma}$[9] to measure potential aggregate output under efficient land and labor allocation. Therefore, the output gains or aggregate TFP gains from efficient reallocation of land and labor equals to $Y^e/Y - 1$, and Y is the observed total output. Table 2 shows that eradicating misallocation across household farms within a province increases output or aggregate TFP by 23.6%. This result is higher than the 20% reported by Zhu et al. (2011) and 10% by Chari et al. (2020), who used data from 2003 to 2007 and 2003 to 2010 collected by the Chinese Ministry of Agriculture's Research Center of Rural Economy (RCRE). However, it is lower than the 36% found by Gai et al. (2017) using RCRE data from 2004 to 2013. Divergent results may stem from different methods for calculating output gains, distinct research periods, and

[8] Given aggregate labors and lands constant, the TFP gain can also been taken as output gains.

[9] L and C are the total inputs of lands and labors in the counties or townships. $\bar{S} = (\sum_{i=1}^{N} s_i)/N$ is the mean of pure farmer's TFP. s_i is the pure farming ability by using equation (9) and (10), and N is the total number of farmers in the counties or townships.

Table 4
Impact of farmland leasing on aggregate TFP and the mediating path through distortion reduction in South Jiangsu.

	Aggregate TFP (Log)		Distortion (Log)	
	(1)	(2)	(3)	(4)
Farmland leasing	1.134**(0.460)	0.507***(0.124)	−0.294**(0.135)	−0.231**(0.113)
Farmland leasing × TRS reform		1.167***(0.370)		−0.354*(0.189)
Temperature	0.649(0.933)	0.162(0.558)	1.519*(0.849)	1.926**(0.908)
Precipitation	−0.025(0.020)	−0.088*(0.045)	0.008(0.018)	0.003(0.019)
Sunshine duration	0.056(0.065)	0.176*(0.095)	0.002(0.060)	−0.048(0.063)
Per capital GDP	0.138***(0.029)	0.148***(0.056)	−0.020(0.027)	−0.049(0.031)
Township fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Endogeneity test (P value)	0.000	0.000	0.018	0.015
Under identification	0.000	0.004	0.000	0.000
Weak identification test①	20.889②	10.136②	20.889②	10.136②
Observations	487	487	487	487

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses. ①It reports Cragg-Donald Wald F statistic. ②The value of the Stock-Yogo weak ID test critical value at 15% maximal IV size is 8.96 for Column (1) and (3), and is 4.58 for Column (2) and (4).

varying study areas. Using the same method, the aggregate TFP gain reported in this paper is lower than that of 53.2% in Adamopoulos et al. (2022)'s paper and this may because the misallocation level in Jiangsu province is lower than China's average level. Notably, output gains from factor reallocation decrease when confined to villages (Adamopoulos et al., 2022). Our findings corroborate this trend, with aggregate TFP gains dropping to 12.4% and 4.1% when factor reallocation is limited within county and township, respectively. Furthermore, aggregate TFP gains after the TRS reform are lower than those before the reform, possibly due to a significantly reduction in input misallocation resulting from the TRS reform.

The computed aggregate TFP gains represent the maximum theoretical value that can be achieved by eliminating factor misallocation. In practice, TRS reform, which separates operational rights from contract rights, can facilitate the transfer of farmland towards more productive farmers and thus reduce factor misallocation. We calculate the aggregate TFP at county level and township level using equation (8) and subsequently plot it against distortion. Fig. 1 shows a negative correlation between aggregate TFP and distortion, implying that more productive regions experience lower distortion. Moreover, we observe a negative relationship between distortion and farmland leasing, suggesting that farmland leasing may lead to reduced distortion. This unconditional relationship between farmland leasing and TFP will be furtherly examined using rigorous economic approaches to explore causal effects and the influence channel through distortion.

5.2. *The impact of farmland leasing on aggregate TFP and influential mechanism analysis*

Replacing the egalitarian-based allocation of farmland with an ability-based farmland allocation is a crucial strategy for reducing factor misallocation. Farmland leasing, particularly the development of a market-oriented farmland leasing mechanism induced by TRS, can promote the flow of farmland and other factors toward more productivity farmers. This section investigates the impact of farmland leasing on aggregate TFP and examines the mediating path through distortion reduction.

As previously mentioned, we use 2SLS model to address the potential endogeneity issue. Table 3 reports the results for the impacts of farmland leasing on aggregate TFP and the mediating path through distortion reduction. The baseline results using OLS are reported in column (1). The endogeneity test results shown in column (2) and (3) reveal a significant rejection of the null hypothesis at a 1% significance level, implying farmland leasing is endogenous. Consequently, we estimate a 2SLS model and report the first-stage estimates in Appendix A2. The under-identification test and weak identification support the assumption that the IV is not weak.[10]

The coefficient of the farmland leasing variable shown in column (2) is positive and statistically significant, indicating that farmland leasing promotes aggregate TFP growth. Our finding is consistent with Chari et al. (2021) and Adamopoulos et al. (2022), as well as the conclusions drawn by Adamopoulos and Restuccia (2020) and Gottlieb and Grobovšek (2019) that an administrative land allocation policy reduces agricultural productivity. Specifically, we introduce an interaction term between farmland leasing and TRS to determine whether the effect of farmland leasing on aggregate TFP remains consistent before and after TRS. The interaction term exhibits a significant and positive coefficient, implying that aggregate TFP gains from farmland leasing are larger after TRS than before. A 1% increase in the mean share of farmers who lease in farmland results in a 1.087% rise in aggregate TFP at the township level. This paper highlights that TRS can furtherly unleash farmland vitality and increase aggregate TFP. Additionally, our results indicate that temperature has a negative and statistically significant effect on aggregate TFP, corroborating Chen and Gong (2021)'s findings that extreme temperatures adversely affect China's agricultural TFP.

Column (4), (5) and (6) in Table 3 present the results for mediating effect of farmland leasing on aggregate TFP at the township level using a 2SLS model. The endogeneity test rejects the null hypothesis, indicating that farmland leasing is endogenous. Both the under-identification test and weak identification test support the assumption that the IV is not weak. The coefficient of farmland leasing, reported in column (5), is negative and statistically significant at 5% significance level, implying that farmland leasing can reduce factor misallocation. Our finding is consistent with Gao et al. (2021) and Gai et al. (2020), who found that land certification and the implementation of the Rural Land Contracting Law could lead to farmland redistribution toward more productive farmers. Specifically, we furtherly discover that distortion reduction from farmland leasing is larger after TRS compared to before TRS, and a

[10] The literature has many arguments over the test standards of Weak Instrument (e.g. Cragg, and Donald, 1993; Staiger and Stock 1997; Stock, Wright and Yogo 2002; Staiger and Stock 2005). For the case of single endogenous variable, Staiger and Stock (1997) suggest declaring instruments to be weak if the first-stage F-statistic is<10, which is a widely-used thumb rule. For a general case, Stock, Wright and Yogo (2002) define instruments to be strong if a 5% hypothesis test for the relative bias between 2SLS and OLS rejects "no more than (say)15% of the time" (pp.521–522). As this paper has two IV's in estimation, we use the critical value of 15% for the Stock-Yogo weak ID test (Stock, Wright and Yogo,2002). In this study, for the case of one variable, the first stage F-tests are greater than 10 for almost all estimations (except of the robust check in Table 7, but also close to 10), while all the Stock-Yogo weak ID tests are greater than the critical values of 15%. Hence, we can claim that our IVs are strong.

Table 5
Impact of farmland leasing on aggregate TFP and the mediating path through distortion reduction for other regions in Jiangsu.

	Aggregate TFP (Log)		Distortion (Log)	
	(1)	(2)	(3)	(4)
Farmland leasing	0.507***(0.190)	0.426***(0.137)	0.028(0.121)	−0.002(0.108)
Farmland leasing × TRS reform		0.733**(0.353)		−0.272(0.277)
Temperature	−0.995**(0.458)	−0.617*(0.337)	−0.127(0.290)	0.013(0.265)
Precipitation	0.011(0.008)	0.008(0.006)	−0.000(0.005)	−0.002(0.005)
Sunshine duration	0.016(0.056)	−0.046(0.058)	−0.043(0.036)	−0.066(0.045)
Per capital GDP	0.122***(0.047)	0.077**(0.039)	0.087***(0.030)	0.071**(0.030)
Township fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Endogeneity test (P value)	0.000	0.000	0.008	0.005
Under identification	0.006	0.001	0.006	0.001
Weak identification test①	10.337②	5.258②	10.337②	5.258②
Observations	913	913	913	913

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses. ①It reports Cragg-Donald Wald F statistic. ②The value of the Stock-Yogo weak ID test critical value at 15% maximal IV size is 8.96 for Column (1) and (3), and is 4.58 for Column (2) and (4).

Table 6
Robustness check: Impact of farmland leasing on aggregate TFP and the mediating path through distortion reduction on township level by using the mean size share of leasing farmland.

	Aggregate TFP (Log)		Distortion (Log)	
	(1)	(2)	(3)	(4)
Farmland leasing	1.593***(0.458)	1.062***(0.181)	−0.335**(0.140)	−0.218**(0.086)
Farmland leasing × TRS reform		0.581**(0.238)		−0.210***(0.033)
Temperature	−0.634**(0.273)	−0.809*(0.421)	0.258(0.210)	0.267***(0.092)
Precipitation	0.018**(0.007)	0.012(0.009)	0.006(0.005)	−0.000(0.005)
Sunshine duration	−0.107**(0.042)	−0.315***(0.118)	−0.079**(0.032)	0.070***(0.018)
Per capital GDP	0.220***(0.047)	0.218***(0.068)	0.125***(0.036)	−0.045***(0.008)
Township fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Endogeneity test (P value)	0.000	0.000	0.007	0.000
Under identification	0.000	0.006	0.000	0.000
Weak identification test①	36.915②	5.985②	36.915②	5.985②
Observations	1400	1400	1400	1400

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses. ①It reports Cragg-Donald Wald F statistic. ②The value of the Stock-Yogo weak ID test critical value at 15% maximal IV size is 8.96 for Column (1) and (3), and is 4.58 for Column (2) and (4).

1% increase in the mean share of farmers who lease in farmland can reduce the standard deviation of distortion index by 0.267%. Rising temperatures may increase distortion, possibly because TFP loss from warming prevents more productive farmers from leasing in farmlands. Based on Jiang (2022)'s work, the results provide suggestive evidence that reducing misallocation is a channel through which farmland leasing promotes aggregate TFP.

5.3. Heterogeneous analysis

Table 4 and Table 5 present the results for the impacts of farmland leasing on aggregate TFP and the influencing mechanism for South Jiangsu[11] and other regions of Jiangsu, respectively. There are substantial differences in farmers' income, off-farm employment, and agricultural inputs between South Jiangsu and other regions (Hu et al., 2019). We find that the marginal effects of farmland leasing on aggregate TFP are 0.826% and 0.620% for south Jiangsu and other regions of Jiangsu, respectively. The TFP gain and distortion reduction from farmland leasing for South Jiangsu are consistent with those of the whole province. However, for other regions of Jiangsu, farmland leasing can only increase aggregate TFP but not reduce factor misallocation, implying that the mediating effect does not exist. Why is distortion reduction from farmland leasing found in South Jiangsu but not in other regions? Promoting the reallocation of farmland toward more productive farmers does not necessarily reduce misallocation, as farmers face the problem of farmland fragmentation. Fragmented land limits the use of large machinery, restricts farmers from fully utilizing their management ability, and may even result in diseconomies of scale (Zhang et al., 2019b). Hong and Wang (2019) point out that farmland leasing in South Jiangsu is based on farmland concentration because South Jiangsu can afford the cost for farmland consolidation and provide farmers with more off-farm employments. Therefore, farmland fragmentation may limit the effect of farmland leasing on misallocation reduction.

5.4. Robustness check

5.4.1. An alternative measure for farmland leasing using the mean size share of leasing farmlands

To confirm the robustness of our results, we replace the mean share of farmers who lease in farmland with the mean size share of leasing farmlands at the township level. The results reported in Table 6 show that a 1% increase in the mean size share of leasing farmlands result in a mean aggregate TFP gain of 1.217% and a misallocation reduction of 0.274%, which are consistent with those in Table 3. We also find that a 1% increase in per capital GDP leads to an increase in aggregate TFP by 0.218%.

5.4.2. Using county level data

Additionally, we estimate the impact of farmland leasing on aggregate TFP and the mediating path at the county level. The results in Table 7 show that a 1% increase in the mean number share of farmers who lease in farmland could increase aggregate TFP by 1.453% and reduce factor misallocation by 0.504%. The results reported in Table 7

[11] South Jiangsu includes Nanjing, Suzhou, Wuxi, Changzhou and Zhengjiang.

Table 7
Robustness check: Impact of farmland leasing on aggregate TFP and the mediating path through distortion reduction on county level.

	Aggregate TFP (Log)		Distortion (Log)	
	(1)	(2)	(3)	(4)
Farmland leasing	0.994*(0.560)	0.960*(0.575)	−0.371*(0.213)	−0.363*(0.209)
Farmland leasing × TRS reform		1.842**(0.868)		−0.526*(0.301)
Temperature	−1.044(1.083)	−0.393(0.606)	0.435(0.503)	0.429*(0.237)
Precipitation	0.007(0.019)	0.001(0.024)	−0.006(0.014)	−0.005(0.009)
Sunshine duration	0.106(0.137)	0.260(0.161)	−0.033(0.073)	−0.032(0.063)
Per capital GDP	−0.044(0.050)	0.028(0.034)	−0.056**(0.026)	−0.056***(0.013)
Township fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Endogeneity test (P value)	0.000	0.000	0.000	0.000
Under identification	0.038	0.035	0.038	0.035
Weak identification test[①]	9.215[②]	6.691[②]	9.215[②]	6.691[②]
Observations	461	461	461	461

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses. ①It reports Cragg-Donald Wald F statistic. ②The value of the Stock-Yogo weak ID test critical value at 15% maximal IV size is 8.96 for Column (1) and (3), and is 4.58 for Column (2) and (4).

are consistent with those in Table 3. Notably, the aggregated TFP gain and factor misallocation reduction from farmland leasing are larger at the county level than those at the township level, supporting the findings in Table 2 that the greater the scope of farmland reallocation, the larger the aggregate TFP gains. The first-stage estimates are reported in Appendix A3.

6. Conclusions and policy implications

Input misallocation across farmers has led to a large part of differences in TFP and thus labor productivity between developing and developed countries. China's HRS made great contribution to agricultural growth, while it led to misallocation between farmlands and farmers' ability due to egalitarian-based allocation of farmland. We develop a theoretical framework to show the relationship among farmland leasing, misallocation and aggregate TFP, and estimate the impact of farmland leasing on aggregate TFP and the mediating path through misallocation reduction using an integrative dataset.

The empirical results show that efficient input reallocation across farmers within the province yields a 23.6% gain in aggregate TFP, which decreases with the reallocation scope in theory. In practice, the results using a 2SLS model show that a 1% increase in farmland leasing resulting in a 1.087% gain in aggregate TFP and a 0.267% reduction in misallocation. These marginal effects after TRS are larger than those before TRS, implying that TRS can further enhance farmland vitality and promote agricultural TFP growth. The results also provide suggestive evidence that reducing misallocation is a channel through which farmland leasing improves TFP.

The policy implications are clear. Farmland leasing is an essential measure to reduce input misallocation and increase aggregate TFP, playing a curial role in ensuring China's food security and narrowing the income gap between rural and urban households. Therefore, governments need to focus on eliminating obstacles to market-oriented farmland reallocation, such as reducing transaction costs associated with farmland leasing. Farmland is a vital property and input for farmers' livelihoods. Many countries impose numerous restrictions on farmland markets to prevent land consolidation and ensure equity and social stability. However, these regulations often reduce efficiency resulting from market distortions, as studied in this paper. Balancing equity, stability, and efficiency while minimizing regulations is an important consideration in designing land institutions.

This paper has some limitations. Firstly, the results of the heterogeneous analysis show that the mediating effect of farmland leasing on aggregate TFP via distortion reduction found only in South Jiangsu may be attributed to their farmland concentration. However, we don't explore this hypothesis due to data limitations. Secondly, this paper primarily focuses on the case of Jiangsu province in China, and other provinces may experience different effects due to differentiated production conditions. These areas will be the focus of our future research.

Data Availability Statement

The data that support the findings of this study are available from Xiaoheng Zhang upon request.

CRediT authorship contribution statement

Xiaoheng Zhang: Conceptualization, Methodology, Software, Writing – original draft. **Lingxiao Hu:** Data curation, Conceptualization, Visualization. **Xiaohua Yu:** Conceptualization, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

See (See Table A1-A3.).

Table A1
The estimation results of equation (9) and equation (10).

Variable	Measured farm-level TFP Equation (9)	Farmer fixed effects Equation (10)
Temperature	0.657 (0.524)	
Precipitation	−0.032*** (0.010)	
Sunshine duration	0.012 (0.077)	
Soil quality		−0.069** (0.029)
Elevation		−0.123*** (0.026)
Time fixed effect	Yes	
Farmer fixed effect	Yes	
Township fixed effect		Yes
Constant	3.359** (1.534)	
N	4315	4294
R^2	0.401	0.341

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses.

Table A2
First-stage for farmland leasing affects aggregate TFP and distortion on township level.

	farmland leasing rate	farmland leasing rate	farmland leasing rate × TRS reform
Rice commodity rate	0.002***(0.000)	0.001***(0.000)	0.000(0.000)
Rice commodity rate × TRS reform		0.002***(0.000)	0.001***(0.000)
Temperature	1.444***(0.511)	0.601**(0.236)	−0.052(0.091)
Precipitation	−0.017(0.011)	−0.008(0.012)	−0.000(0.004)
Sunshine duration	−0.054(0.077)	−0.176***(0.040)	−0.021(0.015)
Per capital GDP	−0.024(0.031)	0.011(0.015)	−0.007 (0.006)

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses.

Table A3
First stage for farmland leasing affects aggregate TFP and distortion on county level.

	Farmland leasing rate	Farmland leasing rate	Farmland leasing rate × TRS reform
Rice commodity rate	0.994* (0.560)	0.001**(0.001)	0.000(0.000)
Rice commodity rate × TRS reform		0.002***(0.000)	0.001***(0.000)
Temperature	−1.044 (1.083)	0.506**(0.406)	−0.053(0.152)
Precipitation	0.007(0.019)	−0.007(0.017)	−0.001(0.006)
Sunshine duration	0.106(0.137)	−0.187***(0.068)	−0.020(0.025)
Per capital GDP	−0.044 (0.050)	0.018(0.025)	−0.009 (0.009)

Note: ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$; Robust standard errors are presented in parentheses.

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