Analysis of total-factor cultivated land efficiency in China's agriculture

Analýza celkové faktorové efektivnosti obdělávané půdy v čínském zemědělství

Chih-Hai YANG[1], Leah WU[2], Hui-Lin LIN[3]

[1]*Department of Economics, National Central University, Jhongli, Taiwan*
[2]*Macau University of Science and Technology, Macau, Macau*
[3]*National Taiwan University, Taipei, Taiwan*

Abstract: Along with the rapid economic growth, there has been a booming demand for agricultural products in China, but the increased land usage for the manufacturing sector has caused a decrease in the total cultivated land. Through the data envelopment analysis (DEA) approach, this study first constructs the index of the total-factor cultivated land efficiency (TFCLE) by taking the ratio of the actual cultivated land input to target the cultivated land input. Next, we examine the determinants of inefficiency on the cultivated land use. Based on a province-level panel data over 1997–2006, the empirical estimates indicate that the TFCLE is moderate and fluctuates during the sample period, ranging from 0.601 to 0.713, suggesting room for efficiency improvement in Chinese farmland use. The coastal regions are found to experience a significantly higher degree of the TFCLE compared with non-coastal regions. Overall, there is no significant competition effect brought on by the WTO entry on promoting TFCLE, though this effect differs between the coastal and non-coastal regions. The second-stage regression results show that the natural and artificial disasters, flood, drought, and pollution are the the main causes of inefficiency. Innovative activity and the FDI are evidenced to have a significantly positive relation with the TFCLE in Chinese agriculture. We also find the positive TFCLE-enhancing the effects of production diversification and import competition.

Key words: total-factor cultivated land efficiency (TFCLE), innovation, agriculture, China

Abstrakt: Rychlý ekonomický růst Číny s sebou také přinesl rapidní nárůst poptávky po zemědělských produktech. Výrazně rostoucí potřeba zemědělské půdy pro průmyslové a stavební účely však způsobila úbytek celkové obdělávané plochy v zemědělství. Studie nabízí index celkové faktorové efektivnosti obdělávané půdy (TFCLE), zkonstruovaný s využitím DEA analýzy jako podíl vstupu skutečně obdělávané půdy k cílové ploše obdělávané půdy. Dále jsou zde určeny determinanty efektivnosti obdělávané půdy. Empirické odhady založené na údajích panelu dat na úrovni provincií pro období let 1997–2006 ukazují, že ukazatel TFCLE dosahuje středních hodnot a kolísá v průběhu sledovaného období v rozmezí hodnot 0,601 až 0,713, což ukazuje na existenci prostoru pro zlepšení efektivnosti využití zemědělské půdy v Číně. Dále bylo zjištěno, že přímořské regiony dosahují výrazně vyšších hodnot TFCLE ve srovnání s vnitrozemskými. Dále lze konstatovat, že vstup Číny do WTO nepřinesl žádný výrazný efekt konkurenceschopnosti, jenž by se projevil v hodnotách ukazatele TFCLE, i když se tento efekt opět liší mezi přímořskými a vnitrozemskými regiony. Dvoustupňová regresní analýza výsledků ukázala, že hlavními příčinami neefektivnosti jsou přírodní a lidskou činností způsobené katastrofy, záplavy, sucha a znečištění životního prostředí. Inovace a přímé zahraniční investice (FDI) mají výrazný pozitivní vztah k úrovni TFCLE v čínském zemědělství. Bylo rovněž zjištěno, že pozitivní hodnoty TFCLE podporují efekty produkční diversifikace a konkurence dovozu.

Klíčová slova: celková faktorová efektivnost obdělávané půdy (TFCLE), inovace, zemědělství, Čína

Following the implementation of the economic reform in the late 1970s, China has experienced a remarkable high growth rate of the real per capita GDP at more than 9% in average over the past three decades. The impacts of these reforms on agricultural productivity and efficiency have become the topics of

interest to many economists (McMillan et al. 1989; Lin 1992; Kalirajan et al. 1996; Mao and Koo 1997; Fan et al. 2004). On the other hand, an emerging and growing line of research began to discuss the dynamics of agricultural productivity growth and to identify its determinants, such as Fan and Pardey (1997), Jin et al. (2002), Huang et al. (2003), and Chen et al. (2008).

China's fast economic growth has led to a significant improvement in people's living standards and the average income, but along with such rapid economic growth, several serious problems related to agricultural productions have arisen. First is the booming demand on agricultural products and food. China has almost one-fourth of the global population, but it has only 7% of the world's arable land (Liu and Zhuang 2000). The increased incomes have resulted in people consuming more and more food gradually, while whether or not China has the ability to supply food efficiently is now a critical issue. For example, the annual growth rate of agricultural outputs decreased from 8% in 1991–1998 to 4.3% in 1998–2003 (Chen et al. 2008), but the China's population is still growing. Second, to meet the needs of economic development and to attract foreign direct investment (FDI), some farmlands, particularly in the urban fringes, have been transformed into non-agricultural use, causing the depletion of farmland at an unexpected rate. Other agricultural resources, such as the irrigating water and agricultural labour, are decreasing as the economy further develops. For instance, the amount of arable land decreased by about 80 000 hectares during 1996–2004, yet during the same period, China's rural labour force declined, in average, by 0.65% annually. Third, the by-products of industrial development, acid rain, irrigating water, and air pollution, may harm the intrinsic quality of the cultivated land and the crop growth, threatening agricultural performance substantially. Moreover, as a result of the China's WTO commitment to be a model member, the policy measures adopted to increase the grain production, such as price supports and input subsidies, do not conform with the WTO rules and have been abolished or significantly curtailed (Zhu 2004).

Faced with the abovementioned challenges, the question of whether China agricultural production is sustainable is important and topical. The growth of agricultural output can come from the input growth and the change in the total factor productivity (TFP). The TFP growth is recognized as the most important way to raise agricultural outputs, and some studies have

tried to identify the factors of promoting agricultural productivity, such as Jin et al. (2002), Huang et al. (2003), and Chen et al. (2008). Among the agricultural inputs, farmland is a unique input that possesses an irreversible feature, like an energy resource. The total amount of arable land is limited and is difficult to expand rapidly. Once farmland has been converted to non-agricultural use, it is very difficult to change it back to agricultural use. Specifically, if the cultivated land is polluted by the heave metal elements, such as cadmium, emitted along with the industrial production, then it takes at least several decades to recover from the pollution. Faced with the growing food demand and the declining farmland resource, the state council believes that the self-reliance on agricultural crops is very important from the perspectives of food security, social stability, and sovereignty. Therefore, the China's authority has launched a series of land policy reforms to improve the land-use policy.[1] Specifically, the "Basic Farmland Protection Regulations" were enacted in 1994 and revised in 1997, in order to designate the basic farmland protection districts in accordance with the provincial farmland preservation plan. Through strict protection, the Chinese government aims to improve the farmland-use efficiency and to secure long-run food security.

Unlike the previous studies focusing on examining agricultural productivity or efficiency, this paper aims to directly examine the efficiency of the cultivated land in China. As discussed previously, the efficiency of the cultivated land use should be of concern especially under the China's food and land policies. Cultivated land alone cannot produce just any agricultural crop – it must be put together with other inputs in order to produce outputs. Therefore, a multiple-input data envelopment analysis (DEA) approach is applied to assess the cultivated land efficiency in a region. Applying the concept of the total-factor input efficiency developed in Hu and Wang (2006) and the dual theory, this study constructs an index of cultivated land efficiency – named the total-factor cultivated land efficiency (TFCLE) – to assess the cultivated land efficiency across China's regions. The out-of-date technology level and the inefficient production process may generate a redundant portion of input consumption which needs to be further adjusted, implying that, under constant agricultural outputs, the use of cultivated land can decrease if the total-factor cultivated land efficiency does not approach one.

In contrast to manufacturing production, the cultivated land efficiency that contributes to agricultural production is affected heavily by the natural environ-

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[1]For the land policy reforms in China, please refer to Ding (2003).

ment conditions, such as the rainfall, temperature, and their variations. Although agricultural productivity has been evidenced to grow at the rate of 1.5% annually over 1990–2003 (Chen et al. 2008), this growth is lower than the average provincial productivity growth of 2.6% in the 1990s (Zheng and Hu 2006)[2]. Agricultural policies, investments in research and development (R&D), infrastructure, and education on technical change contribute to stimulating the TFP growth, while the influences of natural conditions are essential and may serve as the major determinants of land efficiency. In the second stage, this study aims to examine the determinants of the cultivated land efficiency, especially identifying how important the natural environment factors are.

ARABLE LAND, AGRICULTURAL PRODUCTION, AND FOOD CONSUMPTION IN CHINA

China is one of the largest economies in the world in the terms of area and population. China's territory comprises 9.6 million square kilometres, which ranks one third or one fourth in the world by area and accounts for about 6.45% of the world's total area, and its population of over 1.3 billion is approximately one-fifth of the global population. Despite the ter-

ritory being quite large, it does not imply that there is enough arable land to provide a sufficient food in China due to the diverse landscape. Indeed, the Gobi Desert and the forest steppes dominate the dry expanse in the China's Northern part, while the lush subtropical forests grow along the Southern borders. In the West, the terrain is rugged and a high altitude, with high mountain ranges forming the natural borders with the neighbour countries. China's arable land is concentrated on the Eastern seaside which is low-lying and has a long coastline. In fact, only 130 million hectares of cultivated land accounted for 13.54% of total area in 1996, implying the potential deficiency of food supply due to the limited cultivated land.

The areas of cultivated land have decreased along with the China's rapid industrialization since mid-1990. As Table 1 indicates, the area of cultivated land decreased steadily from 130.039 million hectares in 1996 to 121.800 million hectares in 2006, with the average 0.65% decrease annually. On the supply side, the output of agricultural production was not stable during 1996–2006 due to the influence of climate. There was a bountiful harvest in the late 1990s that reached the peak of 512.30 million tons of crops, but the harvest of magnitude decreased sharply during 2000–2003 and has risen moderately since 2004. On the demand side, China's population has risen from

Table 1. Cultivated land, agricultural productions, and food consumption in China

Year	Cultivated land (million hectares)	Agricultural output (million tons)	Population (million)	Food consumption (million tons)
1996	130.039	504.54	1 223.89	467.46
1997	129.903	494.17	1 236.26	470.23
1998	129.642	512.30	1 247.61	472.30
1999	129.205	508.39	1 257.86	478.39
2000	128.243	462.18	1 267.43	483.18
2001	127.616	452.64	1 276.27	484.50
2002	125.930	457.06	1 284.53	488.02
2003	123.392	430.70	1 292.27	489.22
2004	122.593	469.47	1 299.88	493.00
2005	122.067	484.02	1 307.56	497.75
2006	121.800	497.48	1 314.48	500.00

Sources: All figures except for food consumptions are obtained from the China Statistical Year Book. The amounts of food consumptions are estimated by the Chinese Academy of Agricultural Science

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[2]Adopting the growth account approach and using various data of time period and estimating approaches, the existing studies show that the TFP growth rate ranges from 1.3% to 4.5%. See Islam et al. (2006) for a comprehensive review.

1 223.89 million in 1996 to 1 314.48 million in 2006, which reflects an increase of about 9 million people each year. The demand for food has not only gone up due to a higher population, but along with the rapid economic development, the per capita demand for food has risen accordingly. Food consumption in China has stably increased from 467.46 million tons in 1996 to about 500 million tons in 2006.

One important point worth noting is that the supply of agricultural products turned out to be insufficient, beginning from 2000, which has not happened since 1984 and which has put up a wide concern over the issue of food security. Although technological progress can improve agricultural productivity, the availability of cultivated land dropped along with the rapid economic development, adding stress to the natural environment. Thus, understanding the efficiency of cultivated land is the first step from the perspective of the government policies. Assessing the relative importance of the natural environment and technological progress factors is helpful to improve the efficiency of the limited resource of arable land.

METHODOLOGY AND DATA

Methodology of DEA and measuring cultivated land efficiency

To assess the cultivated land efficiency in China, this study constructs the total-factor cultivated land efficiency (TFCLE) index, which borrows heavily from the total-factor energy efficiency developed by Hu and Wang (2006). The calculation of the TFCLE includes two steps: the first step estimates a multiple-input DEA based on the viewpoint of the total factor productivity. An efficiency frontier is established by the DEA composed of the region with the best production efficiency and with the cultivated land input considered. The TFCLE index is then measured in each region for how far apart each one is from the efficiency frontier.

Charnes et al. (1978) propose a data envelopment analysis (DEA) approach to construct a best-practice frontier without specifying either a production technology or the weights on different inputs and outputs. Using a linear programming technique to assess the efficiencies of decision-making units (DMU), the DEA takes account of all inputs and outputs as well as the differences in technology, capacity, and demographics, and then produces a detailed information on the efficiency of the unit, not only relative to the efficiency

frontier, but also to the specific efficient units which can be identified as the role models or comparators (Hawdon 2003).

This study adopts the DEA approach to construct the best-practice frontier across provinces at each time period in the Chinese agricultural sector. Indeed, this method has been applied to examine agriculture productivity there recently, such as Mao and Koo (1997) and Chen et al. (2008). Assume that there are K inputs and M outputs for each of N units and they are represented by the column vectors x_i and y_i for the i-th unit. The $K \times N$ input matrix X and the $M \times N$ output matrix Y represent the data for all N units. The output-oriented DEA model then solves the following linear programming problem for unit i in each year:

$$\max_{\theta, \lambda} \theta$$

$$s.t. - \theta y_i + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0 \qquad\qquad (1)$$

$$\lambda \geq 0$$

where: θ is a scalar and λ is a $N \times 1$ vector of constants.

The value of θ is the inverse of the efficiency score for the i-th firms, with $\theta \geq 1$. The value of unity for θ indicates a point on the frontier and hence a technically efficient unit, according to Farrell's (1957) definition. That is, a higher value of θ implies a lower efficiency score. The vector λ consists of the reference weights of DMU i over all DMUs.

The DEA identifies not only the most efficient point on the frontier as a target for those inefficient DMUs to achieve, but also recognizes a practical minimum level for inputs on the frontier. The required minimum input is called the "target input", which represents a practical minimum level of an input in conjunction with other inputs so as to produce economic output. The out-of-date technology level and the inefficient production process generate a redundant portion of input consumption which needs to be further adjusted. The amount of the total adjustment (including slack and radial adjustments) is regarded as the inefficient portion of an input in a region, implying the more total adjustments, the less efficient the input used in the region will be. Based on the concept, Hu and Wang (2006) developed the total-factor energy efficiency (TFEE) which is constructed as the ratio of the target energy input that is suggested from the DEA to the actual energy inputs in a firm[3] Borrowing this concept, this study constructs the total-factor cultivated land efficiency as:

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[3]For a detailed concept on constructing the TFEE index, please refer to Hu and Wang (2006).

$$TFCLE\ (k,i) = \frac{\text{target cultivated land input } (k,i)}{\text{actual cultivated land input } (k,i)} \quad (2)$$

which implies in the k-th region and in the i-th year.

The TFCLE index represents the efficiency level of the cultivated land usage in a region. As the target cultivated land input is the best practical minimum level of land input that a region uses, the actual cultivated land input is therefore larger than or equal to the target cultivated input. This makes the TFCLE score range between 0 and 1. As the TFCLE equals one, it implies that a region reaches the highest efficiency on the cultivated land usage. Conversely, if the actual land input level is far away from the suggested target land input, then the TFCLE index approaches zero, representing a low cultivated land efficiency.

Data and variable specification

The data used in this study contain 31 provinces in China during 1997–2006, yielding 310 observations. As mentioned previously, the "Basic Farmland Protection Regulations" were revised to strictly protect farmland in 1997, but the problem of food deficiency has been encountered since the year 2000. Therefore, the analyses based on the 1997–2006 period can provide insightful implications for land as well as food policies. All data come from various issues of the China Statistical Yearbook and the China Agricultural Statistical Yearbook.

The choice of the agricultural output variable is the gross value-added of farming at 1997 constant prices, obtained by deducing the value of intermediate inputs from the gross value of farming output. Most previous studies on China's agricultural productivity have adopted the gross value-added of agricultural output (including farming, forestry, animal husbandry, and fishery). This study focuses on examining the cultivated land efficiency and then adopts the gross value-added of farming rather than the gross value-added of agriculture as the output measure. The value-added statistics are deflated by the price index of plant products.

Three inputs are considered in the DEA method: labour, machinery, and cultivated land. Labour is measured as the number of agricultural workers at the year-end. Machinery refers to the total power of farm machinery. Finally, cultivated land is the area of cultivated land in each province, reflecting the actual utilization condition of China's arable land. Table 2 displays the definition and basic statistics of the variables used in this study.

EMPIRICAL ANALYSIS OF TFCLE

Figure 1 depicts the time trend of the total-factor cultivated land efficiency in China. The calculated average TFCLE is 0.649 over the entire 1997–2006 period, which indicates a potential cost saving of 35.1% on average. To meet the need of the high-tech industries' development, many industrial and science parks were established since the mid-1990s, causing the fast depletion of farmland. The worsened quality of farmland and the climate changes have caused the use efficiency of cultivated land to decrease year by year. The government responded to this situation by passing the Aggregate Planning of Land Use, in order to protect the environmental and agricultural lands by setting the annual land quotas for land conversion from farmland into non-agriculture land. Affected by the increasing strict protection on farmland, the TFCLE seemed to have recovered moderately and then remained stable, hovering between 0.625 and 0.649, since 2001 and onward.

Table 2. Definitions and basic statistics of input and output variables

	Variable name	Definition	Mean (s.e)
Output	Y	Gross value-added of farming: measured by deducing the value of intermediate inputs from the gross value of farming output. (RMB million)	30 932.364 (22 799.024)
Input	x_1	Agricultural labour: measured as the number of agricultural workers at year-end (thousand)	10 226.448 (8 009.292)
	x_2	Agricultural machinery: measured by the total power of farm machinery (thousand KW)	18 167.577 (19 234.037)
	x_3	Cultivated land: the area of cultivated land in each province (thousand acres)	5 004.165 (3 406.978)

Note: The means and standard errors are calculated by pooling the data for the 1997–2006 period
Data sources: China Agriculture Statistical Yearbook

China became a member country of the WTO in 2001, implying that China has to open its agricultural product markets gradually. Does the openness of the agricultural product markets really force China to improve the technical efficiency of farmland use, in order to meet the competition brought on by the WTO entry? The average TFCLE for the post-WTO period (2002–2006) is 0.636, but the average efficiency for the pre-WTO period of 1997–2001 is 0.664, suggesting that the opening up of agricultural product markets did not improve the land use efficiency.

Previous studies on the provincial productivity growth and efficiency claim that coastal regions have a higher efficiency of the aggregate production than their corresponding non-coastal counterparts (e.g. Flesher and Chen 1997; Liu and Li 2006). Is this situation applicable for the efficiency of cultivated land use? As the dash lines in Figure 1 indicate[4], the mean TFCLE of the coastal region is much higher compared to the non-coastal region in each year. The difference test shows that the average TFCLE of the coastal regions (0.833) is significantly higher than that of the non-coastal regions (0.533) at the 1% statistical level, indicating that the divergence between the coastal and inland regions exhibits not only manufacturing productivity, but also the technical efficiency of farming production. The higher TFCLE experienced in coastal regions benefits from, at least in some part, better natural environment conditions[5]. It also probably benefits from a faster technological progress across the coastal regions. This study investigates the determinants of the inefficiency of cultivated land use in the next section.

One interesting result arises as we compute the average TFCLE of the coastal and non-coastal regions for the pre-WTO of 1997–2001 and the post-WTO periods, respectively. For the coastal regions, their average TFCLE of the pre-WTO period is 0.824, which is lower than 0.841 for the post-WTO period, implying that the competition effect of the WTO entry seems to improve the technical efficiency of farmland use. Alternatively, the corresponding mean TFCLE of the non-coastal regions is 0.562 and 0.504 for the pre-WTO and post-WTO periods, respectively. The difference test is significant at the 5% statistical level, indicating that the farmland use efficiency in the inner China decreases rather than rises after the WTO entry. The findings suggest that the competition effect brought on by the WTO entry may differ between the coastal and non-coastal regions in China.

From the regional perspective, which regions experience the best and worst efficiency of the cultivated land use? Table 3 summarizes the calculated TFCLE for each province over 1997–2006. The figures display that the Beijing, Hainan, and Xinjiang province are persistently experiencing the highest TFCLE over the 1997–2006 period. The reasons Beijing witnessed the highest TFCLE rank are perhaps two-fold. One is the accurate and precise planning and dynamic adjustment of arable lands. The other is the strength of the capital and technology inputs, enabling farm production to reach the technological frontier. Hainan and Xinjing are resource-abundant provinces and they act as the traditional resource of China, especially for fruit. Moreover, the Shanghai, Zhejiang, Guangdong, and Fujian provinces experienced a high average TFCLE of 0.958 during 1997–2006. It is apparent that most of the high TFCLE provinces, except for Xinjiang, are located in the coastal regions.
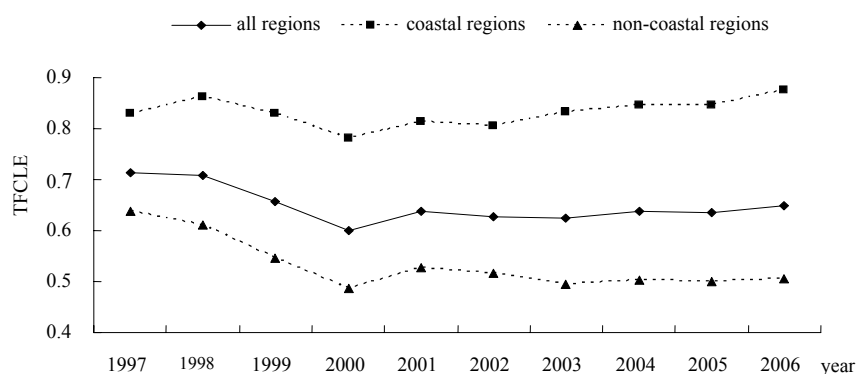

Figure 1. Total-Factor Cultivated Land Efficiency in China, 1997–2006

[4]According to the geographical feature of whether a province is adjacent to the ocean, this study classifies twelve provinces into the coastal region, including Liaoning, Shandong, Hebei, Beijing, Tianjin, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan.
[5]There is a so-called "Aihui-Tengjoan" geographical line that separates China into two regions – Southeast and Northwest parts – according to the 400 mm isohyets. Coastal regions are located in the right-hand side of this line and enjoy a warm weather and a sufficient rainfall which are favorable for farm production.

Table 3. Total-factor cultivated land efficiency by regions, 1997–2006

Province	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Beijing	1	1	1	1	1	1	1	1	1	1
Tianjin	0.898	0.890	0.857	0.711	0.630	0.607	0.691	0.686	0.663	0.735
Hebei	0.546	0.550	0.549	0.494	0.491	0.507	0.568	0.592	0.620	0.723
Shanxi	0.371	0.400	0.287	0.313	0.287	0.320	0.334	0.344	0.288	0.311
Neimenggu	0.465	0.512	0.548	0.502	0.584	0.608	0.436	0.509	0.503	0.523
Liaoning	0.806	1	0.907	0.708	0.808	0.811	0.698	0.740	0.718	0.769
Jinin	0.711	0.893	0.920	0.623	0.813	0.879	0.663	0.677	0.659	0.731
Heilongjiang	0.606	0.513	0.504	0.406	0.459	0.496	0.379	0.428	0.461	0.466
Shanghai	0.728	0.958	0.849	0.820	0.967	0.987	1	1	1	1
Jiangsu	0.842	0.805	0.780	0.715	0.804	0.817	0.819	0.957	0.961	0.996
Zhejiang	0.875	0.907	0.890	0.963	1	1	1	1	1	1
Anhui	0.560	0.484	0.523	0.452	0.466	0.421	0.363	0.424	0.390	0.404
Fujian	0.918	0.944	0.937	0.942	0.996	0.940	1	0.975	0.955	0.939
Jiangxi	0.636	0.541	0.456	0.428	0.471	0.466	0.480	0.497	0.482	0.481
Shandong	0.593	0.642	0.642	0.632	0.630	0.592	0.714	0.680	0.692	0.767
Henan	0.534	0.547	0.553	0.536	0.551	0.498	0.401	0.485	0.504	0.513
Hubei	0.781	0.683	0.570	0.501	0.566	0.572	0.594	0.632	0.619	0.640
Hunan	0.711	0.629	0.568	0.520	0.598	0.550	0.546	0.592	0.588	0.546
Guangdong	1	1	1	0.950	0.968	0.939	1	1	1	1
Guangxi	0.767	0.658	0.550	0.453	0.480	0.460	0.511	0.529	0.551	0.575
Hainan	1	1	1	1	1	1	1	1	1	1
Chongqin	1	0.822	0.559	0.487	0.518	0.522	0.590	0.621	0.661	0.563
Sichuan	1	1	0.653	0.575	0.579	0.550	0.585	0.622	0.643	0.616
Guizhou	0.761	0.648	0.438	0.381	0.394	0.352	0.364	0.356	0.365	0.361
Yunnan	0.630	0.549	0.504	0.455	0.473	0.449	0.452	0.461	0.451	0.459
Tibet	0.642	0.651	0.739	0.745	0.735	0.669	0.738	0.405	0.359	0.476
Shanxi	0.566	0.532	0.456	0.419	0.461	0.448	0.446	0.469	0.488	0.475
Gansu	0.400	0.451	0.400	0.358	0.406	0.366	0.405	0.400	0.402	0.397
Qinghai	0.337	0.344	0.304	0.225	0.283	0.274	0.299	0.300	0.295	0.279
Ningxia	0.415	0.431	0.406	0.325	0.357	0.365	0.304	0.348	0.343	0.375
Xinjiang	1	1	1	1	1	1	1	1	1	1

The Shanxi, Gansu, Qinghai, and Ningxia provinces experienced in average a low TFCLE of below 0.4. Actually, the natural conditions of arable lands in these provinces are relatively unsuitable for farm production, such as unirrigated farmlands, steep slopes, freezing weather, and high altitude. This implies that the conditions of natural environment seem to be particularly relevant to farm production. For example, the high altitude province of Qinghai has 0.467 million hectares of farmland located on steep slopes of higher than a 25 degree gradient, accounting for 71.23% of farmland. Along with the freezing weather and the low annual rainfall, it experienced an extremely low TFCLE of below 0.3 in most years.

DETERMINANTS OF TOTAL-FACTOR CULTIVATED LAND INEFFICIENCY

Actually, the TFCLE varies by individual province and year, and the inefficiency on farmland use is affected by the individual province's characteristics of environmental factors, technological activities, as well as production characteristics. This section inves-

tigates the determinants of inefficiency of farmland use by incorporating the broad influences – mainly environmental factors and technological factors. The empirical model is specified as follows:

$$INEFF_{it} = \beta_0 + \beta_1 CVTEM_{it} + \beta_2 CVRAIN_{it} +$$
$$\beta_3 CVSUN_{it} + \beta_4 FLOOD_{it} + \beta_5 DRY_{it} +$$
$$\gamma_1 INNO_{it} + \gamma_2 FDIR_{it} + \gamma_3 POLLU_{it} + \gamma_4 EDU_{it} +$$
$$\xi_1 SIZE_{it} + \xi_2 HHI_{it} + \xi_3 IMPR_{it} + \varepsilon_{it} \qquad (3)$$

where *INEFF* is the inefficiency measure of cultivated land use which is measured by one subtracting the value of the *TFCLE* for individual provinces in each year.

Farm production is mainly affected by the climate conditions, such as the temperature, rainfall, and sunshine. Distinct plants can be cultivated under various climate conditions, implying that the average values of weather conditions are not particularly relevant to farm production. Instead, the variation of weather conditions is perhaps a basic one affecting farm production. We thus include the coefficient of variation of the temperature, rainfall, and sunshine. They are measured by the ratio of standard deviation to the mean of the monthly average temperature, rainfall, and hours of sunshine, respectively. We denote these three variables as *CVTEM*, *CVRAIN*, and *CVSUN*. A moderate variation of weather is advantageous to the quality of crops, while it is harmful if the variation is too large. There is no distinct expectation on the coefficient associated with these variables, because the weather conditions for each crop vary significantly. Alternatively, the harvest of crops is significantly affected by natural disasters, such as typhoons, droughts, and insect pests, which can inflict heavy losses on farm production. This study therefore includes the ratio of the destroyed cultivated land brought on by flood (*FLOOD*) and drought (*DRY*) and expects that both variables should be associated with a significantly positive coefficient – that is, a higher ratio of the ratio of the destroyed cultivated land brings a lower value of the total-factor cultivated land efficiency.

The influences contributed by technological progress matter also to farm production and promote the agricultural productivity. A province can improve its technological capability through the in-house R&D and the external technology imports into China (Kuo and Yang 2008). This study includes the innovative activity (*INNO*) measured by the logarithm of the sum of R&D expenditures and technology imports so as to capture a province's technological capability[6]. Technological progress has been the main driving force of the TFP growth in China's agricultural sector in the past decade (Chen et al. 2008), and we expect it to impact positively improving the efficiency of the cultivated land use. The term *FDIR* is the ratio of foreign direct investment to the province's gross domestic product (GDP). FDI are an important channel to transfer technologies and absorb the advanced management skills from developed countries. This spillover effect of knowledge may also be applied to improve the quality of farmland, the tilling method, and the plant variety, and it then exhibits a negative impact on the *INEFF* (lower the inefficiency).

Industrial and technological development brings a negative by-product of pollution that worsens the quality of water and air. To consider the potential negative impact caused by the negative externality effect of the technological progress, a pollution variable *POLLU* is included. This variable is measured by the thousand tons of the industrial waste water and th sulphur dioxide SO_2 emission per thousand hectares. Polluted water and air may destroy soil quality and cause pathologic crops, resulting in a lower efficiency on farmland use. Education is also related to the TFP growth of agriculture in China (Chen et al. 2008), because human capital denotes not only the quality of labour input, but also the absorptive ability of learning foreign technologies. The term *EDU* is the proxy of agricultural human capital which is measured by the ratio of the number of high school students to the overall agricultural labour in each province. One region's *TFCLE* may hinge on the quality of human capital in which a better human capital can effectively combine the use of inputs and then obtain higher farmland efficiency.

Furthermore, the term *SIZE* denotes the farm size which is measured by the average area of landholding per household in a rural area. This variable captures not only the return-to-scale effect, but also the efficiency advantages or disadvantages associated with a cultivation scale, such as the size-related factor market distortion and land quality (Feder et al. 1993). It is therefore expected to have a negative coefficient, meaning the inefficiency drops as the farming size increases. The price of various agricultural products varies substantially, and an individual crop is suitable to be planted under a distinct natural environment. Planting various kinds of crops probably

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[6]Due to a lack of the R&D expenditure and technology imports on agriculture alone, the R&D expenditure and technology imports used here include the outlays expended by the independent research institutions, large and medium-sized enterprises as well as higher education.

utilizes the existing cultivated lands effectively[7]. To test this conjecture, we include the diversification of farming production (*HHI*) which is measured by the Herfindahl index calculated from the ratio of farmland use of nine crop classifications[8]. A lower value of the Herfindahl index means a more diversified farming production and it is helpful to utilize all farmland and then raise the TFCLE. Finally, the ratio of imports of agricultural products to the agricultural value-added for a region (*IMPR*) is also included to capture the potential effect of foreign competition. As discussed previously, the commitment to be a model member of the WTO forces China to open its market to foreign agricultural products. The accompanying competition effect brought on by such imports may stimulate local farmers to put forth more efforts on raising the quantity as well as the quality of farm production.

The TFCLE can also be improved. Table 4 shows the basic statistics of variables.

Because the inefficiency measure is a censored variable which ranges between 0 and 1, the Tobit model is employed to estimate the determinants of inefficiency. Table 5 displays a series of estimates[9].

Column 1 presents the estimates including all explanatory variables as specified in the equation (3). Moreover, columns 2–4 display estimates considering two categories of factors, aiming to soften the problem of a high correlation across some variables. While all the estimates are quite similar, the natural environment conditions and technological progress seem to be more relevant to the inefficiency of the cultivated land use.

We first look at the influences of weather conditions. The coefficients of *CVTEM* and *CVSUN* are found to

Table 4. Definitions and basic statistics of inefficiency determinants

Variable name	Definition	Mean (s.e)	Data source
CVTEM	Ratio of standard deviation to the mean of monthly average temperature	0.790 (0.597)	(1)
CVRAIN	Ratio of standard deviation to the mean of monthly rainfall	5.017 (2.497)	(1)
CVSUN	Ratio of standard deviation to the mean of monthly sunshine hours	0.317 (0.147)	(1)
FLOOD	Destroyed ratio of cultivated land brought on by floods	0.066 (0.069)	(1)
DRY	Destroyed ratio of cultivated land brought on by drought	0.175 (0.162)	(1)
INNO	Innovative activity: the logarithm of sum of R&D expenditure and technology imports (RMB million)	11.519 (2.349)	(2)
FDIR	Ratio of foreign direct investment to a province's gross domestic production	0.164 (0.595)	(1)
POLLU	Pollution: ratio of sum of industrial waste water and sulphur dioxide SO_2 emission to cultivated land (ton/hectares)	1.692 (1.689)	(3)
EDU	Outward foreign direct investment (US$ million)	0.224 (0.100)	(1)
SIZE	Operational scale: acre per farmer	2.203 (1.957)	(4)
HHI	Agriculture diversification: the Herfindhal index calculated from the ratio of farmland use of nine crop classifications.	0.521 (0.133)	(5)
IMPR	Import intensity: ratio of imports on agricultural products to a province's agricultural value-added	0.145 (0.373)	(4)

Note: The means and standard errors are calculated by pooling the data for the 1997–2006 period

Sources: (1) China Statistical Yearbook, (2) China Science and Technology Yearbook, (3) China Environment Statistical Yearbook, (4) China Agriculture Statistical Yearbook, (5) Calculated by the authors from the information contained in China Agriculture Statistical Yearbook

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[7]Liu and Zhuang (2000) also argue that the output variable is an aggregate measure of multiple outputs sold at both contract and market prices. Therefore, this variation should not be regarded as real efficiency differences.

[8]The nine crop classifications include grain crops, oil-bearing crops, cotton, fiber crops, sugar crops, tobacco, vegetables, tea, and fruits.

[9]The TFCLE index is calculated from the base of the year-to-year technical efficiency of farming production, implying that the impacts of determinants on inefficiency are essentially cross-sectional rather than panel features. Therefore, we do not employ the technique of the panel Tobit model.

be significantly negative at a conventional statistical level, meaning that a province with a moderate variation of average monthly temperature and/or sunshine experiences a better performance on the TFCLE. It is probably that a moderate variation of temperature and sunshine is advantageous to the quality of crops, especially for fruits and vegetables. However, we cannot infer a causality relationship from the variation of weather to cultivated land efficiency. More importantly, we find that the estimated coefficients of *FLOOD* and *DRY* are significantly positive in all estimates, suggesting that the natural disasters of flood and drought lower the level of the cultivated land efficiency for Chinese agriculture. Even though there is a high quality of agricultural labour and capital, the fixed area of cultivated land can produce fewer agricultural outputs if it encounters natural disasters that destroy the crops. While the above findings are intuitive and seem to be common sense, the effects of environmental conditions are not well controlled in the existing studies which examine the productivity or efficiency of Chinese agriculture.

In addition to environmental factors, technological progress also matters to the efficiency of the cultivated land use. The significantly negative relationship between the innovative activity (*INNO*) and INEFF suggests that a province with a larger amount of expenditures on the R&D and technology imports can lower the inefficiency of the cultivated land use, resulting in a better performance on the TFCLE. This result

Table 5. Determinants of inefficiency on the TFCLE

	(1)	(2)	(3)	(4)
Constant	0.351*** (0.124)	0.624*** (0.089)	0.038 (0.111)	0.268** (0.127)
CVTEM	−0.132*** (0.042)	−0.101*** (0.025)	−0.065 (0.045)	
CVRAIN	0.004 (0.005)	0.007 (0.005)	−0.008 (0.006)	
CVSUN	−0.401*** (0.087)	−0.301*** (0.089)	−0.355*** (0.092)	
FLOOD	0.396** (0.197)	0.500** (0.210)	0.473*** (0.212)	
DRY	0.406*** (0.084)	0.608*** (0.084)	0.388*** (0.089)	
INNO	−0.015** (0.007)	−0.025*** (0.007)		−0.024*** (0.007)
FDIR	−0.758*** (0.127)	−0.219*** (0.127)		−0.668*** (0.127)
POLLU	0.043** (0.019)	−0.011 (0.018)		0.062*** (0.019)
EDU	−0.100 (0.125)		−0.388* (0.028)	−0.038 (0.227)
SIZE	0.003 (0.012)		−0.009 (0.013)	−0.017** (0.008)
DIVER	0.526*** (0.138)		0.771*** (0.149)	0.707*** (0.144)
IMPR	−0.307*** (0.077)		−0.323*** (0.077)	−0.360*** (0.080)
Year Dummies	Yes	Yes	Yes	Yes
Sigma	0.174*** (0.008)	0.187*** (0.008)	0.195*** (0.009)	0.189*** (0.009)
# of observation	310	310	310	310
log-likelihood	52.761	28.883	13.599	27.670
Schwarz B.I.C	10.342	25.746	40.899	21.091

Note: Figures in parentheses are standard deviations. ***, **, and * indicate significance at the 1%, 5%, and 10% statistical levels, respectively

is consistent with the finding in Chen et al. (2008) that technological progress is one of the main driving forces of the TFP growth in China's agricultural sector. Moreover, *FDI* are found to be associated with a significantly negative coefficient, indicating that if a province's capital formation is composed of a larger share of foreign capital; it experiences a higher level of the TFCLE. This result is attributed to the inflows of advanced technologies and management knowledge along with the inflow of foreign investments.

China's rapid development of its manufacturing sector has caused a wide concern due to its accompanying pollution. The pollution may worsen the quality of water and air, harming the growth of crops. As expected, the estimated coefficient of *POLLU* is significantly positive, highlighting the potential negative externality of industrial development on agricultural production. One cannot ignore the importance of this issue, because some toxic elements can cause a long-term and serious destruction on farmland, inducing fallow land for several decades.

The roles of human capital and the economies of scale seem to exhibit a slightly efficiency-enhancing effect. The estimated coefficients of *EDU* and *SIZE* are found to be significantly negative only in columns 3 and 4, respectively. While education can promote the quality of agricultural labour, inducing an efficiency gain in the cultivated land use, work experience is perhaps more relevant to agricultural production compared with education. The significantly negative coefficient of *SIZE* lends the preliminary evidence that there exists a return-to-scale effect on farmland use in China. The cause why the size effect is not significantly sizeable may be attributed to the misidentification of the effect of soil quality where areas with greater soil quality tend to be more densely populated, leading to a subdivision of land into small holdings (Liu and Zhuang 2000).

The *HHI* captures the cultivated land efficiency gain from diversification in agricultural production. As expected, the estimated coefficient of *HHI* is positive and significant at the 1% statistical level in all estimates, suggesting that farmland use with a greater concentration on a variety of crops is associated with a higher level of inefficiency. Planting various kinds of crops can utilize the existing cultivated lands effectively not only to capture the benefit of product diversification, but also to effectively utilize the limited time between planting crops.

Finally, one point worth noting is that we find a strong TFCLE-enhancing effect brought on by the competition of the imported agricultural products. While the open policy of the domestic agriculture product market has been enforced by being a model member of the WTO, the deficiency of food caused by the growing population is another reason. Along with the impact of the growing amount of imports of agricultural products, domestic farmers are not only forced to improve their production efficiency in terms of the cultivated land use, but they also obtain plant seeds of new varieties and try to improve the quality of the incumbent crops.

CONCLUSIONS AND POLICY IMPLICATIONS

The rapid economic growth has caused the depletion of farmland at an unexpected rate in China. This development has attracted wide concerns over whether China has the ability to supply food efficiently. This study first constructions the index of the total-factor cultivated land efficiency (TFCLE) by taking the ratio of the actual cultivated land input to target cultivated land input, and it is conducted through the DEA. Next, we employ the technique of the Tobit model to examine the determinants of the inefficiency on cultivated land use, considering the importance of weather conditions and factors of technological progress.

Based on the province-level dataset during 1997 to 2006, the empirical analyses indicate that the TFCLE is moderate and fluctuates, ranging from 0.601 and 0.713. The moderate TFCLE suggests that there is room for efficiency improvement in China's agriculture. Moreover, this study finds that the coastal regions experience a significantly higher degree of the TFCLE compared with the non-coastal regions. As for the competition effect brought on by the WTO entry, overall it seems not to stimulate an improvement in the cultivated land efficiency, while the effect of the WTO entry differs between the coastal and non-coastal regions.

In the second stage, we investigated the determinants of the inefficiency of cultivated land use. Empirical results show that natural disasters of flood and drought play significant roles among the weather factors. The influence of technological progress, innovative activity and the inflow of FDI have a significantly negative relation with the inefficiency of the cultivated land use, implying that technological progress is one of the main driving forces to promote the TFCLE in Chinese agriculture. However, the negative by-product of economic development, pollution, negatively impacts the total-factor cultivated land efficiency. Finally, we also find a positive relation between the production diversification and the TFCLE and between the import competition and the TFCLE.

Some key agriculture policy implications are derived from this analysis. While the estimated total-factor cultivated land efficiency is moderate, it is hard to expect a scenario of high TFCLE in China, because unexpected natural disasters will destroy crops and reduce the value-added of agricultural outputs substantially. This is the distinct feature differentiating agricultural and manufacturing productions. Fortunately, technological progress can improve not only manufacturing productivity, but also agricultural productivity and efficiency. Therefore, the government and private sector should persistently devote more efforts to the innovative activity, especially in agricultural technologies. From the viewpoint of the regional development policy, the non-coastal regions should emphasize innovative activity as well as attract more FDI in order to improve both agricultural and manufacturing productivity. It will help to narrow the widened regional disparity. Finally, well-functioning factor/product markets and marketing environment are needed to meet the emerging competition brought on by the China's WTO entry.

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