Meseret Chanie ABATE* and Yuan-pei KUANG*

The impact of the supply of farmland, level of agricultural mechanisation, and supply of rural labour on grain yields in China

In order to provide food security for a growing population, abundant crop production is necessary. Globally, unpredictable natural and human factors are the result of the unforeseen consequences of agricultural productivity. Appropriate land tenure, proper labour allocation, and higher agricultural mechanisation levels are the fuel to boost agricultural productivity. China has implemented various policies such as its farmland protection policies, rural-labour allocation to off-farm industries, and agricultural mechanisation subsidies to induce grain self-sufficiency. However, farmland loss is an increasing trend; surplus rural labour continues to exist; and agricultural mechanisation has not reached the required level of quality and quantity. With this in mind, this study examines the long- and short-term impacts of farmland supply, rural-labour supply, and agricultural mechanisation development on grain-crop yields in China. The Autoregressive Distributed Lag (ARDL) approach to co-integration and error correction was applied to data over the period 1978-2017. The results show that farmland supply and agricultural mechanisation developments are positively associated with the growth of grain-crop yields in both the short- and long-term. However, the impact of the rural labour supply on grain yield is insignificant. Strengthening farmland protection policies and promoting innovation-based agricultural mechanisation development plays an important role in sustainable food production. Future research should focus on improving the quality of farmland, agricultural mechanisation, and finding effective strategies to protect farmland for sustainable food production. Moreover, China's efforts to enhance the multidimensional level of agricultural mechanisation should be encouraged.

Keywords: farmland; agricultural mechanisation; rural labour; grain yield

JEL classification: Q11, Q14, Q1

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Introduction

Currently, one of the most prominent objectives for worldwide food security is to optimise accessible land and water resources to cope with the growth of the world's population. The allocation of labour and technological innovation is used as a route to sustainable agricultural productivity (Adenle *et al.,* 2019; East, 2018; He *et al.,* 2019). In most cases, hunger, malnutrition, and undernourishment occurs owing to the failure in land, labour, and technology allotments in agrarian societies (Santos *et al*., 2014). Researchers have revealed that the efficient allocation of these agricultural production factors thorough various policy incentives can be used as a driving force for sustainable agricultural productivity and rural development.

In 1978, China adopted the basic rural reform and policy measures to feed 20 percent of the world's population with 10 percent of its arable land (Gong, 2017). The reform prioritised the improvement of grain yield as a key to attaining self-sufficiency in food. The government has since developed and implemented various agrarian support policies. For instance, the household responsibility system enables households to cultivate and manage their own farmland (Krusekopf, 2002). The system also encourages farmers to grow crops according to their own interest. In China, farmland loss is one of the biggest challenges now inducing a reduction in grain output. It is largely a result of land degradation (Rozelle *et al.*, 1997), farmland transfer (Liu *et al.*, 2018), land-use change, urbanisation, and the expansion of non-agricultural industries. Land protection policies and the forces of urbanisation have become antagonistic due to the pace of China's desire for socioeconomic development. Nonetheless, we claim that, to sustain grain yields, grain farmland protection mechanisms must be prioritised in order to maintain the national food security demand of the growing population. The population of China is forecast to peak within 10 years and to start shrinking quite rapidly afterwards. This suggests that increasing population is not much of a long-term concern. Perhaps the greater concern is that people want to consume more, rather than that there are more people to feed.

The socioeconomic shift also has also caused a shift in land-use from grain crop farmland to urban-based industrial expansion (Wang *et al.*, 2018b). The government developed strategies and policies to address the transformation of the nation's cropland. The prevention mechanism has included implementing farmland protection policies (Lichtenberg *et al.,* 2008; Huang *et al.,* 2019) and land reclamation (Xin *et al.,* 2018). Researchers have assessed the effectiveness of these farmland loss-prevention mechanisms. Chen *et al.* (2003) stated that a rise in the supply of farmland will play a significant role in boosting the growth in grain yields. Analysing the costs and benefits, Liu *et al*. (2019) for example recently concluded that the reclamation effort must focus on high-quality farmland in order to reduce the economic cost of reclaiming less productive farmland.

Rapid economic growth and a decreasing trend in its share of world agricultural production pushed China to subsidise farmers in order to buy agricultural machinery, thereby seeking to increase grain yields (Lopez *et al.,* 2017; Yi *et al.,* 2015). Moreover, the government has promulgated a grain subsidy policy to enhance grain yields. However, since the reform period, it is unclear whether these measures have had an important impact on the growth of grain yields in China, and to what extent the policies have been responsible for what growth there has been. The accumulation of surplus labour has been preventing China from developing medium- and large-scale agriculture. Nonetheless, China has met the demand for grain with small-scale agriculture. When the urban and rural industries surpassed the growth of agriculture, the off-farm real wage growth attracted rural labours. The government has also introduced surplus rural labour allocation policies (Bowlus *et al.,* 2003). Consequently, the question arises as to whether the transfer of rural labour has influenced grain yields.

China produces grain in excess of that required for domestic consumption (Johnson, 1994). The grain yield increased from 304.7 million tons in 1978 to 661.5 million tons in 2017, nearly doubling in four decades (NBSC, 2017). According to a report from the Ministry of Agriculture in 2017, the grain output remained above 600 million tons for five successive years, making China the world's foremost grain producer. However, as explained by Lin *et al.* (1997), grain-yield growth instability was found in various periods, and spatial and temporal shifts were observed (Yu *et al.,* 2019).

Researchers have indicated different reasons for the rise and decline in the rate of growth in grain yield. The increase in the rate of growth rate, for instance, was in part due to changes in institutional structure (Zhang and Carter, 1997), research-induced technical change (Fan *et al.*, 1997), and chemical fertiliser application (Zhang *et al.,* 2013). Wang *et al.* (2018a) revealed that the spatial and temporal shift of grain yield occurred as a result of farmer-protecting grain subsidies and drastic improvements in agricultural infrastructure. On the other hand, factors such as environmental degradation (Huang and Rozelle, 1995), climate change, and land-use change induced by urbanisation (Lu *et al.*, 2017) caused a reduction in the rate of grain yield growth. Porkka *et al.* (2013) suggest that China's national demand for grain can be fulfilled by adjusting trade policies and importing more grain from foreign markets. However, relying on imported grain cannot be a sustainable solution for the growing population due to global trade uncertainty. Thus, the adequate allocation of resources such as farmland, labour, and technology can provide a long-term solution for achieving the sustainable production of grain.

To the best of our knowledge, no study has determined the short- and long-term impacts of farmland supply, the agricultural mechanisation level, and rural-labour supply on grain yield since the major economic reform and opening up policy began in 1978. Few studies conduct related analyses over short periods of time (Rozelle *et al.,* 1997). He *et al.* (2019), for example, revealed that farmland supply preservation policies can play a substantial role in reducing arable land loss, which in turn helps to maintain grain output. Yao and Zinan (1998) revealed that the technical elements (agricultural mechanisation) of the farming scheme remain the basic way forward for long-term sustainable grain production. They advocate yield-enhancing inputs such as fertilisers and irrigation to increase grain yield in the short-term. Li *et al.* (2017) also found that agricultural mechanisation was a critical requirement for allowing farm size increases, as well as for enabling the growth of grain yields. Researchers are in two minds concerning the impact of rural labour supply dynamics on grain production in China. On the one hand, rural labour migration causes a decline in agricultural productivity owing to the loss of skilled farmers (Bowlus *et al.,* 2003; Dazhuan *et al.,* 2018). On the other hand, the rural labour flow due to off-farm rural and urban employment opportunities facilitates land-leasing and leads to the emergence of large-scale farmland and operations that improve grain-yield (Den *et al.,* 2007).

The purpose of this study is to provide insights into the long- and short-term impacts of farmland supply, the level of agricultural mechanisation, and the rural-labour supply on grain yield in China. We have used the ARDL bounds test for co-integration and error correction approach adopted by Pesaran *et al.* (2001). The findings enabled us to evaluate the influence of the supply of grain-crop farmland, the agricultural mechanisation level, and the rural labour supply on grain yield. This benefits policy makers in formulating effective policies and productivity incentive measures to strengthen sustainable grain productivity for the increasing population. In addition, the findings obtained provide a window on China's efforts to realize modern agriculture and revitalise rural areas.

The article is organized as follows: Section 2 explains the conceptual framework and hypotheses; Section 3 discusses the data and methodology; Section 4 describes the empirical outcomes and discussion; and Section 5 illustrates the conclusion and policy implications.

Conceptual framework

One of the basic inputs for grain production is the supply of adequate farmland. Fluctuation in the supply of farmland has an enormous impact on grain crop production. In China, one of the primary purposes of the rural reform undertaken in 1978 was to increase the efficiency of agriculture and to improve farmers' income by dismantling the People's Commune system and allocating farmland to households using the household responsibility system as the nation's land tenure scheme. Since then, grain yield and the per capita income of farmers has increased, showing a dynamic growth trend. The supply of grain farmland has been affected by numerous challenges such as urbanisation, industrial expansion, and land degradation, which has caused farmland losses. Specific farmland protection policies and farmland reclamation measures have been introduced in the face of these difficulties.

Hypothesis 1. Total supply of grain-crop farmland has had a significant positive impact on grain-yield since the period of rural reform starting in 1978.

Agricultural mechanisation promotes agricultural production from farmland to the processing stage. The level of mechanisation of agriculture is a measure of a nation's level of agricultural modernisation. There are factors that have a negative impact on the development of agricultural mechanisation. For instance, farmland fragmentation, farmers' income, and topography are the most important challenges hindering the development of agricultural mechanisation, especially in nations such as China where the majority of farmers are smallholders. China has provided numerous subsidies as an incentive to encourage sustainable grain production and to increase farmers' income. These have included subsidies for agricultural machinery.

Hypothesis 2. The development of agricultural mechanisation has had a significant and positive impact on grain yield growth over the last four decades.

Agricultural production in China is labour-intensive, which places huge cultivation pressure on, and reduces the quality of, farmland. The major economic reform and opening up policy have fostered industrial growth and facilitated nationwide urbanisation. The development of urban sectors has created employment opportunities for rural surplus labour and resulted in huge rural-to-urban migration. Researchers have found both positive and negative impacts of rural-to-urban migration on the allocation of labour in both areas. Reducing excess rural labour, for instance, facilitates farmland transfer through farmland leasing and renting between farmers. As a result, large-scale farmland that is appropriate for agricultural mechanisation is emerging.

Hypothesis 3. The decrease of surplus rural labour has a beneficial impact on China's grain-yield productivity growth.

The real-wage rise due to rural off-farm and urban industries growth causes the transfer of rural labour. This reduces the accumulation of surplus rural power in the agriculture sector and promotes farmland consolidation. Moreover, the reduction of surplus labour reduces the pressure of overcultivation of farmland caused by excessive farm labour. Consequently, the decline in surplus rural labour induces growth in grain yields.

Therefore, based on the above hypotheses, we lay out the following conceptual framework:

Data and Methodology

Data Source and Descriptive Statistics

The annual data used in this article are the output of grain crops (OGC), the total power of agricultural machinery (TPAM), the total sown area of grain crops (TSAGC), and the total number of employed rural labourers (TNREL). The data were collected from the National Bureau of Statistics of China (NBSC) over the period 1978-2017. We relied on data from 1978 onwards because the economic reforms were launched in that year, and almost all of the agricultural production indicators, including grain-yield, show an overarching change driven by these policies and incentives. The NBSC defines the variables as follows:

Output of Grain Crops (tons): this includes the total output of grain produced by farmers and other agricultural production actors in the whole year. The output of grain crops includes all cereals including rice, wheat, corn, millet, jowar, barley, beans. The unit of the measurement for the grain crop is tons.

Total power of agricultural machinery (Kilowatt): this refers to the total rated capacity of all agricultural machinery used for activities such as ploughing, planting, weeding, harvesting and construction of farmland infrastructure.

Total sown area of grain crops (Hectares): this includes

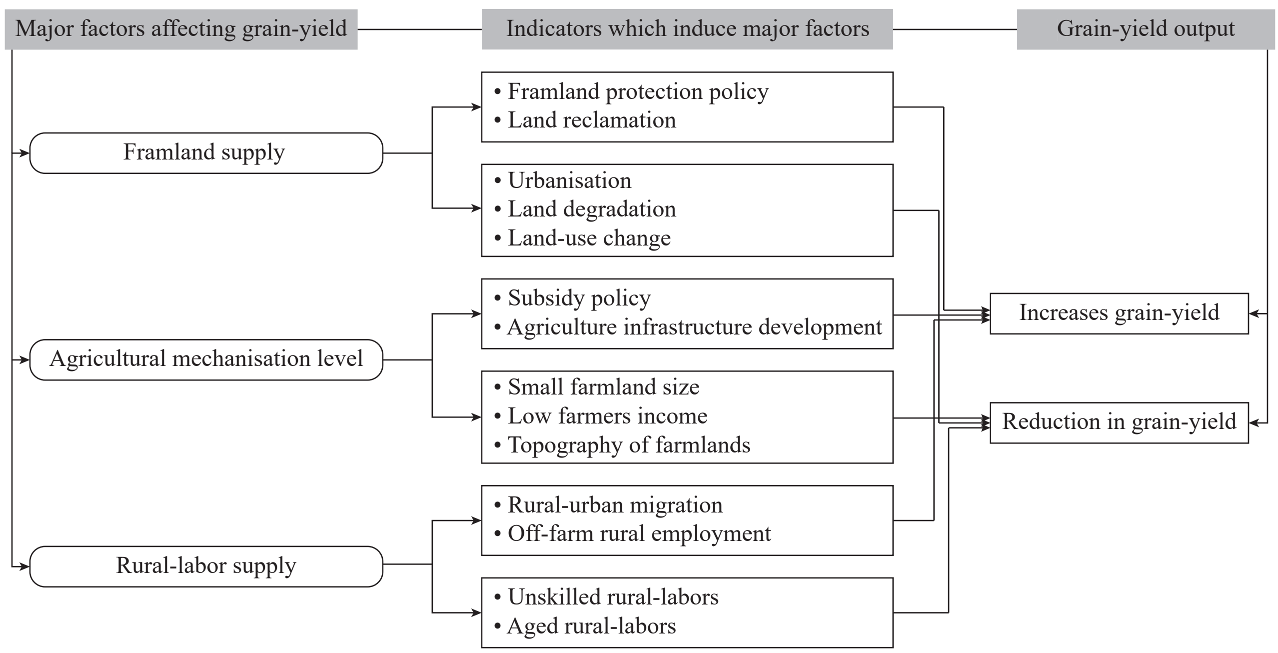

Figure 1: Conceptual framework for determining the presence and extent of the impact of farmland supply, the level of agricultural mechanisation, and the supply of the rural labour supply on grain yields in China.

Source: Own composition.

both arable and non-arable land on which farmers and other agricultural producers harvest grain crops. Grain crops sown in the previous year, but harvested this year, are considered as the current year.

Total number of rural employed labourers (people): all rural people 16 and over who are involved in on- and off-farm employment.

Model Specification

The article aims to examine the impact of farmland availability, agricultural mechanisation level, and rural-labour supply on grain yield. Thus, based on previous study of basic economic theory and the data availability we specify the following model:

$$\ln GY_t = \alpha + \beta_1 \ln REL_t + \\ + \beta_2 \ln AGC_t + \beta_3 \ln AM_t + \mu_t \quad (1)$$

where ln*GY*, ln*REL*, ln*AGC* and ln*AM* denote grain yield, number of employed rural labourers, sown area of grain crops, and total power of agricultural machinery, respectively. According to the standard economic model, $\beta_1>0$, $\beta_2>0$, $\beta_3>0$ and the disturbance term is adopted as normally distributed. The coefficients β_1, β_2 and β_3 are the elasticity of grain yields with respect to ln*REL*, ln*AGC*, and ln*AM* respectively. The basic economic model is as follows:

$$LNOGC = \alpha_0 LNTNREL + \\ + \alpha_1 LNAGC + \alpha_2 LNTPAM + \mu_i \quad (2)$$

where:
LNOGC = Natural logarithm of Output of Grain Crops
LNTNREL = Natural logarithm of Total Number of Employed Rural Labour
LNAGC = Natural Logarithm of Total Sown Area of Grain Crops
LNTPAM = Natural Logarithm of Total Power of Agricultural Machinery

In our analysis, *LNOGC* is a dependent variable, whereas *LNTNREL*, *LNAGC* and *LNTPAM* are independent variables. Since the major economic reform period, the Communist Party of China has used these four core agricultural indicators to guide policy, and incentive tools to drive the growth of agricultural productivity. Thus, the growth of grain yields has been induced by the formulation and implementation of land, labour, agricultural mechanisation, and subsidy policies in rural areas of China.

Method of Empirical Analysis

We investigate the long- and short-term impact of farmland availability, agricultural mechanisation level, and rural labour supply on grain yield in China. We employed the autoregressive distributed lag (ARDL) modelling approach to cointegration analysis. Engle and Granger (1987) formulated a cointegration analysis that could not be applied to variables which are integrated in different orders (such as in the first difference I(1)). However, Johansen and Juselius (1990) created a cointegration approach for variables which are integrated in different orders. However, their cointegration analysis is only applicable to small samples, and only able to determine long-term relationships between variables. To fill these gaps, we employed the ARDL modelling approach to cointegration analysis (Pesaran *et al.,* 2001). We

Table 1: Latent variables and indicators.

Latent variables	Observable/measured Variables	Codes	Measurement unit
Farmland supply	Total sown area of grain crops	TSAGC	Hectares (Ha)
Agricultural mechanisation level	Total power of agricultural machinery	TPAM	Kilowatt (KW)
Rural-labour supply	Total number of rural employed labour	TNREL	Peoples
Grain-yield	Output of Grain Crops	OGC	Tons

Source: own composition

Table 2: Descriptive statistics table.

Variables	LNOGC	LNTNREL	LNAGC	LNTPAM
Med.	19.95	19.57	18.54	19.89
Max.	20.31	19.78	18.61	20.83
Min.	19.54	19.16	18.41	18.58
S.D.	0.21	0.17	0.04	0.68
Obs.	40	40	40	40
LNOGC	1	-	-	-
LNTNREL	-0.54	1	-	-
LNTSAGC	0.44	-0.27	1	-
LNTPAM	-0.54	0.10	-0.04	1

Source: own composition

clearly adopted a step-by-step ARDL modelling approach to cointegration analysis as follows:

Step 1. The level of the stationarity of all variables included in the analysis was tested. The variables must be stationary only at level I(0) or at first difference I(1). This test was necessary because some time series variables may show divergence in their means. This causes the production of spurious regression and consequently, inaccurate outcomes. Thus, we applied an augmented Dickey–Fuller test (ADF) unit root test, developed by (Dicky and Fuller, 1979; Perron and Vogelsang, 1992). These unit root tests have been employed by econometric researchers to detect unit roots, which could originate from time-varying mean or variance (or both) (Harris, 1992). To determine these two unit-root tests, lag length must be determined.

Step 2. We specified the ARDL model, adopted and based on the available data and variables as follows:

$$\begin{aligned}\Delta LNOGC_t &= \alpha_0 + \sum(i=1)\ p1\ \alpha_{1i}\Delta LNOGC_{t-1} + \\ &+\sum(i=1)\ p2\ \alpha_{2i}\Delta 1LNTNREL_{t-1} + \\ &+\sum(i=1)\ p3\ \alpha_{3i}\Delta LNAGC_{t-1} + \\ &+\sum(i=1)\ p4\ \alpha_{4i}\Delta LNTPAM_{t-1} + \\ &+\beta_1(LNOGC_{t-1}) + \beta_2(LNTNREL_{t-1}) + \\ &+\beta_3(LNAGC_{t-1}) + \beta_4(LNTPAM_{t-1}) + \mu_t\end{aligned} \quad (3)$$

where:
$P1$ - $P4$ = represents optimal lag length of the variable
D = first difference operator
α_0 = intercept
α_1-α_4 = Short-run coefficients
β_1-β_4 = long-run coefficients
μ_t = white-noise disturbance term

Step 3. We conducted a cointegration bounds test to check for the existence of a long-term cointegration between variables. Thus, we applied the approach developed by Pesaran *et al.* (2001), assuming that errors in all the variables must be serially independent. The selection of the maximum lags for each variable may be affected by this assumption. Here is the equation for bounds test:

$$\begin{aligned}\Delta LNOGC_t &= \alpha_0 + \sum(i=1)\ p1\ \alpha_1\Delta LNOGC_{t-1} + \\ &+\sum(i=1)\ p2\ \alpha_2\Delta 1LNTNREL_{t-1} + \\ &+\sum(i=1)\ p3\ \alpha_3\Delta LNAGC_{t-1} + \\ &+\sum(i=1)\ p4\ \alpha_4\Delta LNTPAM_{t-1} + \upsilon_t\end{aligned} \quad (4)$$

To elucidate the presence of a long-term equilibrium among variables, we performed F-test. The hypothesis is:
H_0: $\alpha_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$ (Null hypothesis)
H_1: $\alpha_0 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq 0$ (Alternative hypothesis).
The rejection of the null hypothesis shows the existence of long-term co-integration among variables.

Step 4. We drew an unrestricted error-correction model (ECM_{t-1}), which is a modified ARDL model. The main objective of the re-expression of ARDL model in error correction form is to isolate short-term linkage of variables from the long-term equilibrium relationship (Mills, 2019; Ericsson, 1995).

$$\begin{aligned}\Delta LNOGC_t &= \alpha_0 + \sum(i=1)\ p1\ \alpha_1\Delta LNOGC_{t-1} + \\ &+\sum(i=1)\ p2\ \alpha_2\Delta 1LNTNREL_{t-1} + \\ &+\sum(i=1)\ p3\ \alpha_3\Delta LNAGC_{t-1} + \\ &+\sum(i=1)\ p4\ \alpha_4\Delta LNTPAM_{t-1} + \lambda ECT_{t-1} + \upsilon_t\end{aligned} \quad (5)$$

The definition of the variables explained in Step 2 are:
α_0 = intercept
α_1-α_4 = Short-run coefficients
υ_t = error term
l = the speed of adjustment parameter to a long-term equilibrium.
ECT_{t-1} = the error correction term

Step 5. In this step, we conducted two major tests to check the appropriateness and strength of the model. Firstly, we tested the sensitivity of the model through an estimating normality test, serial correlation test, and heteroscedasticity test. Secondly, we tested the stability of the model by applying a Cumulative Sum Control Chart (CUSUM) and Cumulative Sum Square Estimation (CUSUMQ). The CUSUM and CUSUMQ tests can help the researcher detect changes among the variables over time (Grigg *et al.,* 2003). The data analysis was conducted using Stata 14.

Results and Discussion

Since the 1978 economic reform and opening-up policy, China's agrarian society has witnessed multi-directional development in areas such as growth of grain yield, improvement in agricultural infrastructure, and growth of farmers' income. The growing national demand for food has also been supported by the government's devotion to food self-sufficiency strategies at every level of the nation's Communist Party. Thus, post-reform agricultural policy prioritises grain-yield growth as a key instrument to improve food accessibility and affordability for millions of undernourished people. The grain-producing sector is driven by land policy reforms, subsidies, and allocation of rural labour triggered by urban industrial development. This article examines the short- and long-term impacts of the supply of farmland, the level of agricultural mechanisation, and the supply of rural labour on grain yields in China over the period 1978-2017.

In the ARDL bounds test of co-integration analysis, all of the variables must be co-integrated at level I(0) or at first difference I(1). A mixture of I(0) and I (1) variables are also accepted. As indicated in Table 3, the ADF and the PP unit root test reveal that all the variables are significantly (1%) integrated at the first difference I(1). Akaike Information Criterion (AIC) as used as a criterion for appropriate lag length selection (Cheung *et al.,* 1995). The ADF and PP tests provide evidence about the existence of stationarity (co-integration) between the variables used in the analysis.

Disclosing the existence of long- and short-term relationships between this study's variables has been the primary goal of many econometric researchers because the results would be a valuable input for future economic policymakers. In this article, the bounds test co-integration analysis, based on F-statistics or Wald statistics described in Table 4, demonstrates the existence of a strong long-term relationship between the supply of farmland, the level of agricultural mechanisation, and the supply of rural labour with grain-yield in China since 1978. The estimated F statistic is 5.949, which is significant and greater than the lower bound I(0) and upper bound I(1) at 1%, 2.5%, 5% and 10% based on the level specified by (Pesaran *et al.,* 2001). The result obtained in the bounds test of co-integration suggests the possibility of conducting long- and short-term impact assessments between the variables.

The ARDL bounds test approach employed in this study is appropriate. Diagnostic tests play an important role in the application of the ARDL model. As indicated in Table 5, the results from the Breusch-Godfrey Serial Correlation LM test indicates that our model is free of any serial correlation error term. The model employed is also free of conditional heteroscedasticity. In Table 6, all the diagnostic data disclosed that the model is properly employed and well-fitted.

In addition, the cumulative sum control chart (CUSUM) and cumulative sum square estimation (CUSUMQ) help to interpret the model's stability in econometrics research. Typically, it enables us to identify changes among the variables within a given time span (Grigg *et al.,* 2003). The CUSUM and the CUSUMQ tests in Figures 2 and 3 show the model's stability. The middle line in both graphs lies between the two straight boundary lines. Thus, the model is appropriate and properly utilised in the overall estimations.

The impact of farmland supply on grain-yield in China

The question of feeding future generations with the available land resources puts huge pressure on stakeholders in food security. For populous nations like China, this challenge is more stressful. The nation has made huge efforts to supply food for 20% of the world's population with only 10% of farmland resources. Given that the other inputs for grain production are constant, it follows that the more farmland is sown with grain, the higher the grain yield. One of the key elements of rural reform in 1978 was the dismantling of the People's Commune system. Because farmers did not have the right to complete ownership for deciding how to use their farmland, the household responsibility system (HRS) was launched in the land management law of 1978. In the first six years, it was introduced only on a trial basis in a few provinces, but in 1986 it had already covered almost 90 percent of the country. Since then, there has been a sharp increase in grain yields. The HRS provided farmers

Table 3: Unit root test results.

Variables	ADF		PP	
	Level	1st Difference	Level	1st Difference
LNOGC	-2.399	-6.290***	-2.505	-6.289***
LNAGC	-1.847	-4.283***	-1.545	-4.311***
LNTPAM	0.187	-4.717***	-0.218	-4.774***
LNTNREL	-0.795	-4.332***	-0.385	-4.312***

Note: *, ** and *** stand for significance at 10%, 5% and 1% levels, respectively.
Source: own composition

Table 4: Bounds test result.

Critical Value	Lower Bound Value (I(0))	Upper Bound Value (I(1))
1.0%	4.29	5.61
2.5%	3.69	4.89
5.0%	3.32	4.35
10.0%	2.72	3.77
F-Statistics = 5.949	The number of regressors (K) = 3.0	

Note: *LNOGC*, *LNTNREL*, *LNAGC* and *LNTPAM* (1, 0, 1, 2), where *LNOGC* is a dependent variable. The decision of the bound test result is based on the rule specified by Pesaran *et al.,* (2001). The rule states that if the estimated F statistics is significant and greater than the lower bound I(0) and upper bound I(I) values, there is long and short term relationship between the variables.
Source: own composition

Table 5: Model diagnostic test results.

Test	Diagnostic Check	P-value
Breusch-Godfrey Serial Correlation LM test	0.04	0.9804
White's test	36.85	0.3832
Heteroskedasticity	36.85	0.3832
R^2	0.98	
DW statistic	1.84	
Cusum Test	Stable at 5% level	
Cusum of Squares Test	Stable at 5% level	

Source: own composition

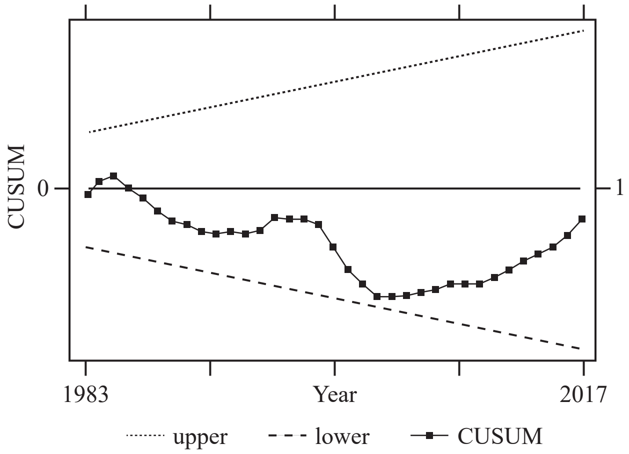

Figure 2: CUSUM test of recursive residuals.
Source: own composition

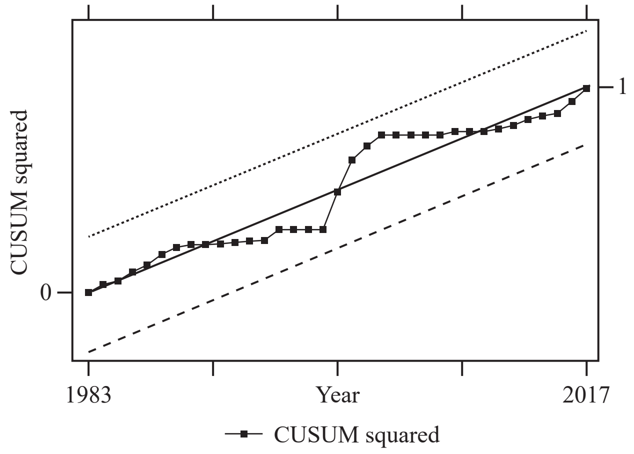

Figure 3: CUSUM square stability test of recursive residuals.
Source: own composition

Table 6: The result of long-run ARDL co-integration model

Variables	Coefficient	Std. Error	t-Statistics
LNTNREL	0.1794	0.1152	1.5600
LNAGC	1.3884	0.4371	3.1800***
LNTPAM	0.2278	0.0381	5.9700***

Note: *, ** and *** stand for significance levels of 10%, 5%, and 1% levels, respectively. LNOGC, LNTNREL, LNAGC and LNTPAM (1, 0, 1, 2), where LNOGC is a dependent variable.
Source: own composition

Table 7: The result of ARDL co-integrating short-run restricted error–correction model

Variables	Coefficient	t-statistics	P-value
ΔLNTNREL	0.0644	1.3700	0.1790
ΔLNAGC	2.1092	7.7200	0.0000***
ΔLNTPAM	-0.0486	-0.3400	0.7360
$\Delta LNTPAM_{t-1}$	-0.2090	-1.0000	0.3250
$\Delta LNTPAM_{t-2}$	0.3393	2.5400	0.0160**
Constant	-4.9156	-1.1600	0.2560
ECT_{t-1}	0.3592	-3.5900	0.0010***
R^2	0.9853	-	-
Adjusted R^2	0.9819	-	-
Durbin-Watson(D-W)	1.8414	-	-

Note: *, ** and *** stand for significance levels at 10%, 5%, and 1% levels, respectively. ΔLNOGC, ΔLNTNREL, ΔLNAGC and ΔLNTPAM (1, 0, 1, 2), where ΔLNOGC is a dependent variable.
Source: own composition

with the right to land transfers for their farmland. In addition, the scheme stabilised and mobilised farmers to grow grain. The supply of farmland, however, entered a vibrant phase that induced fluctuations in the grown of grain yields. Our research, therefore, elucidates the impact of a farmland supply variability on grain yields. Our findings in Table 6 show that the supply of farmland has positive and significant impact on the grain yield in the long run at a 1% significance level. The coefficient of grain crop sown area (LNAGC) is positive and significant at the 1% level. This shows that a 1% increase in the supply of farmland creates a 1.38% rise in the output of grain, and a 1% decline in the supply of farmland creates a 1.38% decrease in the grain yield in the long run. Furthermore, the findings in Table 7 also show the significant and positive impact of supply of farmland on grain yields in the short term at a 1% level of significance. A 1% increase in farmland supply leads to 2.1% growth of total grain crop yield in the short term.

Our findings are clear on how these prevention mechanisms have helped China to maintain farmland for attaining the increase in grain yields since the major reform and opening up policy, in both the short- and long-run. Contrary to these claims, Lichtenberg *et al.* (2008) earlier concluded that the reduction in the supply of farmland and the farmland protection policy had not had any significant influence on grain production, arguing that farmland losses can be compensated for by other factors such as fertilisers and agricultural machinery. In the short term, their claims may be true, but reduction in the supply of farmland does not provide sustainability for the increased population of the future. Thus, we highly recommend that the government safeguards grain farmlands from losses with a view to sustainable grain production in China.

The impact of agricultural mechanisation level on grain yield in China

Agricultural mechanisation is a fundamental agricultural input that helps improve the productivity of labour, the level of land output, and the quality of agricultural products. Promoting the level of agricultural mechanisation has a substantial role in enhancing the technical elements of grain production and boosting grain yields (Chen *et al.,* 2003). Agricultural mechanisation in China is one of the targets and former tools of rural reform aimed at transforming the agrarian economy in a sustainable manner. The government promoted agricultural mechanisation through direct agricultural machinery subsidies and the subsidies were aimed at increasing grain yields.

Our research shows that the development of agricultural mechanisation has had a positive and significant impact on grain yields in the long run at a 1% significant level. As seen in Table 6, an increase of 1% in the power of agricultural machinery causes an increase in the output of grain crops of 0.22%. The short-term analysis in Table 6 also demonstrates a positive and significant impact on grain yield at a 5% significance level. A 1% increase in the total power of agricultural machinery has led to a 0.33% increase in the total grain yield in the short term. Our findings show that the achievement of grain production in China has been strongly supported by the government since the major reform period by promoting the use of agricultural machinery through direct subsidy policies, specific strategies, and research and development. According to the National Statistical Bureau of China (NSBC), agricultural machinery subsidies rose from 70 million yuan in 2004 to 30 billion yuan in 2017, while aggregate grain yield increased from 469 million tons in 2004 to 661 million tons in 2017. This figure indicates a positive correlation between growing agriculture machinery subsidies and China's growing grain yields. Supporting our findings, Chen *et al.* (2008) earlier reported that agricultural mechanisation development had had a positive effect on the grain farming system. In addition, Yao and Zinan (1998), revealed that long-term grain yield growth can be accomplished by enhancing agricultural mechanisation.

However, agriculture mechanisation now faces various challenges such as land fragmentation, land-use change, low-income farmers, and inadequate and unwanted farm machinery production. Consequently, these factors are complicating government efforts to implement large-scale farm machinery and management operations in the sector. Thus, our findings remind us that these are all variables that hinder the development of agricultural mechanisation, cause declining grain yield growth in the nation, and play a significant role in holding back sustainable grain productivity. Moreover, in the context of China's most recent pursuit of rural revitalisation and modern agriculture in rural areas, our study reinforces the relevance of incorporating agricultural mechanisation development for sustainable food security and rural development.

The impact of rural labour supply on grain yields in China

Rural labour is one of the most important inputs of grain-production. Rural labour in China has shown a declining trend since the major reform and opening up policy, standing at 70% of the population in 1978 and anticipated to be 10% in 2030 (Johnson, 2000). This happened in two ways. Firstly, owing to fast industrial growth in urban regions, rural-labour migration to urban areas occurred as labourers sought to take advantage of urban employment opportunities. The release of labour from agriculture causes the government to invest in other factors of production (Wang *et al.*, 2019). Second, emerging rural industries attracted rural labour to participate in rural off-farm employment opportunities. Thus, we will now examine whether this displacement of rural labour has had an effect on grain yields. Our findings demonstrate that the dynamic rural labour supply has had no significant impact on grain yield in China. This is contrary to our expectations and counters Hypothesis 3. Our findings are compatible with Yang *et al.* (2016) who likewise conclude that rural labour migration has had no impact on grain yield in China. Moreover, Chen *et al.* (2011) revealed that a greater focus on labour input and correspondingly less on yield-increasing inputs like agricultural machinery resulted in slow growth in grain yields. This means that fluctuations in the rural labour supply have had no direct impact on grain yields. It may yet, however, have positive or negative indirect effects on grain yields. For instance, a huge surplus rural labour supply puts great pressure on farmland and facilitates farmland degradation and fragmentation. Our findings remind the government, policymakers, and other specialists in food security to place more emphasis on the quality rather than the quantity of rural labour. Investing in the cultivation of trained rural labour in particular will play a significant role in answering the food demands of the growing population.

Conclusions and policy recommendations

Although a lot of research has been done into the factors affecting grain yield, no studies have hitherto investigated the short- and long-term impact of farmland supply, the level of agricultural mechanisation, and supply of rural-labour on grain yields. Thus, the purpose of this article was to examine the existence and extent of the short- and long-term impacts of these three factors over the period 1978-2017. Based on the available data gathered from the National Bureau of Statistics of China, we designed and applied the ARDL co-integration bond test approach and error correction model (ECM). Our findings reveal that both the supply of farmland and the level of agriculture mechanisation exhibit strong and positive short- and long-term impacts on total grain yield. This indicates that

China's dynamic land policy plays a significant role in continuing grain yield growth. The mechanisation policies also contribute significantly to the effective growth of agricultural productivity. Thus, the government should continue to reinforce the nation's farmland protection policy and to advance innovative agricultural mechanisation.

Our findings also reveal that, during the study period, rural labour flow has had no perceptible influence on total grain yield in China. This finding provides a rationale for further investigation into the relationship between China's rural-labour and grain policies, as the supply of rural labour has an indirect impact on grain yields. We conclude that promotion of sustainable growth in grain yields must be regulated in such a way as to facilitate efficient allocation of farmland, innovative labour, and agricultural mechanisation. The scope of this article was limited to determining the existence of the long- and short-term impacts of farmland supply, the level of agricultural mechanisation, and rural-labour supply on grain-yield in China, but the cause-effect relationships between these variables were not discussed. Consequently, the impacts of the interaction between these all variables should be further explored by incorporating other grain-yield improving inputs such as fertilisers, irrigation, agricultural infrastructures, and seed quality into the analysis.

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