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Impact of different straw treatment methods on agricultural production efficiency: An empirical evidence of Jiangsu Province of China

Huan Chen[1], Ehsan Elahi[2] and Xinyuan Lei[3]*

[1]School of Business, Jinling Institute of Technology, Nanjing, China, [2]School of Economics, Shandong University of Technology, Zibo, China, [3]School of Agricultural Economics and Rural Development, Renmin University of China, Beijing, China

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EDITED BY
Arshian Sharif,
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Shan Shan,
Coventry University, United Kingdom
Syed Zaheer Abbas,
Hazara University, Pakistan

*CORRESPONDENCE
Xinyuan Lei,
leixinyuan1998@126.com

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Using county-level panel data collected from Jiangsu Province of China, this study applies the Super-SBM model to investigate the impact of straw retention subsidy and straw burning on agricultural production efficiency. The results found that the agricultural efficiency measurement system with cultivated land quality is more realistic. Agricultural development in the southern part of Jiangsu Province is at the expense of the environment. Straw burning in the open field can significantly improve the efficiency of traditional agricultural production. Moreover, it is found that the straw retention subsidy cannot improve efficiency directly, but it can inhibit straw burning from technical substitution and policy effects. The subsidy may work better when it is applied to local conditions. Moreover, to improve technical efficiency, it is suggested that government should pay attention to both operation training and supervision systems when promoting straw returning technology. In the long run, it is imperative to optimize the comprehensive utilization structure of straws and broaden the range of straw utilization. The findings of the study have broad implications for other agrarian regions with similar issues.

KEYWORDS

production, efficiency, straw burning, super-SBM, China

Introduction

As the perspective of sustainable agriculture has been widely accepted among people (Elahi et al., 2022b), the negative externality of straw incineration has received a huge amount of attention. In addition to using fossil fuels, burning straw generates substantial carbon dioxide into the atmosphere and contributes to severe air pollution (Liu et al., 2011), which imposes a threat to the respiratory system (Chen et al., 2017) and the cognitive health of the human body. To reduce agricultural burning behavior (Mao et al., 2021), the Chinese government issued many policies according to the perspective of "banning and incentive approaches" in 1999 (Sun et al., 2019). Briefly, in terms of banning part, the government put forward a series of strict laws to ban

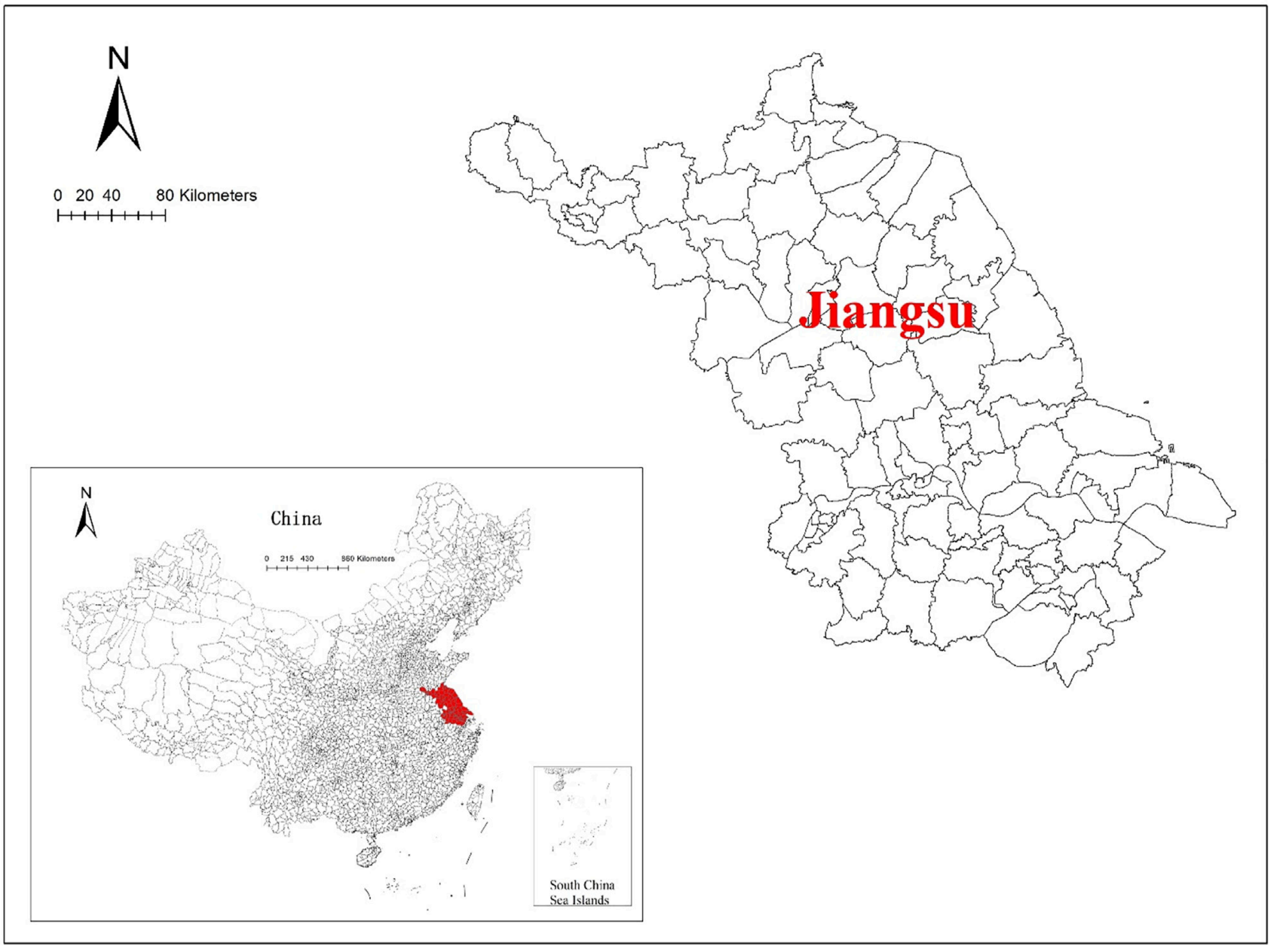

FIGURE 1
Spatial distribution of sample.

TABLE 1 Input-output index system of agricultural production efficiency.

Traditional index system	**Modified index system**				
Output	Total Output Values of Agriculture, Forestry, Pasturage (yuan, 2007 = 100)		Output	Total Output Values of Agriculture, Forestry, Pasturage (yuan, 2007 = 100)	
	Land input	Cultivated land area in the county (100 H A)		Land input	Cultivated land area in the county (100 H A)
		——			Cultivated land quality in the county (g/kg)
Input	Fertilizer input	Application amount of agricultural chemical fertilizer in the county (10,000 tons)	Input	Fertilizer input	Application amount of agricultural chemical fertilizer in the county (10,000 tons)
	Mechanical input	Total power of agricultural machinery in the county (10,000 kW)		Mechanical input	Total power of agricultural machinery in the county (10,000 kW)
	Labor input	Number of agricultural labor force in the county (10,000 people)		Labor input	Number of agricultural labor force in the county (10,000 people)

TABLE 2 Distribution of straw return subsidy in Jiangsu Province.

Year	Allowance = 0	Allowance = 1
2007	39	0
2008	39	0
2009	39	0
2010	39	0
2011	38	1
2012	33	6
2013	2	19
2014	2	37
2015	1	38

TABLE 3 Descriptive statistics of variables.

Variables	Definition	Mean	STD
Y1	Traditional agricultural production efficiency	0.416	0.177
Y2	Modified agricultural production efficiency	0.575	0.200
Intensity	$\frac{number\ of\ incineration\ points}{sown\ area\ of\ crops}$, a/1,000 ha	0.031	0.056
Allowance	1 = Yes; 0 = No	0.288	0.453
Agr	$\frac{sown\ area\ of\ grown\ crops}{sown\ area\ of\ crops}$,%	0.722	0.120
Irrigation	$\frac{effective\ irrigation\ crops}{sown\ area\ of\ crops}$,%	0.504	0.186
gdp	GDP per capita after adjustment,10000yuan	4.806	3.695
Road	Logarithm of road mileage, kilometers	7.638	0.309
Rainfall	Logarithm of annual average rainfall, mm	7.351	0.489
Sun	Average annual sunshine duration, h	5.346	0.516

The bold values represents variable definition and measurement;mean is Variable mean; STD is Standard deviation of variables

crop straw burning and began to monitor straw burning points from synthetic satellite data in 2004. For directing part, the Chinese government has launched a regulation named after "the comprehensive utilization of crop straws," which consists of five utilization ways of straw resources, including fertilizer, fuel, raw material, feed, and base material. However, these policies did not meet expectations. Lots of rural households still choose to burn straw directly in an open field during the harvest season. There were still larger than 6,000 straw burning sites in 2017 in China, and the contribution from straw burning remains significant for daily and annual PM10 in urban areas. This is mainly due to the conflict between private benefit and social benefit.

Previous research on straw treatment mainly focuses on straw burning and straw retention separately. In addition to other synthetic fertilizers (Elahi et al., 2022a), the plant ash after burning straw is a good potassium fertilizer and the eggs of insects will be eliminated at high temperatures. Agricultural burning can improve soil fertility input and control crop diseases and insect pests (Bird, 1997). Crop residue retention is a key component of sustainable cropping systems which can enhance agricultural productivity through improving soil quality and nutrient capacity (Kong, 2014). However, burning residues may cause environmental issues and climate change problems. Environmental protection is important for sustainable development and the ecological environment.

In terms of output, incineration can reduce plant diseases and increase output. In the same way, straw returning behavior can largely reduce the cost of straw removal and also play a role in improving the physic-chemical properties of soil. It is beneficial to the development of the crop root system, and high-quality straw returning behavior will also promote an increase in yield. However, there are still technical disadvantages in straw returning, which may negatively affect the production of the following crops. For example, the improper returning operation may lead to the increase of organic acid in the field (Shan et al., 2008), the aggravation of crop diseases (Guo, 2021), and competition with crops for nutrients (Lai et al., 2022) and other undesirable phenomena. Moreover, agricultural subsidies will affect the production decision-making and management behavior through wealth or expected effect. Straw returning subsidy, as a transfer payment method of government finance, will reduce the liquidity constraints of straw returning farmers and strengthen farmers' ability to invest in agricultural production (Yu and Jensen., 2010).

In the previous literature, scholars have not focused on straw incineration and straw replacement into a unified framework. Moreover, they have not imposed constraints on agricultural total factor productivity in terms of cultivated land quality and lack of empirical evidence at the county level. Therefore, in the current study, we used the county-level panel data collected from Jiangsu Province (from 2007 to 2015) to analyze the effect of straw burning and straw returning subsidy on agricultural production efficiency. The contributions of this study can be written as: 1) This paper collected the relevant policies of straw subsidies and answered the differences in agricultural production efficiency caused by the policies among counties. 2) As one of the key input factors to calculate agricultural efficiency, the "organic matter" index was included, which is corrected the lack of observation on land quality in the previous study of production efficiency. 3) We found that the straw retention subsidy policy did not directly affect agricultural production efficiency, but it was effective in replacing straw burning.

Materials and methods

Data and policy background

The data used for this study were collected from 39 counties of Jiangsu Province, China. Jiangsu, consisting of both developed southern and less developed Northern areas, is one of the major crop straw-producing regions in Eastern China. Figure 1 demonstrates the geographical location of the study province.

Jiangsu is one of the first provinces to pay attention to straw treatment. In 2000, Jiangsu designated straw burning prohibition area in the whole province, covering an area of 37,000 square kilometers, accounting for 37% of the total area of the whole province. In 2008, the government of Jiangsu firstly postulated straw returning to the field and controlling straw pollution. In 2009, Jiangsu implemented the "Standing Committee of Jiangsu Provincial People's Congress on promoting the comprehensive utilization of crop straw," including the goal of "prohibiting the burning of straw in the open air in the whole administrative region in 2012". In the same year, Jiangsu became one of the pilot projects for the subsidy of mechanical straw returning to the field in China. Afterward, the straw retention subsidy has been gradually implemented in various regions. The subsidy standard of Northern, central, and Southern districts differs in Jiangsu. Specifically, southern part is 10 yuan/mu, the central part is 20 yuan/mu, and the northern part is 25 yuan/mu.

Explained variable

The explained variable is agricultural production efficiency. Combined with the previous research results and following the input-output indicators required by the DEA method, the input-output index system of agricultural production efficiency is given in Table 1. Cultivated land quality is one of the important factors affecting agricultural efficiency. Therefore, the index system was modified by adding cultivated land input in the county at the input end. This is called modified production efficiency. If it did not include cultivated land input in the county, it would be called traditional production efficiency. This study also used the Super-SBM model to calculate two kinds of agricultural production efficiency, which are traditional production efficiency and production efficiency, including cultivated land quality input.

Explanatory variable

The core explanatory variables are straw retention subsidy and straw burning intensity. Straw returning is the individual behavior of farmers, which cannot be obtained from the county level. Alternatively, a straw retention subsidy policy is used to denote it. This is collected from the official statistical data of each county (Due to the availability of data, we finally retained the data of 39 counties.), that is, whether the relevant straw return subsidy policies have been issued in the region. If the policies have been issued *allowance = 1*, if there is no relevant policy, *allowance = 1*. The straw returning situation in the sample counties is reported in Table 2.

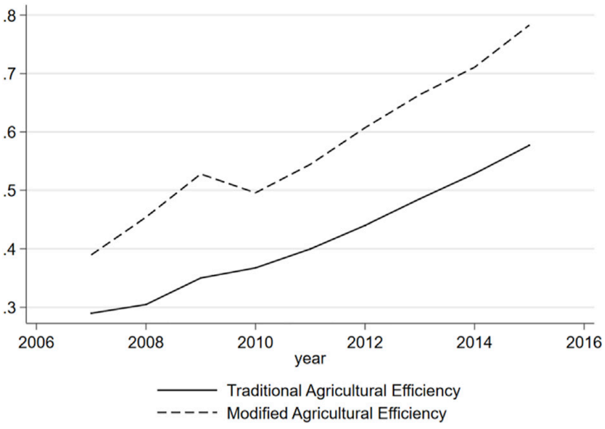

FIGURE 2
Change of agricultural efficiency rate of Jiangsu Province from 2007 to 2015.

The number of burning points is collected from the straw burning monitoring report of the Ministry of ecological environment of the people's Republic of China, which is detected by a high-resolution satellite. Considering the burning points may be related to the plating area, the incineration intensity (*intensity*) is calculated by the number of incineration points divided by sown of crops. The sown area of crops is from "Jiangsu Statistical Yearbook".

Control variables

Table 3 presents descriptive statistics of all variables used in the regression analysis.

Agr: sown structure. The higher the proportion of grain crops, the easier it is to achieve scale management, which is conducive to the improvement of production efficiency. The data was collected from the "Jiangsu Statistical Yearbook", calculated by sown area of grain crops divided by the sown area of crops (unit: %).

Irrigation: Proportion of effective irrigation area. In arid areas, water resource is the bottleneck to improving agricultural production efficiency. And, the increase in effective irrigation area proportion will lead to a large increase in production, which is conducive to improving production efficiency. In the area with sufficient rainfall, increasing the proportion of effective irrigation area will increase the input of other factors, but the increase of output is limited, so it may not be conducive to improving production efficiency. The data is calculated by effective irrigation area divided by the sown area of crops (unit: %)"Effective irrigation area" is from "China

TABLE 4 The difference between traditional agricultural efficiency and modified agricultural efficiency between counties.

		Traditional agricultural efficiency		Modified agricultural efficiency					Traditional agricultural efficiency		Modified agricultural efficiency		
District	County	Average	Rank	Average	Rank	Rank change	District	County	Average	Rank	Average	Rank	Rank change
South	Jiang Yin	0.676	3	0.680	8	−5	North	Feng	0.432	14	0.714	5	9
								Pei	0.429	15	0.715	4	11
	Yi Xing	0.435	12	0.569	18	−6		Sui Ning	0.292	32	0.476	32	0
	Li Yang	0.411	19	0.562	19	0		Xin Yi	0.304	31	0.470	33	−2
	Chang Shu	0.604	4	0.658	12	−8		Pi Zhou	0.418	18	0.695	6	12
	Zhang Jiagang	0.602	5	0.611	15	−10		Dong Hai	0.250	39	0.487	30	9
	Kun Shan	0.678	2	0.680	9	−7		Guan Yun	0.273	37	0.402	37	0
	Tai Cang	0.822	1	0.822	3	−2		Guan Yang	0.312	29	0.434	35	−6
	Dan Yang	0.537	6	0.635	13	−7		Lian Shui	0.404	21	0.688	7	14
	Yang Zhong	0.505	8	0.505	25	−17		Hong Ze	0.333	27	0.407	36	−9
	Ju Rong	0.335	25	0.500	28	−3		Xu Yi	0.291	33	0.507	24	9
	Average	0.561	——	0.622	——	——		Jin Hu	0.317	28	0.392	38	−10
Center	Hai An	0.411	20	0.570	17	3		Xiang Shui	0.312	30	0.540	21	9
	Ru Dong	0.421	17	0.673	11	6		Bin Hai	0.282	35	0.523	22	13
	Qi Dong	0.352	24	0.602	16	8		Fu Ning	0.271	38	0.487	31	7
	Ru Gao	0.388	22	0.620	14	8		She Yang	0.469	11	0.911	1	10
	Hai Men	0.537	7	0.679	10	−3		Jian Hu	0.356	23	0.511	23	0
	Bao Ying	0.428	16	0.461	34	−18		Dong Tai	0.502	9	0.910	2	7
	Yi Zheng	0.481	10	0.501	27	−17		Average	0.347	——	0.571	——	——
	Gao You	0.433	13	0.561	20	−7							
	Xing Hua	0.284	34	0.505	26	8							
	Jiang Jiang	0.279	36	0.280	39	−3							
	Tai Xing	0.333	26	0.488	29	−3							
	Average	0.395	——	0.54	——	——							

TABLE 5 Effect of straw retention subsidy and straw burning intensity on agricultural production efficiency.

	Agricultural production efficiency			Modified agricultural production efficiency		
	(1)	(2)	(3)	(4)	(5)	(6)
Straw burning intensity	0.179*		0.253**	0.091		0.202
	(0.105)		(0.111)	(0.124)		(0.130)
Allowance		0.011	0.034		-0.002	0.034
		(0.020)	(0.023)		(0.024)	(0.027)
Straw burning intensity*allowance			−0.532**			−0.781**
			(0.256)			(0.300)
Agr	−0.284	−0.285	−0.296	−0.307	−0.306	−0.322
	(0.198)	(0.199)	(0.197)	(0.232)	(0.232)	(0.230)
Irrigation	−0.046*	−0.047*	−0.048*	−0.072**	−0.072**	−0.074**
	(0.027)	(0.027)	(0.027)	(0.032)	(0.032)	(0.031)
gdp	0.023***	0.023***	0.021***	0.018**	0.018**	0.016**
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.009)
Road	−0.043	−0.047	-0.047	−0.062	−0.063	-0.066
	(0.059)	(0.059)	(0.059)	(0.069)	(0.069)	(0.069)
Rainfall	0.047***	0.044***	0.048***	0.027	0.025	0.028*
	(0.014)	(0.014)	(0.014)	(0.017)	(0.017)	(0.017)
Sun	0.001	−0.002	0.004	0.015	0.013	0.018
	(0.017)	(0.017)	(0.017)	(0.020)	(0.020)	(0.020)
Constant	0.396	0.482	0.419	0.775	0.811	0.788
	(0.465)	(0.465)	(0.464)	(0.546)	(0.545)	(0.542)
Individual fixed effect	Control	Control	Control	Control	Control	Control
Time fixed effect	Control	Control	Control	Control	Control	Control
N	351	351	351	351	351	351
R2	0.649	0.646	0.654	0.678	0.677	0.685

*, **, ***Show the parameters' significance level at 10%, 5%, and 1%, respectively.

county Statistical Yearbook" and "Sown area of crops" is from "Jiangsu Statistical Yearbook".

GDP: Per capita GDP. The higher the per capita GDP is, the better the local agricultural production efficiency will be. In addition to the investment in the industrial sector, the investment in agricultural development will be more in areas of economic development, which may increase agricultural production efficiency. The data is from the "Jiangsu Statistical Yearbook", to eliminate the influence of inflation, GDP per capita was reduced to 2007 (unit: 10,000 yuan).

Road: Road mileage. The longer the road mileage is, the better the labor migration will be, and then the degree of farmers' specialization is reduced, which is not conducive to improving agricultural production efficiency. The data is from the "road mileage" in the Jiangsu Statistical Yearbook, and the unit is a kilometer.

Meteorological variables. It includes annual average rainfall and annual average sunshine duration. Meteorological factors will affect agricultural production and then affect agricultural production efficiency. The data is from "China Meteorological Data Network's surface climate data daily value data set (V3.0)". The annual average meteorological variables are calculated by daily meteorological variables divided by days (daily meteorological variables including rainfall and sunshine duration).

Empirical methods

Super-SBM model

Data Envelopment Analysis (DEA) evaluates the relative efficiency of decision-making units (DMUs) but does not allow for a ranking of the efficient units themselves. To solve this problem, Andersen and Petersen., (1993) proposed a super-efficiency model to differentiate DMUs in the Frontier further. Compared with the traditional DEA radial models BBC and CCR, the SBM model proposed by

TABLE 6 Regression results of instrumental variables.

	Agricultural production efficiency		Modified agricultural production efficiency	
	(1)	**(2)**	**(3)**	**(4)**
Straw burning intensity	−0.242	−0.514	−0.823	−0.843
	(0.806)	(1.012)	(1.003)	(1.213)
Allowance		0.011		0.002
		(0.040)		(0.047)
Straw burning intensity*allowance		0.048		0.010
		(0.809)		(0.970)
Agr	−0.282	−0.282	−0.302	−0.302
	(0.203)	(0.213)	(0.253)	(0.256)
Irrigation	−0.047*	−0.047	−0.073**	−0.073**
	(0.028)	(0.029)	(0.034)	(0.035)
gdp	0.025***	0.027***	0.024**	0.024*
	(0.009)	(0.010)	(0.011)	(0.012)
Road	−0.049	−0.055	−0.076	−0.077
	(0.062)	(0.064)	(0.077)	(0.077)
Rainfall	0.039*	0.035	0.010	0.010
	(0.020)	(0.023)	(0.025)	(0.028)
Sun	−0.007	−0.012	−0.004	−0.004
	(0.024)	(0.028)	(0.030)	(0.033)
Constant	0.570	0.693	1.152	1.162
	(0.580)	(0.616)	(0.722)	(0.738)
Individual fixed effect	Control	Control	Control	Control
Time fixed effect	Control	Control	Control	Control
N	351	351	351	351
R2	0.6299	0.5982	0.6184	0.6159
First Stage Regression Results				
Education level of county Party Secretary	0.004*	0.004*	0.004*	0.004*
	(0.002)	(0.002)	(0.002)	0.002
Replacement of county Party Secretary	0.009	0.006	0.009	0.006
	(0.006)	(0.006)	(0.006)	(0.006)
Hausman Test (*p*-value)	Chi (16) = 0.51 *p* = 1.0000	Chi (18) = 1.12 *p* = 1.0000	Chi (16) = 2.98 *p* = 0.9998	Chi (16) = 2.69 *p* = 1.0000

*, **, ***, Show the parameters' significance level at 10%, 5%, and 1%, respectively. Number of burning points.

Tone (2002) allows the non-effective DMU not to follow the non-effective ray direction for the same proportion of can maximize the improvement. Tone further proposes a Super-SBM model to modify the relaxation variables to solve the problem of sorting the relatively effective elements, which is a nonradial, non angle DEA model.

Suppose to measure the efficiency of N decision-making units $DMU_j\,(j = 1, 2, \ldots, n)$. For each DMU, there are m kinds of inputs, expressed by $X_i = (x_{1k}, x_{2k}, \ldots x_{mk})$ and q kinds of outputs, expressed by $Y_r = (y_{1k}, y_{2k}, \ldots y_{qk})$. The Super-SBM model can be written as:

$$min\,\rho = \frac{1 + \frac{1}{m}\left(\sum_{i-1}^{m} s_i^- / x_{ik}\right)}{1 - \frac{1}{q}\left(\sum_{r-1}^{q} s_r^+ / y_{rk}\right)} \tag{1}$$

$$s.t. \sum_{j-1, j \neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \tag{2}$$

$$\sum_{i=1, j \neq k}^{n} y_{rj}\lambda_j - s_i^+ \leq y_{rk} \tag{3}$$

$$\lambda, j, s^-, s^+ \geq 0 \tag{4}$$

$$i = 1, 2, \ldots, m; r = 1, 2, \ldots 1; j = 1, 2, \ldots n(j \neq k) \tag{5}$$

TABLE 7 Effect of straw retention subsidy and straw burning points on agricultural production efficiency.

Variables	Agricultural production efficiency			Modified agricultural production efficiency		
	(1)	(2)	(3)	(4)	(5)	(6)
Straw burning intensity	0.002**		0.003***	0.001		0.002*
	(0.001)		(0.001)	(0.001)		(0.001)
Allowance		0.011	0.037		−0.002	0.031
		(0.020)	(0.023)		(0.024)	(0.027)
Straw burning intensity*allowance			−0.005**			−0.005***
			(0.002)			(0.002)
Agr	−0.274	−0.285	−0.288	−0.302	−0.306	−0.317
	(0.197)	(0.199)	(0.195)	(0.232)	(0.232)	(0.230)
Irrigation	−0.050*	−0.047*	−0.053**	−0.073**	−0.072**	−0.077**
	(0.027)	(0.027)	(0.027)	(0.032)	(0.032)	(0.031)
gdp	0.022***	0.023***	0.021***	0.018**	0.018**	0.016**
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
Road	−0.046	−0.047	−0.055	−0.063	−0.063	−0.072
	(0.058)	(0.059)	(0.058)	(0.069)	(0.069)	(0.069)
Rainfall	0.047***	0.044***	0.047***	0.026	0.025	0.027
	(0.014)	(0.014)	(0.014)	(0.017)	(0.017)	(0.017)
Sun	−0.000	−0.002	0.002	0.014	0.013	0.015
	(0.017)	(0.017)	(0.017)	(0.020)	(0.020)	(0.020)
Constant	0.422	0.482	0.489	0.789	0.811	0.854
	(0.461)	(0.465)	(0.458)	(0.544)	(0.545)	(0.541)
Individual fixed effect	yes	yes	yes	yes	yes	yes
Time fixed effect	yes	yes	yes	yes	yes	yes
N	351	351	351	351	351	351
R2	0.652	0.646	0.660	0.678	0.677	0.685

*, **, ***, Show the parameters' significance level at 10%, 5%, and 1%, respectively.

Regression model

To examine the impact of straw burning and straw retention subsidy on agricultural production efficiency, we used a fixed effect (FE) model as follows

$$y_{n_{it}} = \alpha + \beta_0 + \beta_1 allowance_{it} + \beta_2 intensity_{it} + \beta_3 allowance_{it} \times intensity_{it} + \beta_4 Z_{it} + \eta_i + \nu_t + \epsilon_{it} \quad (6)$$

Eq. 6 is estimated with a different dependent variable. An explained variable y_{it} represents the agricultural production efficiency measured by different input-output frameworks, $n = 1$ expresses the traditional agricultural production efficiency, $n = 2$ and expresses the modified agricultural production efficiency. $allowance_{it}$ Stands for straw retention subsidy, $intensity_{it}$ stands for the number of burning points/planting area of crops $allowance_{it}$ x $intensity_{it}$ and stands for the interactive item by multiplying subsidy and burning behavior. Control variable Z includes agr_{it} standing for planting structure, $irrigation_{it}$ standing for effective irrigation area, gdp_{it} standing for per capita GDP,$road_{it}$ standing for mileage of roads in different counties, $rainfall_{it}$ standing for average annual rainfall, sun_{it} and standing for average annual sunshine duration. ε represents the error term assumed to be normally distributed with zero mean value and constant variance (Elahi et al., 2021).

Results and discussion

Estimation of agricultural production efficiency

Figure 2 reported the difference between traditional and modified agricultural efficiency of Jiangsu Province from 2007–2015. When considering the quality of cultivated land, the agricultural productivity has significant change, which shows that it was distorted and unrealistic to ignore the quality of cultivated land to calculate agricultural efficiency.

The calculation of agricultural production efficiency was obtained by constructing a certain Frontier, which can only

TABLE 8 Effect of straw retention subsidy and straw burning intensity on agricultural production efficiency without 2009.

Variables	**Agricultural production efficiency**			**Modified agricultural production efficiency**		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Straw burning intensity	0.216*		0.292**	0.123		0.224*
	(0.110)		(0.116)	(0.119)		(0.125)
Allowance		0.011	0.035		0.003	0.035
		(0.021)	(0.024)		(0.023)	(0.026)
Straw burning intensity*allowance						
			−0.531**			−0.701**
Agr	−0.382*	−0.370*	−0.393*	−0.339	−0.332	−0.351
	(0.212)	(0.213)	(0.211)	(0.228)	(0.229)	(0.227)
Irrigation	−0.047*	−0.047*	−0.049*	−0.066**	−0.066**	−0.068**
	(0.028)	(0.028)	(0.028)	(0.030)	(0.030)	(0.030)
gdp	0.015**	0.017**	0.014*	0.009	0.010	0.007
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
Road	−0.024	−0.030	−0.029	−0.036	−0.039	−0.041
	(0.062)	(0.062)	(0.062)	(0.067)	(0.067)	(0.066)
Rainfall	0.051***	0.047***	0.053***	0.028	0.026	0.030*
	(0.016)	(0.016)	(0.016)	(0.017)	(0.017)	(0.017)
Sun	0.006	0.001	0.009	0.012	0.010	0.016
	(0.018)	(0.018)	(0.018)	(0.020)	(0.020)	(0.020)
Constant	0.291	0.394	0.308	0.632	0.688	0.642
	(0.488)	(0.489)	(0.486)	(0.527)	(0.526)	(0.523)
Individual fixed effect	yes	yes	yes	yes	yes	yes
Time fixed effect	yes	yes	yes	yes	yes	yes
N	312	312	312	312	312	312
R2	0.657	0.652	0.663	0.729	0.728	0.735

*, **, ***, Show the parameters' significance level at 10%, 5%, and 1%, respectively.

reflect the relative state. Therefore, the difference between counties and regions should be expressed by ranking. Organic matter content was one of the main indicators used to measure cultivated land quality, attributed to "good" investment. When it is included in the input-output system, the calculated theoretical production efficiency will be more connected to reality. Therefore, under the same conditions, the more organic matter content, the higher the county's agricultural production efficiency. This showed that compared with the traditional productivity, areas with improved productivity ranking are mainly due to their better-cultivated land quality.

As we can see in Table 4, no matter whether the quality of cultivated land was included in the input-output system or not, the agricultural production efficiency in the central and northern areas of Jiangsu was lower than that in the southern areas. This indicated the development of the agricultural economy in the central and northern areas of Jiangsu Province is slow. Comparing the traditional and modified agricultural production efficiency, great changes have taken place in all counties. Specifically, the ranking of agricultural production efficiency of most southern counties has declined significantly. The agricultural production efficiency of 14 counties in Northern Jiangsu has increased hugely, among which Lianshui County's agricultural production efficiency has increased by 14. These results indicated that the agricultural economy in Southern Jiangsu Province showed extensive growth at the cost of serious damage to the ecological environment.

Furthermore, the regression results are presented in Table 5. Columns (1–3) reported the results of traditional agricultural production efficiency, and columns (4–6) reported the results of modified agricultural production efficiency. It can be seen from the regression results in column 1 of Table 5 that the estimated coefficient of incineration intensity was positive, and its estimated parameter was 0.176, which passed the significance test at the level of 10%. Results showed that incineration intensity had significantly promoted traditional agricultural production efficiency. This may be because the high temperature kills the worms' eggs and reduce the incidence of plant diseases in the next crop, and the incineration of the grass and wood ash can play a role in fertilizer. This may be the reason why straw burning is forbidden repeatedly. However, the same effect has not been rediscovered in the modified agricultural efficiency. A possible explanation for this finding was that burning straw will lead to deleterious effects on soil health (Kumar et al., 2019).

Surprisingly, the straw retention subsidy had no statistical influence on two kinds of agricultural production efficiency in our sample areas, not conforming to expected results. The possible reasons were: firstly, the low rate of subsidy and the manner of subsidization for straw retention were not suitable to influence the farmers' production decision-making. This means the agricultural production behavior cannot be effectively adjusted. Secondly, the straw retention behavior is part of the long-term cultivated land quality protection behavior. In the short term, if the technical operation is not standardized, the irregular straw retention behavior may lead to the returning straw being difficult to decay, and this is not conducive to the growth of the next crop, such as the exorbitant stubble length, scarce chopping degree of straw, or unbalanced sprinkled straw. This result was also consistent with the fact that some farmers in our early research did not know specific technical standards about straw retention.

Results also indicate that straw retention subsidy can reduce the effect of straw burning on the two agricultural production efficiency. This is because promotion in straw retention can consequently lead to a decrease in straw burning in rural areas through technological substitution. When the quality of cultivated land is included, the subsidy for returning farmland will restrain the burning behavior to a greater extent. Therefore, the subsidy can effectively reduce farmers' straw-burning behavior and make up for the loss of farmers.

Robustness test

Instrumental variable method

Table 6 reported the regression results of instrumental variables. Considering the possible endogeneity of the burning point, this study used the instrumental variable method to test its robustness. In reality, many areas have inherent characteristics, including natural resources endowment and local policies. The omission of these variables may bring endogenous problems. Therefore, in this study, we chose the education level of the county Party Secretary and his replacement information as the instrumental variables of incineration intensity. County Party Secretaries with higher education levels are expected to perceive stronger environmental awareness. Therefore, the parties should pay attention to the regional environment and promote the reduction of the number of straw burning points. In addition, the new county Party Secretary can be more strict with implementing the policy, so the number of straw burning points may be smaller. The education level and replacement information of the county Party secretary are completely exogenous. According to the Hausman test, the original hypothesis cannot be rejected, which means there is no significant difference between IV fixed effect and OLS fixed effect regression. Therefore, the results of panel data have a fixed effect model.

Number of burning points

To enhance the robustness of the results, we changed the calculation method of straw burning. The number of burning points replaced the burning intensity, and the results were stable (see Table 7).

Removing 2009 sample

Because the observation data of the burning point in 2009 suddenly decreased drastically, so we deleted the data in 2009 and regressed the model again (see Table 8). Our results passed the robustness test.

Conclusion and policy implications

Crop straw is the main by-product of food grain production important renewable energy in developing countries. However, with economic development in China, rural households have begun to disuse their crop straws and tend to burn them directly in open fields, going against sustainable development. To ban straw burning, the Chinese government launched several policies and gave financial support to encourage the comprehensive use of crop straws. Straw returning is one of the main treatments comprehensive use. To explore the influence of straw returning subsidy and straw burning on the agricultural production efficiency, this study used the panel data of Jiangsu Province from 2007 to 2015.

Results reveal that the measurement framework of agricultural efficiency, including cultivated land quality was more closely connected with the actual situation. The rapid growth of agricultural efficiency of southern Jiangsu is at the expense of cultivated land quality. Burning intensity is effective in promoting traditional agricultural efficiency, but it presents there is no marked impact on modified efficiency. The current straw retention subsidy policy does not affect both efficiencies. Straw retention subsidy can restrain straw burning behavior through technical substitution and policy effect of subsidy, which limit the effect of straw burning on traditional and modified agricultural production efficiency.

These findings provided critical knowledge on designing and reforming current programs for crop straw management from a long-term and short-term perspective. Firstly, in calculating agricultural production efficiency, the important index of cultivated land quality should be included in the input end of the framework so that the calculated value of production efficiency is more closely related to the real value. Secondly, due to multiple constraints, straw returning technology is the first choice in short-term straw treatment. While current subsidy policy cannot provide rural households enough direct incentives to implement straw retention in their fields. More financial incentives and subsidies should be given to support the development and extension of straw retention technologies and equipment. At the same time, the government should establish returning supervision mechanism, focusing on the operation training of straw returning farmers to ensure the quality of straw returning to the field and encourage universities and research institutions to develop new agricultural machinery and equipment. Before giving subsidies, administration officials should strictly control the stubble height, fragmentation degree, and depth of digging after straw returning to the field to ensure technical efficiency. The private benefit of farmers will be guaranteed with high-quality straw retention, which is more helpful for farmers to give up straw-burning behavior. Thirdly, the government should optimize the comprehensive utilization structure of straw and expand other ways in the long run. The government should vigorously promote the construction of straw collection and storage systems with farmers' demand as the guide, enterprises as the leader, and professional economic organizations as the backbone, and plan to build straw collection and storage bases.

The above research has promoted the understanding of agricultural productivity about straw burning and straw returning to the field. Unfortunately, due to limitations of sample (lack of national samples) or analysis object (lack of analysis of farmers), the findings are not representative at the national level. Using representative national data for farmers' research, it is important to explore straw burning and straw returning to the field. Moreover, there are significant differences in straw burning and straw returning between regions. Therefore, in future study, it is necessary to focus on the regional differences in agricultural productivity.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

HC and XL were responsible for the data collection and arrangement of relevant literature, data analysis, and article writing. EE edited and improved the final draft of the article.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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