Chapter 5
Impacts of Irrigation, Mechanization and Subsidies on Wheat Efficiency in China: An Application of Two-Stage DEA

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1 Introduction

Agricultural production, especially sufficient and efficient supply of the grain crops, plays an extremely important role in Chinese history. According to the data released by the National Bureau of Statistics on December 10, the total grain output of China in 2020 was 669.49 billion kg, an increase of 56.5 billion kg or 0.9% over 2019. The output remained above 650 billion kg for six consecutive years. In 2020, China's grain output hit a record high and achieved a 17-year consecutive increasing, which provided a solid support for ensuring national food security. In the future, it necessary to ensure grain production capacity and national food security, adhering to the strictest cultivated land protection. Hebei is one of the 13 main grain-growing provincial regions in China, and wheat is an important grain crop. By 2019, the sown area of wheat in Hebei Province was 2.32 million hm^2, accounting for 9.79% of the national figure. As the third level of Chinese local administrative hierarchy, a county is the lowest level having complete government divisions and economic industries. Until 2020, Hebei province has 121 counties including 21 county-level cities, 94 counties and 9 autonomous counties. For thousands of years, agriculture has been the main source of national tax. In December 2005, the 19th meeting of the Standing Committee of the Tenth National People's Congress adopted a decision to abolish the regulations on agricultural tax as of January 1, 2006. At the same time, an agricultural subsidy policy system has been gradually established. In 2006, the state allocated 31.05 billion yuan in various agricultural subsidies, which benefited about 720 million farmers across the country. In China, the amount of funds to subsidize

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agriculture is identified in units of counties. Therefore, we intend to study wheat production efficiency from the perspective of county-level regions in Hebei.

Since the pioneering work of Farrell (1957), literature devoted to estimate efficiency mainly embraced two approaches: the parametric function symbolized by Stochastic Frontier Production (SFP, Aigner et al., 1977), and the nonparametric Data Envelopment Analysis (DEA, Charnes et al., 1978). Requirement of a specified function is the main weakness of SFP. In contrast, the DEA embraces the advantage that multiple inputs and outputs can be considered simultaneously, even in different units. Moreover, this approach avoids the parametric specification of technology as well as the distributional assumption (Coelli et al., 2005).

In agriculture, land, labor, fertilizer, water, and other inputs are used, thus needs a multiple input model is necessary to measure the efficiency. A variety of output variables should be adopted to measure not only the physical yield, but also the market value. Both the input and output variables are in different units, without any parameters can be assumed accurately beforehand. Moreover, what the farmers can control relatively freely would be the quantity of inputs, rather than the outputs. Meanwhile, natural and marketing risks, government regulations, constraints on finance, etc., may cause a farm cannot operate at optimal scale. Therefore, we will adopt input-oriented DEA model with the assumption of VRS,[1] although many prior studies took CRS assumption.

To estimate the DEA scores and relevant determinants in the second stage, there are three major approaches that have been used, including *Tobit* regression (Tobin, 1958), the Papke-Wooldridge (PW) model and the unit-inflated beta (Beta) model. However, as proved by Hoff (2007), Tobit regression performs better that the other two and have adopted by many studies as Javed et al. (2008), Dhungana et al. (2010), etc.

We intend to fulfill the following targets in this chapter: (1) formulating a DEA model appropriate to analyze wheat production efficiencies taking Chinese counties as the DMUs, (2) revealing the overall attributes of wheat production efficiencies, (3) finding out the theoretical margin for the increasing of yields and saving inputs, (4) identifying the significant social and natural factors through the application of Tobit regression, and (5) putting forward referential recommendation for policy makers.

[1] There are two orientations in DEA model, the input-oriented model seeks to reduce in inputs, with outputs hold constant, while the output-oriented model aims to increase outputs, keeping inputs fixed. As to the assumption of return to scale, Constant Return to Scale (CRS) is appropriate when all firms are operating at an optimal scale, while Variable Return to Scale (VRS) is without this limitation.

2 Model and Data

2.1 Defining the Variables

Output variables Yields of main product refers to net weight of raw wheat in standard moisture content, which is the percentage of water and varies in different regions. In most of the cases, it is around 12–13% in Heibei Province. It implicates the physical productivity of wheat, thus the capability to fulfill the food demand and guarantee food safety. *Net profit* is the balance of the minus costs[2] in wheat farming. Generally, this variable reveals the profitability of wheat farming, under a variety of certain technical, marketing and political institutions. Therefore, the former is a technical variable, while the latter is a socio-economic one.

Input variables (1) *Labor inputted* is the standard days of labor needed by wheat farming. To calculate this variable, the farming hours of both family members and hired labors should be standardized, referring to a moderate agricultural labors,[3] and them divided by 8 h. (2) *Land rent inputted* included rent of land circulated from individuals or the collectives, and theoretical rent of own-farming land. (3) Physical amount of seeds used in wheat farming, including the bought, self-produced and donated for free, form the variable of *Seeds inputted.* (4) *Fertilizer inputted* is the amount of fertilizer, which has been standardized according to its contents of active principles. (5) *Machine service rent* is the expenditure for the mechanical operation including plough, sowing, harvest, threshing and transportation. (6) *Water fee inputted* includes the expenditure for the rent of irrigating equipment, and the costs occurred in irrigating. (7) Depreciated value of fixed assets covers assets valued more than 100 yuan, with the durance of no less than one year. To calculate depreciation of the fixed assets, the annual depreciating rate for water channel and motor-pumped well is 10%, mechanical installations with 12.5%, while large and medium farm implements with 20%.

Determinants of efficiency Input variables affect the production directly, that is, wheat cannot be properly produced without any of the variables listed as input in Table 1 (in Chap. 3). By contrast, a determinant usually does not directly determine, but has an indirect impact on technical efficiency (Audibert et al., 2003).

(1) Basic productive factors, including *Agro-labor per farm* and *Average size of farmland*. We set the hypotheses that the more agro-labor and land per farm, the more efficient of wheat production. (2) Basic farming conditions included *Ratio of irrigable land* and *Power of agricultural mechanization*, as irrigation and machinery operations are indispensable guarantees of modern agriculture. (3) Basic political

[2] Costs consist of (1) inputted material and service, including seeds, fertilizer, pesticides, and hired machinery for irrigation, plough, sowing, etc.; (2) value of hired labors and converted value of family labors; (3) value of rented lands and converted value of family-owned farming land allocated by the Household Contract Responsibility System.

[3] A moderate agricultural labor means (1) 18-50 year old male and 18-45 year old female, being able to adapt common labor intensity; (2) labors aged out of the interval stipulated above, but can undertake equivalent labor intensity; or (3) the employed labors.

factors embrace *Extension staffs of agro-tech* and *Agricultural subsidies*. We assume that positive relationships exist amongst the two variables and production efficiency. (4) Basic potential resources include Water resources applicability and *Average schooling length of rural labors*. We introduced water reserves per capita, rather than per hectare, to show the water use efficiency in the whole society. It should be hypothesized that the more plenty in water supply and well-educated farmers, the more efficient that wheat production will be.

2.2 Sample and Data

The data of inputs and outputs were got from the agricultural product survey, conducted by *Price and Cost Inspection Bureau* of Hebei in 2008. The data of this year was selected due to fact that the agricultural tax had just been exempted and the new agricultural subsidy policy system had just begun. On this basis, the main determinants of wheat production efficiency were analyzed, thus to evaluate the accuracy and rationality of following policies promoting agricultural innovations. Wheat production was sampled in 36 counties and the summary statistics were listed in Table 1. In addition, we got some other data from the Bureau of Statistics, Department of Agriculture and Department of Water Resources of Hebei.

3 Efficiency Analysis with DEA

3.1 Expression of the Used DEA Model

The DEA used in this chapter can expressed as the following linear programming (Coelli, 2005):

$$Min_{\theta,\lambda}\, \theta$$

$$st{-}y_i + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0, i = 1, 2, \ldots, 36 \tag{1}$$

where θ is the efficiency score and λ is a vector of constants; $y_i andx_1$ and $y_i andx_1$ is the output and input vectors of county I; Y and X are the output and input matrices, respectively. With the assumption of VRS, three kinds of efficiency scores can be outputted through the software of DEAP 2.1, where

Table 1 Variables and the summary statistics of wheat production efficiency mainly based on the Agricultural Product Survey, 2008 conducted by Price and Cost Inspection Bureau of Hebei

Variable		Description of the variables	Unit	Maximum	Minimum	Mean	Std. D
Output	y_1	Yields of main product	Kg/mu[1]	508.90	308.30	417.84	45.94
	y_2	Net profit	Yuan/mu	319.25	6.21	160.08	81.29
Input	x_1	Labor inputted	Day/mu	8.74	2.77	5.67	1.37
	x_2	Land rent inputted	Yuan/mu	141.67	60.00	101.87	22.76
	x_3	Seeds inputted	Kg/mu	27.33	10.83	17.21	4.01
	x_4	Fertilizer inputted	Kg/mu	39.44	21.13	28.11	4.30
	x_5	Machine service rent	Yuan/mu	115.50	64.44	91.88	12.31
	x_6	Water fee inputted	Yuan/mu	83.15	14.26	45.25	16.28
	x_7	Depreciated value of fixed assets	Yuan/mu	12.17	0.93	5.64	2.86
Determinant	d_1	Agro-labor per farm	Person	153	0.41	0.91	0.29
	d_2	Average size of farmland	Mu	10.16	4.00	6.15	1.43
	d_3	Ratio of irrigated land	%	100.00	54.46	90.67	11.93
	d_4	Power of agricultural mechanization	Kw/ha	78.55	6.72	20.25	13.05
	d_5	Extension staffs of agro-tech	Person/km^2	13.22	0.13	1.97	2.66
	d_6	Agricultural subsidies	Yuan/mu	50.00	21.95	36.91	5.64
	d_7	Water resources applicability	Ton/person	196.08	55.14	92.08	30.81
	d_8	Average schooling length of rural labors	year	9.96	6.78	7.48	0.55

Note [1]as a main unit of land measurement in China 1 mu = 666.67m^2

Table 2 Summary of wheat production efficiency

Type	Number of counties	Means			Number of counties with		
		Total efficiency	Technical efficiency	Scale efficiency	*crs*	*irs*	*drs*
I	11	1.000	1.000	1.000	11	0	0
II	11	0.883	1.000	0.883	0	11	0
III	14	0.842	0.902	0.934	0	12	2
Total	36	0.902	0.959	0.940	11	23	2

Note crs = constant returns to scale; irs = increasing returns to scale; drs = decreasing returns to scale

$$Total efficiency = Technical efficiency \times Scale efficiency \tag{2}$$

3.2 Total, Technical and Scale Efficiencies

From the efficiency summary shown in Table 2, 11 counties as Type I were scored in Total efficiency as 1, thus in full efficiency and can be benchmarks for the other counties. Furthermore, within the rest 25 counties with Total efficiency less than 1, 11 counties, adjustment of any input will not change the efficiency, and it makes adjusting farm scales the only solution to improve efficiency. Meanwhile, there were still 14 counties, referred as Type III, having Technical efficiency less than 1. It means that in these counties, with given farm scales, production efficiency can still be improved through reducing some of the inputs.

Moreover, all the 11 counties in Type I were in the status of constant returns to scale, while all the 11 counties in Type II were in the status of increasing returns to scale. In Type III, 12 counties were being increasing returns to scale, and two counties were in the status of decreasing returns to scale. Therefore, in altogether 23 counties, efficiencies can be improved by enlarging the farm scales, and 2 by contraction.

3.3 Slack Analysis of the Outputs

Slack of an output shows the margin that firm can improve its output through the adjustment by DEA. The output slacks summarized in Table 3 showed that in the *Type* III counties, yields of main product can be increased by 3.08%. Meanwhile, the net profit can be increased by 82.01%. It indicates that comparing with technical improvement, much more margin lies in the socio-economic optimization including

Table 3 Slack analysis of the outputs per *mu*

Type	Number of counties	Mean of main product (kg)			Mean of net profit (yuan)		
		Origin1	Target1	Slack1	Origin2	Target2	Slack2
I	11	459.34	459.34	0.00	245.65	245.65	0.00
II	11	373.87	373.87	0.00	114.95	114.95	0.00
III	14	416.71	429.53	12.81	127.43	231.92	104.05
Total	36	417.84	423.18	5.34	160.08	203.63	43.54
Percent of slack in Type III		100.00	103.08	3.08	100.00	182.01	82.01

marketing regulation, integration of agro-aiding funds, etc., so as to improve the profitability of wheat farming.

3.4 Radial and Slack Analysis of the Inputs

As implicated by Audibert et al. (2003), the slacks provide an indication of the inputs in excess supply, and number of DMS shows the capacity of each variable that constraining production efficiency, the smaller the higher. Within Type III, *fertilizer inputted* was the first constraint limiting output as it was supplied in the excess with only one county. Fixed assets were the least constraining inputs, since 11 counties were supplied with surplus (Table 4). The summary of radial and slack movement means the total amount needs to be adjusted, so as to reach a target input while keeping output unchanged. Fixed assets can be decreased by the largest margin of 37.76%, showing the relatively redundant and inefficient usage of this input. Meanwhile, the input amount of fertilizer shows the most efficient usage with the margin of only 10.97%.

4 Effects of the Determinants

4.1 Tobit Regression and the Results

Effects of the determinants will be evaluated with Tobit regression (Dhungana et al., 2010; Tobin, 1958):

$$\theta_i = \beta_0 + \beta_1 d_{i1} + \beta_2 d_{i2} + \beta_3 d_{i3} + \beta_4 d_{i4} + \beta_5 d_{i5} + \beta_6 d_{i6} + \beta_7 d_{i7} + \varepsilon_i \quad (3)$$

where β_i are parameters to be estimated and ε_i are error terms assumed to be distributed with $N(0, \delta^2)$.

Table 4 Radial and slack analysis of the inputs per mu

		Labor (day)	Land rent (yuan)	Seed (kg)	Fertilizer (kg)	Machinery (yuan)	Irrigation (yuan)	Fixed assets (yuan)
Mean movements	Radial	0.67	11.74	1.83	3.12	10.13	10.13	0.80
	Slack	0.20	2.12	0.77	0.14	5.05	11.37	2.29
	Total	0.87	13.86	2.60	3.26	15.148	17.10	3.10
Percent of movements (%)	Radial	10.51	10.51	10.51	10.51	10.51	10.51	10.51
	Slack	2.49	1.59	4.11	0.46	4.86	18.69	27.25
	Total	13.00	12.10	14.62	10.97	15.37	29.19	37.76
Number of counties	Radial	14	14	14	14	14	14	14
	Slack	3	3	6	1	7	10	11

Through the application of EViews 7.0, maximum likelihood estimations were conducted. The effects of each determinant to the total efficiencies were evaluated and presented in Table 5. Meanwhile, for each determinant, the value of t-Ratio and the statistical significance in the level of 1, 5 and 10% were listed respectively.

Table 5 Effect of the determinants on total production efficiency of wheat

	Determinant	Coefficient	*t*-Ratio
Basic productive factors	Agro-labor per farm	0.112*	1.965
	Average size of farmland	−0.002	−0.146
Basic productive conditions	Ratio of irrigable land	0.003**	2.210
	Power of agricultural mechanization	0.004**	2.282
Basic political factors	Extension staffs of agro-tech	0.011	1.312
	Agricultural subsidies	−0.010***	−3.302
Basic potential resources	Water resources applicability	0.000	0.278
	Average schooling length of rural labor	0.048	1.234
Constant		0.441	1.111
S.E. of regression		0.071	
Log likelihood		17.492	

Note ***, **, and * represent statistical significance in the level of 1, 5 and 10% respectively

4.2 Analysis of Determinants

(1) Effects of basic productive factors. As hypothesized, *agro-labor per farm* has a significant and positive coefficient of 0.112, indicating that the more agricultural labors a farm embraces, the more efficient its production will be. However, our hypothesis on the significant and positive contribution of land size was not supported by the result. It may be explained by the fact that the surveyed farms only embraced farmland less than 10.16 *mu* (0.68 ha), which is not large enough to make scale economy. For most of the farmers, arable land is still basic means of production and taking the role of fundamental social insurance to some extent. Therefore, especially after the agricultural taxes were rescinded, they would prefer to farm by themselves rather than lending out, even if it may lead into larger scale and more efficient production. With the improved land-use policy in China, allocation of land resources and scale management are constantly optimized during recent years. According to the *Measures for the circulation of rural land management rights* released by Ministry of Agriculture and Rural Affairs in 2021, the contracted management of land registration system is established and improved to protect farmers' legitimate rights and interests. Under a principle of voluntariness and compensation by law, famers are more confident to participate in land circulative activities, enlarge cultivated scale moderately and become the real beneficiaries in the land circulation and sale management. Meanwhile, the government is committed to strengthening the vocational education for farmers by operating diversified training activities over the years, which acts an effective power in raising wheat production.

(2) Effects of basic productive conditions. The two factors of *Ratio of irrigable land* and *Power of agricultural mechanization* were both significant and positive to the total efficiency. As hypothesized, it indicates that the irrigation and machinery condition is really indispensable to wheat farming. In terms of irrigable land, the government has put efforts to increase the investment in water infrastructure and conservancy in recent years, aimed to achieve high yield and efficiency in grain production. It makes great extension of the irrigable land and plays a key role in improving the technical efficiency of grain production. According to the data released by the Ministry of Water Resources, the irrigated farmland reached 1.037 billion mu, accounting for more than half of the total cultivated area, producing 75% of grain products in China by 2020 (State Council Information Office, 2021). At the same time, with a higher level of agricultural mechanization and sufficient support for precision agriculture from the government, autonomous agricultural machinery has gradually been used in farmland. At present, the ownership of large and medium-sized agricultural machinery applied in agricultural operations has exceeded 5 million units. In this context, it is easier to adopt an autonomous agricultural machinery system, and hence improve the technical efficiency greatly with combination of automatic and intelligent control systems.

(3) Effects of basic political factors. *Agricultural Sci-tech extension staff* per km^2 was insignificant, indicating that the staff and agencies were inactive and not completely fulfilling with their duty of spreading advanced sciences and technologies. It may due to less educational background of the staff and lack of funds as surveyed by Shi et al. (2007) in some countries of Hebei. Meanwhile, the effect of agricultural subsidy is significant by negative, which maybe against the traditional imagination but interpretable with further analysis. One funding source of subsidy is the transfer payments from higher governments, which is often in favor of the less developed counties. At the same time, subsidy is funded by local fiscal revenue, which may endow superiority to the developed counties. In other words, the best funded farmers are not necessarily most efficient in wheat farming. Another important reason is that although the subsidies are aiming to encourage grain farming, they are usually granted simply according to the land area, rather than the sown area of grain, thus making some non-grain farms be subsided as well and reducing efficiency of the subsidies (Yang et al., 2010). In recent years, with the application of modern information technology in agriculture and the innovation of agricultural engineering technology, the government has strengthened the construction of agricultural database and agricultural information network system, including the collection and sorting of agricultural information, as well as data construction of environmental resources and market information. In addition, the development of agricultural information application software, such as agricultural decision support systems, ecological and biological system modeling, equipment and automation control software, have greatly increased the contribution of agricultural scientific and technological progress. By 2021, in the major grain producing areas of China, 800 million mu of high-standard farmland and ditches have been formed into a network, with the main grain crops being fully covered with quality seeds, and the contribution rate of agricultural science and technology has exceeded 60% (Ministry of Agriculture & Rural Affairs, 2021).
(4) Effects of basic potential resources. Both the two variables were proved to be insignificant. As to water resources applicability, it may be because of the inefficient usage of water in both farming and other sectors. The insignificance of average schooling length of rural labor indicated that most farmers are lack of getting new know-how with their knowledge, and they are just farming according to tradition or imitating the others. To address the issue of inefficient water resources, water-saving irrigation technologies are being developed and popularized in agricultural production. As an integrated technical system, water-saving irrigation concerns water resources, engineering, agriculture, management among other sectors. For instance, sprinkler irrigation and trickle irrigation help to reduce the evapotranspiration and increase water use efficiency. As a new technology of combination with irrigation and fertilizer, trickle irrigation promotes the process of fertilizer entering to the field with water, which increases the nutrients and rainfall use efficiency simultaneously. Meanwhile, to alleviate severe water shortages in Northern China, the major strategic infrastructure, South-to-North Water Diversion Project, diverting water from wet South to dry

North, greatly optimized the allocation of water resources. On the other hand, the government has increased the investment in rural education, which has greatly improved the educational environment of farmers in recent years.

5 Policy Recommendation

(1) To deal with the insignificant size of farmland, circulation of farmland should be accelerated, as larger farm scale can generate more penitential for efficient farming modes. In China, land will perform as self-insurance of subsistence for a period. The governments should encourage the concentration of land on farm's own willing, through favorite subsidies, financial and technological aiding. The application of the blockchain platform should be promoted to give full play to its openness, intelligence, traceability, and anti-tampering, so as to stimulate agricultural land circulation, issue agricultural subsidies intelligently, manage agricultural machinery and equipment, as well as strengthen the promotion and application of technologies for agricultural production (Li & Luo, 2021).

(2) Considering the significant productive conditions, inefficient agricultural subsidies and water application, the improvement of subsidizing efficiency should be integrated with the construction of public agricultural facilities. Funds could be pooled from part of the money aimed to subsidize the farms, and make it exclusive for the public construction of irrigating facilities and extension of agricultural mechanization, etc. Meanwhile, the government should invest more on agricultural innovation, deeply integrate agriculture production and information technology, encourage the development of smart agriculture. Strengthen the application of Internet of things (IoT) in agricultural machinery and equipment, promote agricultural automation and intelligence. Popularize the irrigation system with IoT sensing, so as to build up a multi-functional agricultural water-saving irrigation platform.

(3) To tackle with the inactive agricultural technology extension system, insignificant education background but significant number of agricultural labors, concerning institutional reforms should be deepened to accelerate the extension of agricultural technology. It includes the faster introduction of market-driven mechanism to the agencies and staffs. Moreover, individuals and commercial organizations should be encouraged to farm with advanced techniques and ways of management. Thus, attracting more educated people into farming and improve the contribution of science and education to modern agriculture.

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