sustainability

MDPI

Article

Are the Changes in China's Grain Production Sustainable: Extensive and Intensive Development by the LMDI Approach

Tianxiang Li [1], Tomas Baležentis [2], Lijuan Cao [1,3], Jing Zhu [1,3,*], Irena Kriščiukaitienė [2] and Rasa Melnikienė [2]

1 College of Economics & Management, Nanjing Agricultural University, Nanjing 210095, China; garylee0428@gmail.com (T.L.); caolj@njau.edu.cn (L.C.)
2 Lithuanian Institute of Agrarian Economics, Kudirkos 18-2, LT-03105 Vilnius, Lithuania; tomas@laei.lt (T.B.); irena@laei.lt (I.K.); rameln@laei.lt (R.M.)
3 China Center for Food Security Studies, Nanjing Agricultural University, Nanjing 210095, China
* Correspondence: crystalzhu@njau.edu.cn; Tel.: +86-25-84395739

Academic Editor: Marc A. Rosen
Received: 19 August 2016; Accepted: 13 November 2016; Published: 24 November 2016

Abstract: China has experienced an uninterrupted growth of grain output during the past decade. However, a long-term analysis indicates fluctuations in productivity and output levels, as well as dramatic shifts in grain crop mix and regional distribution. This paper, therefore, re-examines the major factors behind the dynamics in China's grain production over the period of 1978–2013. The Index Decomposition Analysis technique, facilitated by means of Logarithmic Mean Divisia Index, is employed to factorize the changes in China's grain output into four effects, i.e., yield effect, area effect, crop-mix effect and spatial distribution effect. The results show that yield effect, having been the major driver behind the growth, is experiencing a declining trend over time, with crop-mix effect gaining increasing importance. The results also indicate that changes in crop-mix caused an increase in the total grain output during 2003–2013, however this was due to abandonment of soybean farming, which is not sustainable in terms of self-sufficiency. The effect of spatial distribution has been diminishing ever since 1984. Therefore, re-allocation of areas sown is not likely to damper the sustainability of grain farming.

Keywords: grain production; sustainability; food security; China; Index Decomposition Analysis; Logarithmic Mean Divisia Index

---

1. Introduction

China has achieved a consecutive grain output growth for the past decade. During 2003–2013, China's grain output increased from 431 million t to 602 million t with an annual growth rate of over 3%. The continuous growth in grain output indicates an important improvement in capacity of China's grain production, which offers a significant contribution to food security both domestically and internationally [1–3].

In fact, the periods of enduring increase in grain production are rather rare in the modern China's history [4], as highly volatile trends had prevailed within a longer time span in the past [5]. Numerous studies have examined factors behind the specific trends in China's grain production [6–9]. However, many of these focused on the aggregate analysis, i.e., the key grain crops were aggregated together, often at the national level, but quite a few have looked at the issue from a disaggregate perspective, i.e., examining the performance of different types of crops across different regions.

As put forward by Zhu et al. [4] and Yang [10], there are at least three key reasons for a disaggregate analysis: First, there is a need to meet specific requirements for grain demand, which, indeed, may differ across individual crops. Clearly, not only does the total output of grain matter for China's food supply, but also types of crops need to meet diverse demand. Second, given that crop yields may differ across both crops and regions, spatial and crop-mix variations might induce changes in the aggregate crop yield even when crop-specific yields remain constant, and, hence, affect the total output. Therefore, analysis of the changes in cropping pattern and their impact on the total grain harvest offers an additional perspective when identifying the sources of growth in China's grain production. Third, the example of China shows that the growth rates of the overall grain output varied during different time periods, which has obviously been influenced by multiple factors. Comparisons relying on multiple driving forces will not only provide an in-depth understanding of China's grain output changes in the past, but will also shed light on the potential scope for further developments.

On the other hand, a deeper analysis of driving forces behind China's grain output change would also be important in regards to sustainability of China's grain output growth and the effectiveness of the comprehensive agricultural development (CAD) in China. As for the former issue, there have been concerns on potential for further growth and sustainability of China's grain production [11,12]. Since grain production is highly dependent on (depleting) natural resources, especially land and water (both directly and through the use of bio-chemicals), the recent upswing in grain output growth has exerted additional environment pressures in China [13,14]. Thus, given severe constraints in land and water endowments, it is important to ascertain whether the changes in China's grain output are to be sustainable. This can be achieved by analyzing sustainability of the underlying driving forces. Additionally, in terms of the CAD, which is expected to boost crop yields and harvest thereby contributing to the goals of food security [15], it has been put into practice via modernization of the farming practices, improved irrigation and rural infrastructure (e.g., concrete roads). Besides the CAD, urbanization has played an important role as a limiting factor in shaping the cropping patterns. Wei et al. [12] argued that urbanization took place to different extent in different regions of China with the coastal regions featuring the highest pace of urbanization. Therefore, the analysis of grain output under interaction of multiple phenomena should identify the sources of changes associated with technical advancement (pure yield change) in order to fully fathom the outcomes of the CAD and similar measures.

This paper, therefore, attempts to look into the issue by considering multiple factors affecting grain output simultaneously and thus identifying intensive and extensive factors behind the changes in China's grain output. An Index Decomposition Analysis (IDA) model is employed to isolate the dynamics in extensive and intensive factors since China's rural economic reform in the late 1970s by using crop- and province-specific data. Unlike most aggregate studies focusing just on two sources of changes in grain output, namely dynamics in areas sown and yields, we factorize the changes in crop output into the four terms, viz., area effect, yield effect, crop-mix effect and spatial distribution effect, in this paper. As one can note, the latter three terms comprise the aggregate yield effect. Noteworthy, the inclusion of both spatial and input-mix effects constitutes a novel facet of grain harvest analysis in China. As regards the implementation of IDA, the Logarithmic Mean Divisia Index is applied to operationalize the decomposition. The technique features such desirable properties as perfect decomposition and time reversal (see more details in Section 4). The results are analyzed in period-wise, crop-wise and region-wise manners.

The rest of the paper is organized as follows: Section 2 presents data used. Section 3 examines the general trends in China's grain production for 1978–2013. Specifically, the patterns of changes in harvest associated with different crops and regions are highlighted. Section 4 introduces the Index Decomposition Analysis technique. Section 5 presents the decomposition results and, therefore, identifies the contributions of different factors to the changes in grain output in China in the aggregate, crop and regional dimensions. Section 6 further discusses the constraints for different driving forces as well as the sustainability of China's grain production in the future. The last section summarizes the major findings and their implications on China's food security.

2. Data Used

The research involves multiple variables to quantify the contributions of different factors of changes in China's grain output. Specifically, national and provincial data on output, areas sown and yields are obtained from the China Rural Statistics Yearbook for each crop and cover the period of 1978–2013.

Noteworthy, the definition of grain in China is different from the concept proposed by international organizations, i.e., FAO and USDA, which mainly refers to cereals (e.g., rice, wheat and corn). Specifically, Chinese statistics applies term "grain" to a much wider range of crops, including rice, wheat, corn, soybeans, potatoes, millet, sorghum, and other crops [16–18]. Thus, to simplify the analysis, we classify the Chinese grain crops into the five groups, namely rice, wheat, maize, soybeans, and "other" grain crops.

In order to deliver more general insights regarding the trends in the grain output, we further group China's 31 provinces, autonomous regions and municipalities into the seven regions according to the terrain types and cropping patterns prevailing there [19,20]: (1) Northeast China (NE) encompasses Heilongjiang, Jilin, Liaoning; (2) North China (NC) includes Beijing, Tianjin, Hebei, Shanxi, Shandong, Inner Mongolia; (3) East China (EC) includes Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi; (4) Middle China (MC) includes Hubei, Hunan, Henan; (5) South China (SC) includes Guangdong, Guangxi, Fujian, Hainan; (6) Southwest China (SW) includes Sichuan, Yunnan, Guizhou, Tibet; (7) Northwest China (NW) includes Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang. (We do not include Hong Kong, Macao and Taiwan here. Hainan and Chongqing appear under Guangdong and Sichuan since the former provinces were established in 1988 and 1997, respectively.)

3. General Trends in Grain Production following the Rural Reform in China

3.1. Changes in China's Aggregate Grain Output

Since the late 1970s, when China began rural economic reform, grain production has exhibited remarkable growth. The general trends in grain area sown and output from 1978–2013 are depicted in Figure 1. During the aforementioned period, China's total grain output has nearly doubled by rising from 304.8 million t to 601.9 million t. This increase is particularly impressive given that it has been achieved along with a decrease in the total area sown under grain crops of nearly 7%. Therefore, the upward trend in grain output indicates a substantial improvement in grain yields.

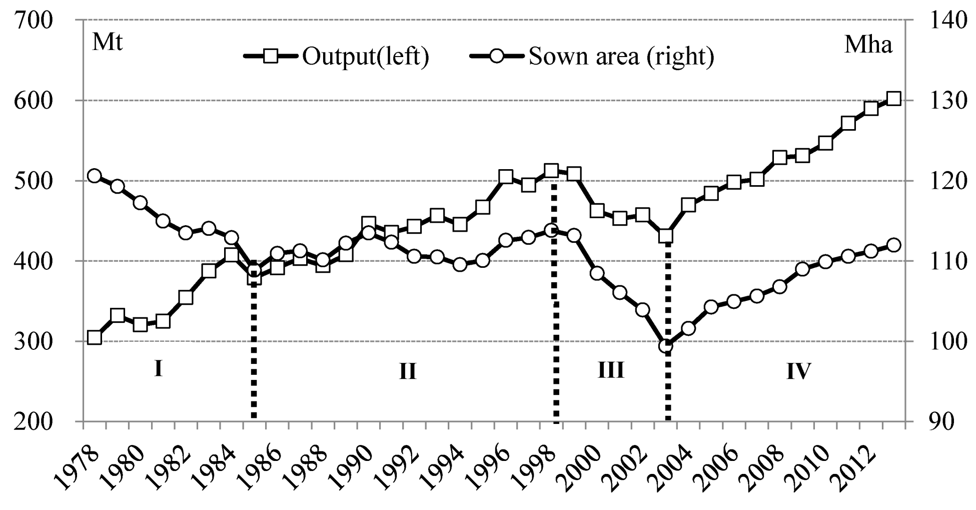

Figure 1. Dynamics of area sown under grain crops and grain output in China, 1978–2013. Source: China Rural Statistical Yearbook (NBSC, various years).

However, as indicated by Figure 1, fluctuations in grain harvest are observed. Indeed, in the spirit of earlier literature, e.g., [5,21,22], the trends in grain harvest in China since the rural economic reform can be analyzed by considering four sub-periods specific with different magnitudes or directions of changes. Sub-period I, 1978–1984, showed a remarkable growth in output with annual growth rate of 5.0%, whereas sub-period II, 1984–1998, was specific with a moderate rate of growth in output of 1.7%, and the area sown virtually stagnated. Sub-period III spans over 1998–2003 and marks a fall in harvest of 15.9% (3.4% p.a.) as well as a 12.6% (2.7% p.a.) decrease in the area sown. Thereafter, sub-period IV, 2003–2013, showed a notable rebound in both area sown (1.2% p.a.) and output (3.4% p.a.) lasting for more than a decade in a row. Therefore, these four time periods will be used as those describing different stages of the development of Chinese grain production.

3.2. Changes in the China's Grain Cropping Pattern

Grain cropping pattern has been significantly altered along with growth in the aggregate output in China. As shown in Table 1, the increase in the rates of growth in the outputs of wheat and maize (126% and 289%, respectively) were higher than the average rate of growth in the total grain harvest (97% during 1978–2013). As a result, the share of the latter two crops has increased in the grain mix. However, at the other end of spectrum, the shares of rice, soybean and "other" grain crops have decreased.

Table 1. Areas sown and output for grain crops in China, 1978–2013.

	Rice		**Wheat**		**Maize**		**Soybeans**		**Others**	
	Output									
	Mt	Share	Mt	Share	Mt	Share	Mt	Share	Mt	Share
1978	136.9	44.9	53.8	17.7	56.0	18.4	7.6	2.5	50.5	16.6
1984	178.3	43.8	87.8	21.6	73.4	18.0	9.7	2.4	58.1	14.3
1998	198.7	38.8	109.7	21.4	133.0	26.0	15.2	3.0	55.8	10.9
2003	160.7	37.3	86.5	20.1	115.8	26.9	15.4	3.6	52.3	12.1
2013	203.3	33.8	121.7	20.2	217.7	36.2	12.0	2.0	47.3	7.8
	Area sown									
	Mha	Share	Mha	Share	Mha	Share	Mha	Share	Mha	Share
1978	34.4	28.5	29.2	24.2	20.0	16.6	7.1	5.9	29.9	24.8
1984	33.2	29.4	29.6	26.2	18.5	16.4	7.3	6.5	24.3	21.5
1998	31.2	27.4	29.8	26.2	25.2	22.2	8.5	7.5	19.1	16.8
2003	26.5	26.7	22.0	22.1	24.1	24.2	9.3	9.4	17.5	17.6
2013	30.3	27.1	24.1	21.5	36.3	32.4	6.8	6.1	14.4	12.9

"Mt" and "Mha" refer to output in million tons and area sown in million hectares, respectively. "Share" refers to the share (in per cent) of each crop in the total grain output or total area sown within a specific year. Source: China Rural Statistical Yearbook (NBSC, various years).

Such changes in grain output structure are highly related to the variations in both areas sown and yields for different grain crops in China. As suggested by Table 1, the notable output growth in maize has been accompanied by equally remarkable increase in areas sown. Specifically, following a slight decline in sub-period I, the area sown under maize has started to emerge rapidly. This process became especially evident in sub-period IV when area sown under maize went up by 50% and maize outpaced rice in terms of both area sown and output. However, the traditional two most important crops—rice and wheat—showed the opposite trends if contrasted with maize as their shares in grain mix firstly increased during sub-period I, but somewhat declined afterwards. The steepest decrease in area sown is observed for "other" grain crops, while the rate of decrease in the area sown was rather limited for soybeans.

As regards changes in yields, all the crops experienced an upward trend, though the gains in soybean yields were rather marginal ones (cf. Figure 2). The highest yield gains are observed for wheat and maize. Specifically, the yields for the latter two crops went from 1.8 t/ha and 2.8 t/ha in 1978 up to 5 t/ha and 6 t/ha in 2013, respectively. Meanwhile, the composite grain yield increased from 2.5 t/ha up to 5.4 t/ha. Notably, the yields of wheat and maize were not affected by the decline during sub-period III to the same extent as it was the case for the remaining crops. Rice remained the most productive crop throughout the period of 1978–2013, even though the yield gap between rice and maize, the second most productive crop, decreased during sub-period IV.

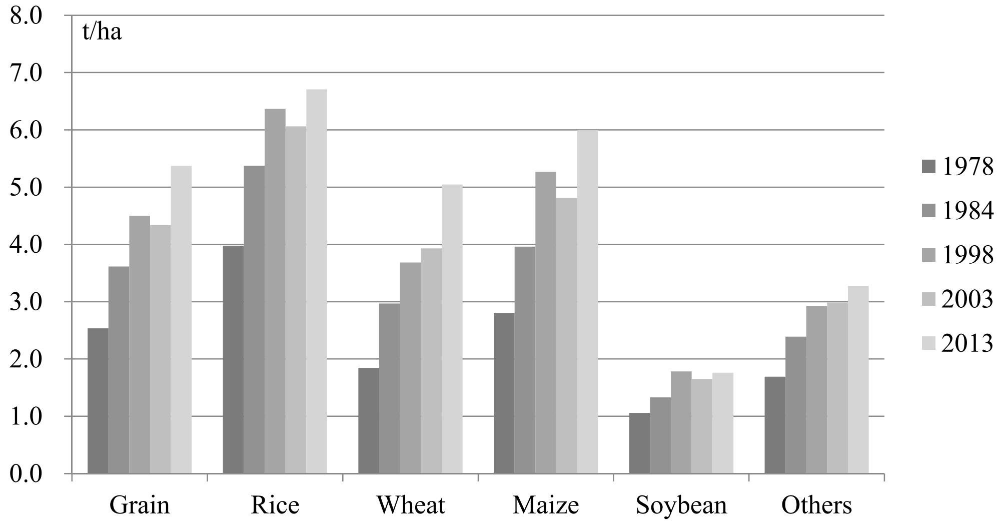

Figure 2. The dynamics of grain crop yields in China, 1978–2013. Source: China Rural Statistical Yearbook (NBSC, various years).

3.3. Spatial Changes in China's Grain Production

Taking a regional perspective, China's grain production showed a clear tendency of shifting from the South to the North (cf. Figure 3a). Obviously, the region of EC saw a sharp decrease in contribution to the overall grain harvest after 1984 (from 22.5% in 1984 down to 16.1% in 2013), whereas NC and NE exhibited the opposite trend. Yet another plunge in contribution to the grain output was that in SC. The overall contribution there had been gradually declining until 2003 (from 10.8% down to 8.9%) and more steeply afterwards ending up at 6.1%. Similar trends prevailed in SW, where a decrease from 15.8% down to 12.4% occurred during 2003–2013. At the same time, the NE region increased its share to the highest extent (from 14.6% in 2003 up to 19.5% in 2013). More detailed information regarding changes and differences in grain yields and crop structure across Chinese provinces is available in Tables A1 and B1, respectively. The aforementioned trends are obviously related to the differences in general economic development existing among Chinese provinces. In particular, as more developed southern provinces saw rapid urbanization along with expansion of non-agricultural activities, importance of the northern provinces increased in the sense of grain production.

In order to present more insights in the underlying causes of the discussed developments, we further focus on the crop-specific dynamics. The changes in the contributions of different regions towards the harvest of each crop are presented in Figure 3b–f.

The production of rice showed the trend of shifting from South to North of China. Traditionally, rice production was mainly distributed in the EC, MC, SC and SW areas (Figure 3b). However, due to improvements in varieties and cultivation techniques, among other factors, rice production has been expanding rapidly in the NE area since the 1990s, and, especially, during 2003–2013. As a result, the share of NE in the national total rice output has increased. During 1978–2013, the rice output increased from 4 million t to 32.9 million t in NE, with regions' relative contribution going up from 3% to 16.2%. Thus, NE has played an increasingly important role in China's rice production, even more significant than that of the SC and SW. In contrast, the share of traditional major rice producing areas—EC, MC, SC and SW—has been declining. Indeed, the shares of EC and SC declined to the highest extent (−4.4 p.p. and −7.5 p.p., respectively).

The production of wheat did not follow the shift from the South to the North. Indeed, as indicated by Figure 3c, wheat is mainly cultivated in NC, MC and EC, with their aggregate share in output amounting to over 70% throughout the period of 1978–2013. Moreover, an obvious tendency of increasing concentration of wheat production in these regions has been observed, with the contribution of NC to the national wheat harvest rising from 32.3% to 33.6%, that of MC rising from 21.1% to 30.0%, and that of EC increasing from 13.9% to 20.4% during 1978–2013. In contrast, the shares of NW, SW, NE and SC have declined. The contribution of NE and SC even came virtually to nil in recent years, indicating these areas have virtually ceased wheat production.

As regards maize harvest, a movement towards the North was observed, yet few regions were affected by such changes (Figure 3d). Specifically, NE and NC remained the major producing areas: the share of these two regions increased from 59.3% to 66.1% during 1978–2013. A stability or even decrease was witnessed by other regions. Especially, the share of SW went down from 15.1% to 9.4% during 1978–2013.

Soybean production has been highly concentrated in NE region (Figure 3e), and the spatial shifts were rather meager for this particular crop. Although the share of NE dropped from 45% to 38% during 1984–1998, it rebounded to 50.4% in 2003. However, it declined significantly in the following decade and ended up at 38.5% in 2013. This was due to expansion of areas sown under maize and rice in NE. As a result, the shares of the other areas, excluding MC, improved steadily.

The "other" grain crops showed an increasing concentration in the South (Figure 3f). The shares of NC and NE declined from 27.6% and 15.8% down to 18.5% and 8.8%, respectively, during 1978–2013. However, the share of NW grew from 7.4% up to 12.2%. The role of EC also decreased as represented by its share falling from 16.8% down to 7.5%. SW appeared as the key region securing its role as "other" grain producer: its contribution increased two-fold from 16.5% up to 35.4%.

Despite the changes in the regional distribution of grain crops in China, there has been a convergence in grain yields among Chinese provinces. Specifically, the coefficient of variation for grain yield shrunk from 0.34 down to 0.18 during 1978–2013. The decrease had been subdued during 1998–2003. Rice and maize show the lowest coefficients of variation for 2013 (0.16 and 0.2, respectively). In contrast, wheat, soybean, and "other" grain crop yields are more diverse across the provinces with coefficients of variation ranging in between 0.31 and 0.34 for 2013. These findings imply that the extent of application of modern farming practices has increased in China as the country-wide trend of increasing yields was followed by a decreasing spread thereof.

In order to reveal the potential impact of spatial distribution on the grain crops, we look at the data on crop productivity across the provinces (cf. Appendix A). As one can note, the aggregate grain yields ranged in between 3.3 t/ha and 7.4 t/ha for 2013. If compared to 1978, the highest rate of increase was observed for the lower bound of the aggregate yields and the lowest rate of increase—for the upper bound. This, indeed, corresponds to the findings of convergence as measured by the coefficient of variation. However, the provinces are rather different in terms of the gains in grain crop yields. The coefficients of correlation are all below the value of 0.67 (which relates soybean and maize yield gains) for the combinations of different grain crops (The coefficients of correlation were calculated between per cent gains in crop yields during 1978–2013 for each pair of crops with provinces being treated as individual observations. Higher values imply that growth in yields is more similar for a combination of the two crops under consideration. The maximum observed value is 0.67 for soybean and maize.) Therefore, the differences in grain yields have been reduced, yet still remain in effect across Chinese provinces.

In summary, there have been structural changes and pure yield changes that caused fluctuations in China's total grain output since its rural economic reform in the late 1970s. The extensive development, as captured by the changes in the area sown, obviously contributed to the dynamics in harvest to a lower extent. In the sequel, we will apply the IDA to decompose the changes in the total grain output over the period of 1978–2013.

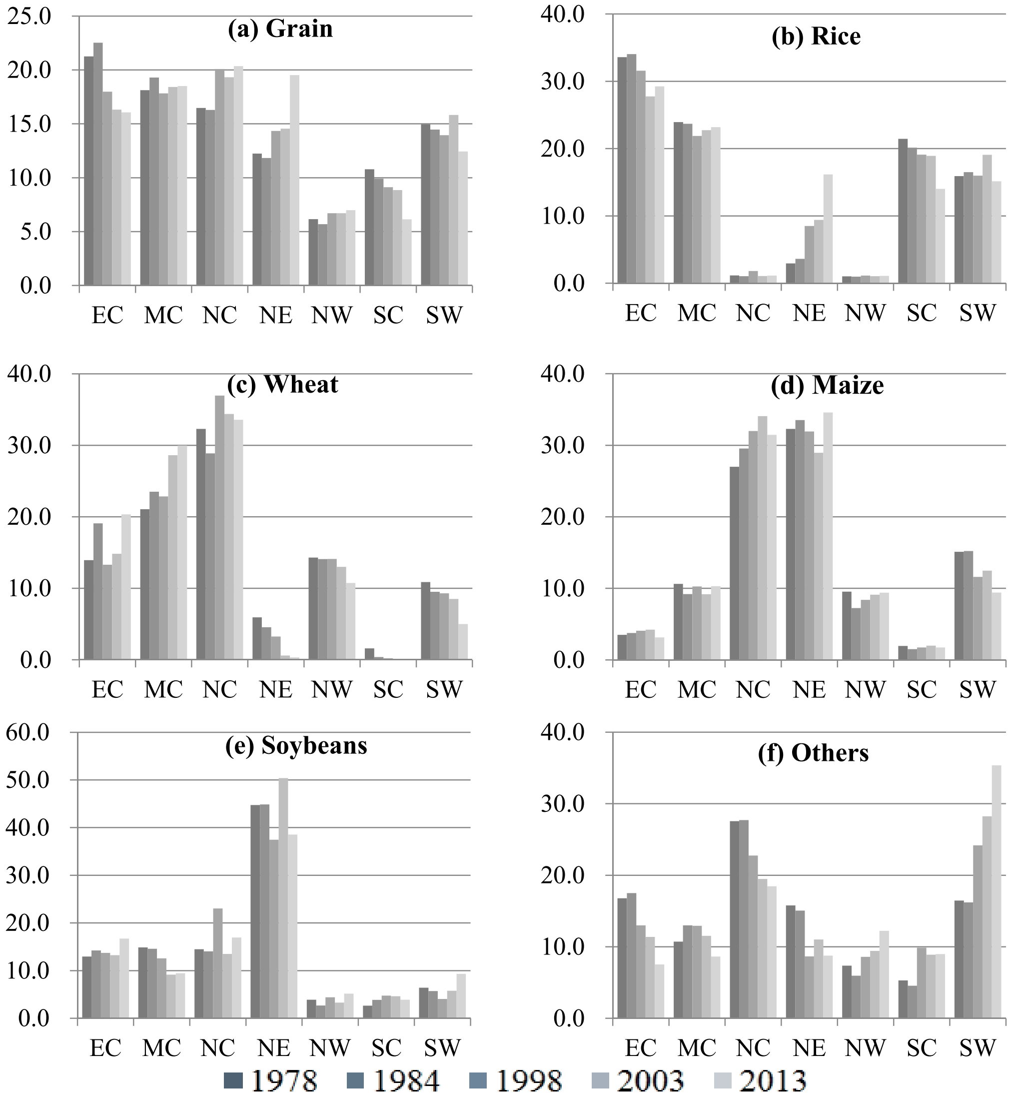

Figure 3. Dynamics in the distribution of grain crops (**a**–**f**) across Chinese regions (%), 1978–2013. Notes: the figure shows the shares (in per cent) of each region in the total grain output for specific years. Source: authors' calculations based on China Rural Statistical Yearbook (NBSC, various years).

4. Preliminaries for Index Decomposition Analysis

Index Decomposition Analysis (IDA) allows one to decompose the changes in a certain variable of interest into a number of effects as represented by multiplicatively related factors. Ang [23] and Xu and Ang [24] summarized the key preliminaries for IDA. From the methodological viewpoint, there are two main strands of the IDA: techniques based on the Divisia index (type I) and techniques based on the Laspeyres index (type II) [25]. Originally, IDA has been extensively applied in the field of energy economics [26–29].

The underlying idea of the index decomposition analysis is to isolate the effects of different factors affecting a certain variable. Indeed, the factors and the resulting variable are related by a functional relationship, which allows for such decomposition. In this paper, we apply the Logarithmic Mean Divisia Index (LMDI), type I, to decompose the changes in China's grain output in terms of factors related to both extensive and intensive development.

The general case of the IDA can be presented in lines with Ang [23]. Say V is the resulting (aggregate) variable, which can be broken down into n factors that fully describe the changes in V throughout the time. Let us denote these factors as $x_1, x_2, \ldots, x_n$. Assume there is index i for sub-categories of the aggregate variable. For a certain sub-category i, the following relationship describes the influence of n factors upon the aggregate variable: $V_i = \prod_{j=1}^{n} x_{ji}$. Summing over sub-categories, one arrives at the general IDA identity:

$$V = \sum_i V_i = \sum_i \prod_j x_{ji}, \tag{1}$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. Furthermore, we look at the changes in the aggregate variable. Therefore, the sub-category value is $V_i^0 = \prod_{j=1}^{n} x_{ji}^0$ for period 0 and $V_i^T = \prod_{j=1}^{n} x_{ji}^T$ for period T. The values for sub-categories can be summed up to arrive at the aggregate values V^0 and V^T.

IDA can be employed to decompose the change in the aggregate variable (i.e., additive decomposition):

$$\Delta V = V^T - V^0 = \Delta V_{x_1} + \Delta V_{x_2} + \ldots + \Delta V_{x_n}, \tag{2}$$

where ΔV_{x_j} is the absolute contribution of the j-th factor towards the change in V.

The techniques for IDA differ in the weighting of factors of decomposition among other issues. The LMDI technique attributes the change in the aggregate variable to the k-th factor as follows:

$$\Delta V_{x_k} = \sum_i \frac{V_i^T - V_i^0}{\ln V_i^T - \ln V_i^0} \ln\left(\frac{x_{ki}^T}{x_{ki}^0}\right), \tag{3}$$

where $k = 1, 2, \ldots, n$. This approach can be applied upon an IDA identity, which, indeed, must be adapted to the phenomenon of interest. The definition of the relationships among the aggregate and factor variables, therefore, constitutes a focal element of the IDA.

In a nutshell, the grain output is determined by the two main factors, namely area sown and yield. In case multiple crops and areas (provinces) are covered, the yield factor can be further decomposed into crop-mix, spatial structure and pure yield effects. Therefore, the following groups of factors can be analyzed: intensity effect (pure yield effect), structural effects (crop-mix and spatial distribution), and area effect (total area sown). More specifically, these effects are defined as follows:

A—area sown effect captures the changes in the overall area sown and, thus, the impact of extensive development;

S_i—spatial distribution effect captures the changes in shares of areas within different provinces relative to the total area sown and their impact upon changes in the aggregate yield;

M_{ij}—crop-mix effect captures the impact of changes in crop structure within the provinces upon the aggregate yield;

Y_{ij}—pure yield effect quantifies the impact of crop-specific yields.

Assuming there are multiple provinces and crops, we define $i = 1, 2 \ldots, m$ as a province index and $j = 1, 2 \ldots, n$ as a crop index. Therefore, the IDA identify can be established to relate the total grain output to the four aforementioned factors:

$$Q = \sum_i \sum_j A \frac{A_i}{A} \frac{A_{ij}}{A_i} \frac{Q_{ij}}{A_{ij}} = \sum_i \sum_j A S_i M_{ij} Y_{ij}, \tag{4}$$

where Q is the total harvest in tons; A is total area sown in hectares; A_i is area sown in hectares for the i-th province; A_{ij} is area sown in hectares for the j-th crop in the i-th province; Q_{ij} is the harvest in tons for the j-th crop in the i-th province. Note that $A_i = \sum_j A_{ij}$.

Consequently, the change in the total harvest additively decomposes as follows:

$$\Delta Q = Q^T - Q^0 = \Delta Q_A + \Delta Q_S + \Delta Q_M + \Delta Q_Y. \quad (5)$$

Following Equation (3), the respective effects ΔQ_A, ΔQ_S, ΔQ_M, and ΔQ_Y can be calculated by employing equations below:

$$\Delta Q_A = \sum_{ij} \overline{Q}_{ij} \ln\left(A^T \big/ A^0 \right), \quad (6)$$

$$\Delta Q_S = \sum_{ij} \overline{Q}_{ij} \ln\left(S_i^T \big/ S_i^0 \right), \quad (7)$$

$$\Delta Q_M = \sum_{ij} \overline{Q}_{ij} \ln\left(M_{ij}^T \big/ M_{ij}^0 \right), \quad (8)$$

$$\Delta Q_Y = \sum_{ij} \overline{Q}_{ij} \ln\left(Y_{ij}^T \big/ Y_{ij}^0 \right), \quad (9)$$

where $\overline{Q}_{ij} = \dfrac{Q_{ij}^T - Q_{ij}^0}{\ln Q_{ij}^T - \ln Q_{ij}^0}$.

The presented framework, therefore, allows one to decompose the change in grain output in terms of both extensive and intensive factors. As Chinese provinces are rather diverse in terms of natural and climatic conditions, the structural effect is a rather important factor for changes in the crop output. However, the latter aspect has been neglected in the literature (see, for instance, [4,24]). The proposed methodology, therefore, allows for a more detailed analysis of changes in the crop production. The analysis can be applied on different time periods in order to ascertain whether the main drivers of changes in grain output vary with time.

5. Decomposition of China's Grain Output Changes during 1978–2013

5.1. Period-Wise Analysis

The period-wise results at the aggregate level are presented in Table 2. One can easily note that, from 1978 to 2013, China's grain output was stimulated by yield gains and the crop-mix effect, while the area sown effect and the spatial effect were negative. However, such patterns varied across sub-periods.

For sub-period of 1978–1984, the decline in areas sown under grain was observed. The output growth was, therefore, mainly attributed to the yield effect. Crop-mix effect also played a somewhat positive role in promoting the grain harvest, whereas the effect of spatial distribution was negative. In general, it is widely believed that reform policies during this period, in particular, the implementation of the Household Responsibility System, offered the incentives for farmers and significantly improved land productivity [30]. Moreover, as mentioned before, the crop-mix changes in the said period were actually the substitution of high-yield wheat and rice for low-yield "other" grain crops. Given rice and wheat have always been the main grain crops in China, such changes in the crop-mix would increase the total output, thus contributing to solving the topical problem of food and clothing (*wen bao wen ti*) at that time (The effect, indeed, was two-fold: Directly, increased food supply allowed to ensure food security. Indirectly, higher share of household income could be allocated top clothing.).

As regards sub-period of 1984–1998, the grain output growth in this period was the combined result of positive yield effect, area effect and crop-mix effect, among which yield effect still prevailed, whereas crop-mix effect and area effect played more important roles than before. However, the spatial effect was the only negative factor. Unlike the case of sub-period of 1978–1984, the crop-mix change was more favorable towards maize during this period, which might be partly associated with the rapid development of livestock farming and the increasing demand for feed. However, since the increase in maize production was accompanied by a decreasing cultivation of rice (which, indeed, showed higher yields than maize did) and other crops, the positive effect of crop-mix was somehow reduced, and amounted to some 10 million t only.

Table 2. Period-wise decomposition of changes in China's grain output, 1978–2013.

Periods	Area Effect		Spatial Effect		Crop-Mix Effect		Yield Effect		Total Change	
	Mt	Share	Mt	Share	Mt	Share	Mt	Share	Mt	Share
1978/1984	−23.4	−23.8	−2	−2.0	5.5	5.6	118.2	120.1	98.4	100
1984/1998	3.6	3.4	−7.4	−7.0	10	9.5	98.7	94.0	105	100
1998/2003	−63.2	77.5	−3.3	4.0	0.7	−0.9	−15.8	19.4	−81.6	100
2003/2013	59.9	35.0	−0.3	−0.2	31.2	18.2	80.5	47.0	171.2	100
1978/2013	**−30.7**	**−10.5**	**−13.6**	**−4.6**	**57.4**	**19.6**	**279.6**	**95.5**	**292.8**	**100**

"Mt" refers to output measured by million tons and "Share" refers to the magnitude of each effect relative to the total change for a given time period. Source: authors' calculations based on China Rural Statistical Yearbook (NBSC, various years).

During the sub-period of 1998–2003, with exception for crop-mix effect, all the other effects contributed to a decrease in the output. Shrinkage in area sown was the prevailing factor for decline in the output, accounting for almost 78% of the total contraction in the output at that time. Moreover, yield loss also played an important role in this process with a contribution of 19.4%. The decline in both grain acreages and yields in the latter period was mainly related to the government policies. Specifically, reduction in grain purchase price, encouragement of agricultural structural adjustment (i.e., promotion of cash crops in lieu of grain), and promotion of ecological projects (i.e., the "grain for green" program) were the most decisive measures at that time [31]. Meanwhile, the rapid industrialization and urbanization in China along with a steep decline in the net revenue from grain farming constituted important factors for land conversion to non-agricultural use and decrease in agricultural inputs for grain production [32].

In sub-period of 2003–2013, the robust growth in grain output was mainly due to the expansion in areas sown as well as yield gains. Meanwhile, crop-mix changes with high-yield maize and rice replacing low-yield soybean and "other" grain crops also significantly contributed to the growth observed during the period, whereas the spatial effect remained negative. The rebound in grain production specific for this period is an outcome of increased motivation for grain farming due to a plethora of subsidy payments and price support schemes [33,34]. Moreover, CAD with public investments into rural infrastructure, agricultural R&D and extension stimulated technical progress [35,36]. Finally, favorable weather conditions positively impacted grain production [4,5,37]. Therefore, a number of causes rendered increases in both areas sown and yields during 2003–2013.

Some general trends can be outlined on the basis of temporal variations in different effects. Most importantly, yield effect has always been the primary factor to stimulate the grain harvest in China, yet its absolute magnitude decreased with time. Area effect increased after 2003, which indicated that the recent increase in grain output in China was highly dependent on expansion in area sown. The importance of crop-mix effect has also increased. Indeed, these developments were fueled by increase in demand of livestock products and price support policies in favor of specific grain crops (i.e., minimum purchase price for rice and wheat; temporary stocking purchase price for maize and soybean) (see [15,33] for further details.). The spatial distribution effect was negative, indicating that the shift of grain production from more productive southern regions to the less productive northern regions has caused negative impacts on the aggregate grain output in China. However, the magnitude of spatial distribution effect diminished thus implying that (1) the structure of the area sown has become more stable in terms of soil fertility; (2) further changes have been bounded by regional differences in resource scarcity (e.g., water and land endowments) and underdeveloped rural infrastructure.

5.2. Crop-Wise Analysis

In this section, we further present the decomposition results in the crop-wise manner. As the "other" grain crops only account for a relative small part of China's grain production (some 8% of the total grain output), this sub-section mainly focuses on rice, wheat, maize and soybeans.

5.2.1. Rice

Figure 4 presents the results of the IDA for changes in rice output. The period of 1978–1984 marked an increase in rice output of some 41 million t. In this case, the increasing yield was the main driver of change, responsible for 113.1% of the total output change, whereas crop-mix effect appeared as much less significant one, albeit positive, with a contribution of 10.7% of the total output change. The loss in harvest due to decreasing areas sown under rice was more than four times smaller than the gain due to pure yield effect. Indeed, the subsequent periods of 1984–1998 and 1998–2003 showed lower growth and even decrease, respectively. The period of 1984–1998 was specific with an increase in rice output of 20 million t. Again, the pure yield effect was the main driver behind the harvest growth. However, the spatial distribution effect caused a loss in the harvest of over 11 million t.

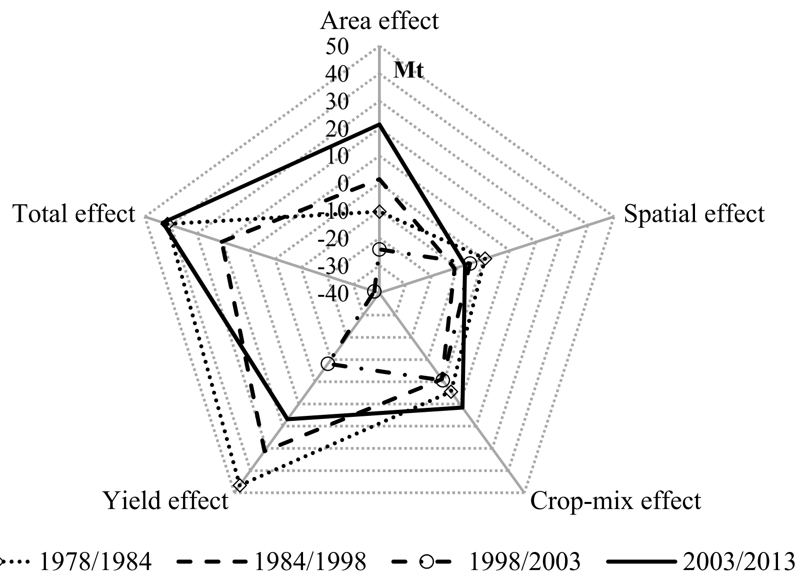

Figure 4. Decomposition of changes in China's rice output, 1978–2013. Source: authors' calculations based on China Rural Statistical Yearbook (NBSC, various years).

Whereas the changes in rice harvest were mainly driven by the pure yield effect, the period of 1998–2013 put the area effect (i.e., changes in the area sown) as a factor of major importance. The crisis period of 1998–2003 rendered a decrease in rice production of 38 million t. In this case, the main factor was a decrease in area sown. The last period of 2003–2013 showed an increase in rice output of 43 million t. The increase in area sown was the main factor, accounting for 50% of the total output change. In addition to that, the pure yield effect and crop-mix effect contributed 39.3% and 27.2% of the output change, respectively, whereas negative spatial distribution effect further pushed the rice harvest down by some 7 million t.

Looking at the trends of individual effects, yield effect showed an obviously diminishing magnitude, while area effect showed a tendency to increase. After casting a negative impact upon the change in total harvest in the 1990s, crop-mix effect has been an important factor to promote rice production in China during the last sub-period. The negative spatial effect persisted indicating that rice production has been moving into less fertile lands. However, one might assume a steady state (or, at least, lower possibility for further shift) is to be approached after the 35-year-long shifting.

5.2.2. Wheat

The changes in wheat harvest are decomposed in Figure 5. Wheat output grew by 34 million t during 1978–1984. Pure yield effect and crop-mix effect were the factors stimulating the increase in harvest during the period with contributions of 89.7% and 21.8%, respectively (as relative to the total change). In contrast, area sown effect induced a decrease of 4.5 million t, i.e., −13.2% of the total change. The harvest increased by 22 million t during 1984–1998. In the latter period, only the pure yield effect had a decisive impact (92.7% of the contribution share) upon change in the harvest.

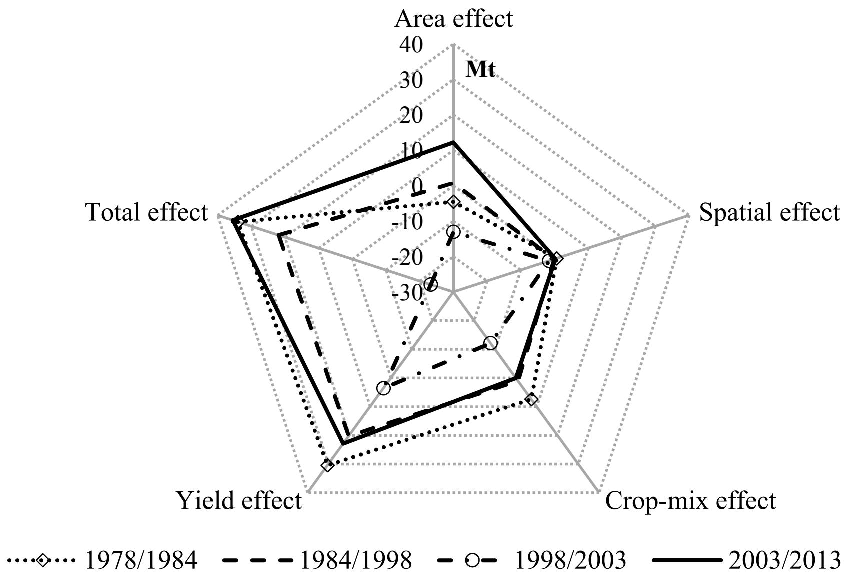

Figure 5. Decomposition of changes in China's wheat output, 1978–2013. Source: authors' calculations based on China Rural Statistical Yearbook (NBSC, various years).

The two subsequent periods were specific with an increasing importance of area and crop-mix effects. Specifically, the decrease of 23 million t for 1998–2003 was driven by area and crop-mix effects of the equal magnitude, with contributions of 56.0% and 52.6%, respectively. The spatial distribution effect had a more important impact only in this particular period. Indeed, wheat output decreased 2 million t due to changes in the spatial distribution of areas sown. The final period of 2003–2013 witnessed an increase in the harvest of 35 million t, which was caused by pure yield effects (64.7%) and area effect (34.5%).

The yield effect for wheat remained rather stable throughout years 1978–2013 (with a plunge for the sub-period of 1998–2003). The two structural effects, viz. spatial distribution and crop-mix, followed downward trends. Therefore, without additional support measures, wheat output gains are likely to mainly rely on yield gains.

5.2.3. Maize

Maize showed the highest rate of growth in harvest among the analyzed crops, namely 289% (from 56 million t in 1978 up to 218 million t in 2013). This is the only crop with an increasing area sown as it grew from 20 million ha up to 36 million ha during 1978–2013. Figure 6 decomposes the change in maize output.

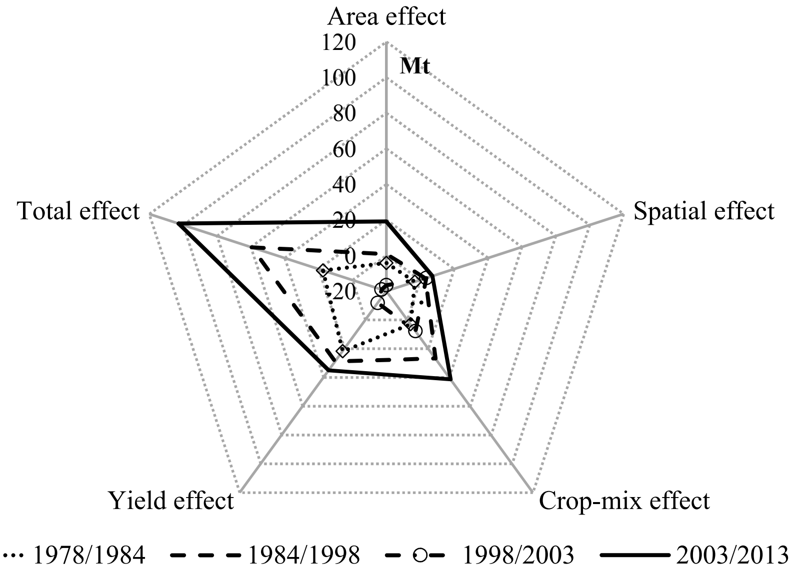

Figure 6. Decomposition of changes in China's maize output, 1978–2013. Source: authors' calculations based on China Rural Statistical Yearbook (NBSC, various years).

During 1978–1984, maize production went up by 17 million t mainly due to increase in yield (the associated contribution amounted to 124.6% of the total change). During the subsequent periods, pure yield effect had not been the only decisive factor behind changes in the harvest. For the period of 1984–1998, the changes in crop-mix and yield were the two equally important factors allowed for increase in the harvest of some 60 million t. As for the crisis period of 1998–2003, the harvest decreased by 17 million t mainly due to the area effect (the effect equaled −97.7% of the total change). The yield effect also had a negative impact (−68.4% of the total change), whereas crop-mix effect (45.6% of the total change) still caused an increase in the output. Maize production spiked in the last period of 2003–2013 (an increase of 102 million t) with the three factors, viz. yield effect, crop-mix effect, and area sown effect, contributing significantly.

The patterns of changes in different components of the IDA model for maize are somewhat distinct if opposed to those for the other crops. The gains in harvest due to area effect seem to be upwards-trended and more robust than those observed in other instances. The yield effect has also been increasing, yet with a serious decline for the third sub-period. Notably, spatial and crop-mix effects have been clearly gaining more importance with time, which might have been partly due to changes in relative prices of grain crops. Indeed, these prices rest on the nutritional transition and adjustments in price support policies in China.

5.2.4. Soybeans

Soybean output increased by about 58% during 1978–2013, i.e., from 7.6 million t up to 12 million t. The change in area sown under soybean was rather meager, namely a decrease of 5% (from 7.1 million ha down to 6.8 million ha). Figure 7 presents the results of the decomposition of changes in the soybean production.

The pure yield effect dominated the other factors during 1978–1998. Accordingly, soybean output went up by 2.1 million t and 5.5 million in 1978–1984 and 1984–1998, respectively. During the latter period, the crop-mix effect exceeded 1 million t. The period of 1998–2003 saw an increase in soybean harvest of just 0.2 million t, which was rendered by structural effects, i.e., spatial distribution and changes in crop-mix. These developments were accompanied by a negative yield effect. The period of 2003–2013 marked a decrease in soybean harvest of 3.4 million t, which was mainly dependent upon shifts in crop-mix. Therefore, the reforms of 2004 onwards seem to have particularly caused a change in farmers' preferences towards the choice of soybean as a cropping culture.

For soybeans, the area effect followed the same trends as it was the case for rice and wheat. Spatial effect followed an upward trend thus indicating movement towards more fertile regions. The crop-mix effect followed the same trend for all but the last sub-periods. The trend for the yield effect remained rather unclear, albeit it can be noticed that the gains due to the said factor have generally decreased after 1998.

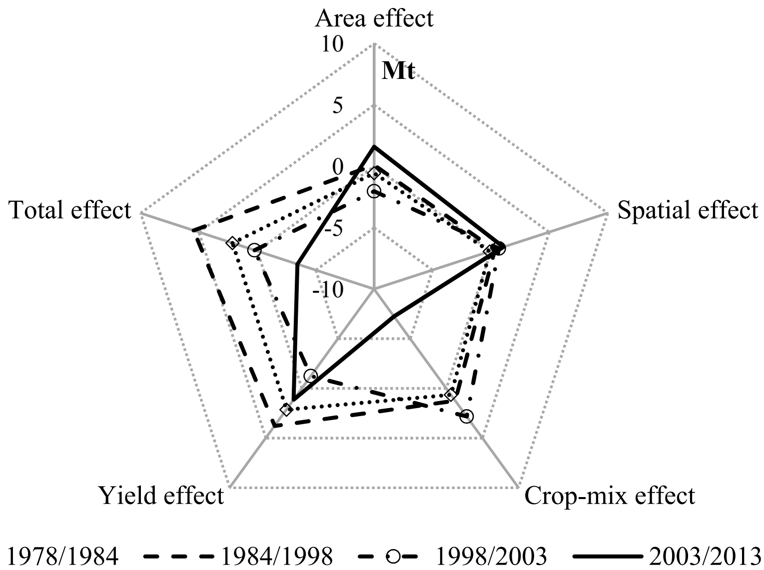

Figure 7. Decomposition of changes in China's soybean output, 1978–2013. Source: authors' calculations based on China Rural Statistical Yearbook (NBSC, various years).

5.3. Region-Wise Analysis

The region-wise analysis suggests that NE and NC were the two main regions contributing to the growth in grain output in China (cf. Appendix B). Indeed, they accounted for 27.4% and 24.7% of the total increase, respectively. The increase in grain output in NE is partly due to spatial distribution effect (as it is not the case for other regions). Therefore, the said region benefited from reallocation of areas sown to the highest extent, whereas EC and SC experienced the opposite trend. Both NC and NE exploited the crop-mix effect while increasing their aggregate yields and total outputs to relatively high extent if compared to the other regions. MC was also an important contributor (18.6%) to the total change in the grain output. EC and SW contributed by some 10% each, whereas NW by 8%. These regions are similar in that yield effect was the main driver for increase in grain output there.

The values of the area effect indicate the extent of harvest change which would have occurred due to proportional changes in area sown across provinces. Due to spatial distribution changes, different crop-mixes and, therefore, aggregate yields, this effect varies across the provinces and regions. Obviously, the main contributors, namely NC and NE, show the lowest values of the latter effect. Therefore, the overall reduction in areas sown would affect grain output to the lowest possible extent there. Furthermore, MC and NW regions are also specific with relatively low values of the area effect. On the other hand, industrialized regions, like EC and SW, are attributed with much higher impacts of the area effect.

As regards crop-mix effect, NC and NE appeared as regions which gained the most due to alterations in crop-mix. A more detailed analysis of the sources of the growth in grain output in the NE region reveals that the yield effect could be further improved. Indeed, yield gains there are not of the same magnitude as observed in the best performing regions (e.g., EC and MC) even though more and more areas sown were concentrated there. Accordingly, extension and consulting services should seek to properly encourage technological development in the presence of extensive growth in NE.

6. Discussion

In summary, the carried out analysis showed that the yield effect has always been the primary factor to simulate grain harvest in China, whereas the area effect has become more important after 2003 and accounted for nearly one-third of the output growth during 2003–2013. Moreover, besides the expansion of area sown under grain and increasing yields, cropping pattern change has also played an important role in ensuring the output growth, while negative impacts of spatial shifts have been observed. In addition, comparison of trends for different effects allows one to gain insights into sustainability and scope of prospective growth in grain output as well as other related issues of, for instance, the effectiveness of CAD and the actual role technical advancement played in promoting China's grain production.

The area sown effect has been becoming more and more important in China's grain production. However, given the serious constraints of land resources in the country, further potential for expansion in area sown is quite limited. Although China possesses the world's third largest arable land area, its huge population renders arable land per capita being just 40% of the world average level [15,38]. Meanwhile, along with rapid industrialization and urbanization, the declines in both land quantity and quality have become a serious concern. Speaking of the period associated with the most evident changes in the land quantity, Figure 8 indicates that the total arable land area in China dropped from 127.1 million ha to 121.7 million ha during 2001–2008, i.e., by 1 million ha per annum. As regards land quality, arable land within high-fertility class currently corresponds to less than one-third of China's total agricultural land area, while the remaining two-thirds fall within middle- or low-fertility classes [39,40]. However, due to the excessive use of chemical fertilizers and pesticides coupled with intensive farming practices, severe land degradation and large scale of land pollution has been observed nation-wide [41]. Furthermore, as industrialization and urbanization process are likely to accelerate, the decline in agricultural area and land quality may not be reversed in the future, thus the growth based on expansion in area sown will not remain as a primary option for further stimulation of grain production in China [42].

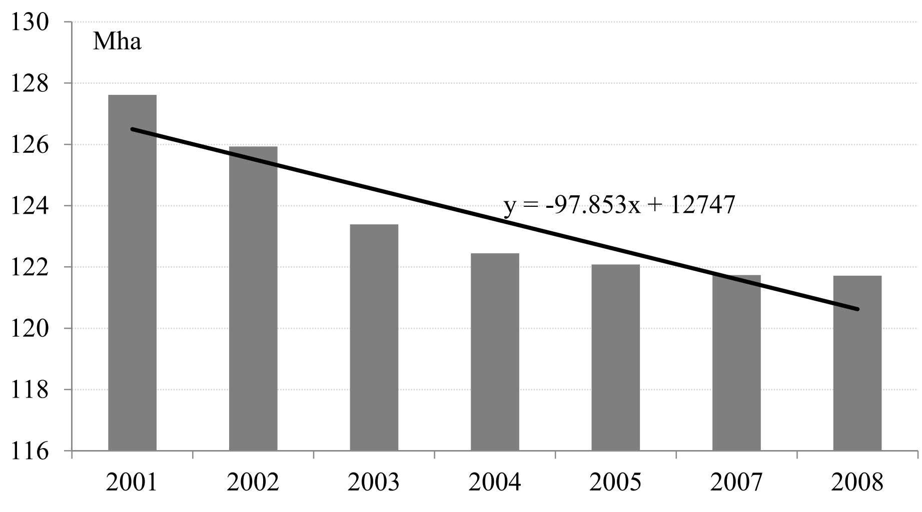

Figure 8. The dynamics in arable land in China, 2001–2008. Sources: China Land and Resources Statistical Yearbook (MLRC, various years).

The effect associated with the spatial distribution of the area sown exerted a negative impact, which indicates that China's grain production has been shifting from more productive southern regions to the less productive northern regions. Anyway, the effect has diminished and, eventually, had a meagre impact. The latter finding implies that spatial distribution effect may no longer appear as an unfavorable factor for grain production in the future. Moreover, spatial distribution of land and water is highly uneven among Chinese regions, with serious mismatches between land and water availability in certain locations [43]. For instance, the northern part of China occupies 3/5 of the country's arable land area, yet only 1/5 of the country's water resources are available there. In contrast, the southern part of China is endowed with 2/5 of land area and 4/5 of water resources [44]. Therefore, further shifts of grain production from the South to the North would definitely be restricted by the already tight water situation in the northern part of China.

Though the changes in cropping pattern have been increasingly important, the potential for growth in grain harvest due to the latter effect is likely to diminish because of the following reasons:

First, the recent replacement of soybean by high-yield maize prevailing in China allows satisfying the booming domestic demand for feed grains to a certain extent and would keep high self-sufficiency in staple foods within the country, yet it would decrease self-sufficiency in oil crops, especially soybeans, whose self-sufficiency rate has already been lower than 15% [45]. Currently, the area sown under soybean constitutes less than 18% of that sown under maize [4], thus the possibilities for further substitution of soybean by maize should be rather limited.

Second, the main drivers behind the changes in crop-mix, as manifested by substitution of maize and rice for soybean and the other grain crops during 2003–2013, are the differences in revenues and profits associated with the latter two groups of crops. These differences are partly due to the price support policies. Table 3 presents yield, price, and profit data for maize normalized by respective data for soybean. Given that maize and soybean are direct substitutes in many areas across China in terms of planting season, the higher net profit for maize motivates famers to expand the production of the latter crop and contract the cropping of soybean. A rapid expansion in area sown under maize has resulted in maize output nearly doubling during 2003–2013 (from 115.8 Mt to 218.5 Mt). However, on the other hand, the growth in maize output has already outpaced that of its demand and led to increased surplus production and stocking in China [46,47]. Thus, having faced this serious situation, the central government has already announced intentions to slowdown stockpiling by reducing purchase price for maize [48]. It can be expected that the relative profit for maize will consequently decrease, as well as the previously positive effects of the crop-mix change.

Table 3. Comparison of average yields, prices and profits for maize and soybean production in China, 2004–2013.

Items	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Relative Yield	2.82	3.10	3.29	3.55	3.26	3.23	3.08	3.13	3.24	3.42
Relative Price	0.41	0.43	0.50	0.36	0.39	0.45	0.48	0.52	0.47	0.46
Relative Profit	1.31	1.37	1.70	1.30	1.19	1.48	1.54	1.84	1.68	1.77

(1) "Relative Yield" refers to the ratio of the yield of maize to that of soybean; (2) "Relative Price" refers to the ratio of the producer price of maize to that of soybean; (3) "Relative Profit" refers to the ratio of the net profit of maize production per ha to that of soybean. Source: authors' calculations based on the National Compilation of Cost and Revenue for Agricultural Products (NDRC, various years).

Third, the changes in international food markets along with interaction between domestic and international food prices will also affect the relative prices of crops under consideration, viz. maize and soybean, and, thus, will impact Chinese farmers' revenue, as well as their decisions regarding crop structure. Indeed, this will add uncertainty to the future crop-mix adjustments in China's grain sector. Thus, in the long run, the room for cropping pattern change in the same direction, as it has been observed in the recent years, will be rather limited.

Methodologically, our findings show the aggregate analysis may overstate the impact and importance of technical progress in promoting grain yield in China, if changes in crop-mix and spatial distribution are not accounted for. It is generally accepted that CAD has positively contributed to China's grain yields and can explain 50% to 60% of increase in the grain output in recent years (cf. [49,50]). However, based on our estimates, though almost 65% of China's grain output growth during 2003–2013 can be attributed to aggregate yield improvement (i.e., the effects of spatial distribution, crop-mix, and yield), the pure yield effect, which should capture the immediate effects of the implementation of CAD, was just 47%. This implies that the effects of the CAD might be overestimated in Chinese agricultural sector.

Given the difficulties associated with relying on land expansion and structural adjustment effects in stimulating grain production, increasing the yields of grain crop varieties through biotechnology might be an unavoidable choice in China in the future. In fact, if compared with the situation abroad, China's grain yields are still lagging behind. As shown in Table 4, China features lower yields of the main grain crops if contrasted to the major producers and/or the countries with the highest yields in the world. Such gaps imply that there is still quite some potential to increase the yields of different grain crops in China.

Table 4. Comparison of grain yields in China and the rest of the world, 2011–2013.

Crops	Rice	Maize	Wheat	Soybeans
China, t/ha	6.74	5.97	3.52	1.80
Major Producer (MP), t/ha	–	9.48	7.40	2.95
World's Highest (WH), t/ha	10.02	28.79	8.93	6.25
China/MP, %	–	62.92	47.58	60.79
China/WH, %	67.25	20.72	39.43	28.73

(1) The data reported are the average values over years 2011–2013; (2) For each crop, we choose the country with the highest yield among the top five producers the world as the "Major Producer". Thus, for rice, maize, wheat and soybean, "Major Producers" are China, the United States of America, France, and the United States of America, respectively; (3) For rice, maize, wheat and soybeans, the highest yields in the world are observed in Australia, United Arab Emirates, Belgium and Thailand, respectively; (4) "China/MP" and "China/WH" refer to the ratios of crop yields in China if compared to those in the "Major Producer" and the "World's Highest", respectively. Source: FAOSTAT.

Looking at results regarding rice production, one can note the area effect has become more and more important, while the importance of yield effect has declined, indicating a rather subdued improvement in rice yield. Though rice also has been enjoying a positive crop-mix effect, especially in recent years, the shift of production from the South to the North has somehow offset the positive effects. Thus, more attention should be paid to R&D thereby fueling technical progress and spillover of technology in rice production.

As regards wheat, the pure yield effect remained as the major effect behind the output change throughout years 1978–2013. Wheat production was rather stable in terms of structural effects. Accordingly, extensive development and pure yield gains remain the main sources for harvest growth.

Extensive development, i.e., the area effect, along with the yield effect, has contributed significantly to growth in maize output. Noticeably, intensive development seems to have become more important as the effects of crop-mix change and spatial distribution change exceeded those of factors associated with extensive development. All in all, maize has become a more preferred grain crop in the past decade as suggested by the crop-mix effect. However, since the favorable relative revenue and net profit of producing maize might no longer be in effect, it can be expected that maize will lose such a favorable position, and the production of maize will shrink in China in the near future.

For soybeans, the area effect and pure yield effect have always been important in terms of harvest variation. Though the area effect, yield effect and spatial effect were all positive in the past decades, they have been offset by unfavorable cropping pattern change. This indicates that soybeans are losing their popularity in less fertile regions.

The region-wise results correspond to those in the other studies [13] in that we have identified similar patterns of crop output change, yet we take a different perspective on decomposition thereof. In general, NE region has seen serious improvements both due to climatic conditions and policy measures taken there. At the other end of spectrum, the coastal region has lost its productive potential due to urbanization and policies promoting abandoning of crop farming. The results indicate that SW region showed moderate growth in the grain output, which was mainly driven by the yield effect. This echoes Wei et al. [13], who argue that "a lack of management techniques" is evident in the area.

Indeed, managerial decisions could further impact the spatial distribution and crop-mix and thus contribute to the growth in the aggregate yields.

7. Conclusions and Policy Implications

This study examined the patterns of China's grain output growth since its rural economic reform in 1978 from a disaggregate perspective. The LMDI technique was employed to quantify the extensive and intensive factors behind the output growth for different grain crops in period-, crop-, and region-wise manners. The results showed that some factors (e.g., spatial distribution) can have little influence at the aggregate level, yet region- or crop-level decomposition rendered somewhat different conclusions. Additionally, accounting for different effects also allows one to gain reasonable insights into sustainability of and scope for prospective growth in grain production as well into impacts of such schemes as the CAD and agricultural technical advancement in China. Therefore, the proposed approach might be useful for revealing the underlying trends in crop harvest which would be neglected otherwise.

Our findings indicate that yield gains have been the major source of growth in grain harvest. The extensive development, as represented by the area sown effect, has also been an important factor since year 2003, when the direction of change in the area sown was reversed due to shifts in the support policies. The most recent period of 2003–2013 is also distinct with the highest impact of the crop-mix effect, which indicates the need for crop-specific analysis in order to address the recent developments in China's crop farming and ensure the implementation of food security objectives.

Looking into the future, the constraints imposed by limited land and water endowments and climate change, among other unfavorable factors, are to emerge. The pressures associated with further growth in grain harvest in China will be even more severe and induce serious ecological costs related to groundwater overuse and nutrient leakage. So far, China's endeavor in ensuring absolute self-sufficiency in staple food has not secured the country's food security needs and, what is more, has caused excessive economic, social, and environmental burden [51]. For instance, almost half of the remarkable increase in China's grain production following 1980 can be attributed to an increasing use of chemical inputs [52]. As shown by Zhang [53] and Luan et al. [54], possessing only 9% of the world's arable land resources, China is responsible for 35% of world's total fertilizer and pesticide consumption due to excessively high rates of application. Overuse of chemical fertilizers and pesticides coupled with intensive farming practices have already contributed to severe degradation of land and large scale of pollution [55]. Thus, to ensure food security and to promote sustainable agricultural development in China, more attention is needed to the following three aspects:

First, given the serious scarcity of arable land and water resources, the primal priority should be to thoughtfully protect and maintain the existing land and water resources. On the one hand, it is important to prevent the loss of the most productive farmland during the ongoing urbanization process. On the other hand, China should pay more attention to improving the quality of cultivated land by encouraging rehabilitation of arable lands that are suffering from ecological degradation and defining strategic measures for improvements of the underperforming cropland. According to some estimates, partial improvements of middle- and low-yield farmlands would increase China's grain production by some 20% [56]. Therefore, improving land productivity through strengthening the agricultural infrastructure and, particularly, irrigation systems, especially in the middle- and low-yield areas, should become important goals of China's agricultural policies in the foreseeable future.

Second, as the structural adjustments will not remain the main impetus for growth in grain output in China, technological progress aimed at improving the specific grain yields will become more important in this sense. As discussed previously, significant gaps among the yields of major grain crops in China and other countries reflects that there is still great potential for improvements in China's grain yields. Therefore, more efforts should be made to intensify the R&D aimed at developing improved varieties corresponding to domestic resource and environmental endowments; i.e., more varieties suitable for the middle- and low-yield areas are needed. In addition, extension and advisory services are highly important in promoting and applying high yield varieties beyond the R&D activities. Finally, besides increase in land productivity, development of water-saving technologies and water price regulation also remain topical issues. These adjustments would allow mitigating hazards resulting from climate change and urbanization.

Third, from an economic perspective, a market-oriented approach is required to achieve food security goals. Indeed, rational exploitation of the international markets would ease China's great environmental and ecological pressures. In recent years, China's total net agricultural imports equaled to substituting 66.7 million ha of agricultural land and 250 billion m^3 water [51,57], thus effectively alleviating domestic shortage of land and water resources. Therefore, rational utilization of the international food markets can effectively supplement the domestic grain supply.

Acknowledgments: Support by Priority Academic Program Development (PAPD) of Jiangsu Higher Education Institutions, the Jiangsu Center for Food Security Studies, the Collaborative Innovation Center of Modern Grain Circulation and Safety, China Social Science Fund (14ZDA038), National Natural Science Foundation of China (71203096, 71303096 and 71303112), Doctoral Program of Higher Education in China (20120097120042 and 20123204120017), and Fundamental Research Funds for the Central Universities (KYRC201407) is acknowledged. The first author would also like to thank the China Institute for Rural Studies, Tsinghua University, for the support.

Author Contributions: Jing Zhu, Tianxiang Li, and Tomas Baležentis proposed the research framework and draft the paper. Lijuan Cao, Irena Kriščiukaitienė, and Rasa Melnikienė worked on the analysis, interpretation of results and discussion. The further revision work was carried out by Tianxiang Li and Tomas Baležentis. All the authors have read and approved the final manuscript.

Conflicts of Interest: The authors have declared no conflicts of interest in this paper.

Appendix A

Table A1. Grain crop yields across Chinese provinces for 1978 and 2013.

	Grain			**Rice**			**Wheat**			**Maize**			**Soybean**			**Others**		
	1978	**2013**	**Change, %**	**1978**	**2013**	**Change, %**	**1978**	**2013**	**Change, %**	**1978**	**2013**	**Change, %**	**1978**	**2013**	**Change, %**	**1978**	**2013**	**Change, %**
Beijing	3.3	6.0	83	4.7	5.0	6	3.4	5.2	52	3.6	6.6	84	2.2	2.0	−11	2.5	3.3	34
Tianjin	1.9	5.2	170	3.5	7.7	122	2.3	5.2	128	1.7	5.3	205	1.3	1.2	−5	1.4	2.3	58
Hebei	2.0	5.3	162	4.9	6.8	37	2.1	5.8	177	2.3	5.5	137	1.3	2.0	57	1.6	3.1	92
Shanxi	1.8	4.0	120	5.3	7.0	32	1.2	3.4	191	3.4	5.7	67	1.2	1.0	−11	1.5	1.4	−5
Neimenggu	0.9	4.9	455	0.7	7.4	894	0.7	3.2	371	3.4	6.5	91	0.7	2.1	211	0.9	2.8	206
Liaoning	2.9	6.8	136	5.5	7.8	43	1.2	4.8	313	4.1	7.0	71	1.0	2.5	146	1.9	4.5	131
Jilin	2.4	7.4	210	4.3	7.8	79	1.1			3.1	7.9	157	1.1	2.1	92	1.8	4.8	158
Heilongjiang	2.0	5.2	165	3.3	7.0	111	1.4	2.9	104	3.1	5.9	90	1.3	1.6	18	1.6	3.7	128
Shanghai	5.1	6.8	33	5.6	8.5	53	3.8	4.0	5	5.5	6.9	27		2.8		4.1	4.1	0
Jiangsu	3.6	6.4	76	4.8	8.5	76	2.7	5.1	87	2.8	5.1	84	1.1	2.2	112	3.2	4.4	37
Zhejiang	4.2	5.9	41	4.8	7.0	47	2.3	3.7	63	2.3	4.2	82	1.8	2.6	39	2.6	3.9	48
Anhui	2.4	5.0	107	3.8	6.2	61	1.6	5.5	241	1.6	5.0	209	0.5	1.2	134	2.1	1.9	−11
Fujian	3.3	5.5	68	3.6	6.1	71	1.4	3.0	122		4.0		0.9	2.5	169	3.2	4.7	45
Jiangxi	2.7	5.7	109	3.2	6.0	88	0.8	2.1	157	1.0	4.1	323	0.9	2.3	147	1.7	3.5	109
Shandong	2.6	6.2	143	3.9	8.4	117	2.2	6.0	179	2.9	6.4	124	1.0	2.5	139	3.2	7.0	118
Henan	2.1	5.7	172	4.5	7.6	67	2.3	6.0	167	2.8	5.6	101	0.8	1.6	106	1.3	3.1	137
Hubei	3.1	5.9	89	4.2	8.0	91	2.0	3.8	87	2.6	4.7	85	1.4	2.3	65	1.7	2.9	69
Hunan	3.3	5.9	82	4.1	6.3	51	1.2	3.4	176	1.5	5.4	256	1.1	2.2	110	1.8	3.9	114
Guangdong	2.8	5.1	84	3.3	5.4	64	1.0	3.3	235	1.2	4.6	272	0.6	2.5	316	1.8	4.6	151
Guangxi	2.2	4.9	129	3.2	5.6	79	0.7	1.7	137	1.6	4.5	178	0.6	1.4	127	1.0	2.5	144
Sichuan	2.9	5.2	77	4.6	7.7	67	2.1	3.4	61	2.8	5.5	98	1.3	2.2	64	2.0	3.7	81
Guizhou	2.4	3.3	38	4.2	5.3	25	0.9	2.0	131	2.6	3.8	49	1.0	0.6	−38	1.3	2.4	88
Yunnan	2.3	4.1	73	4.0	5.8	46	1.3	1.8	43	2.3	4.9	114	1.8	2.5	42	1.4	2.4	75
Xizang	2.5	5.5	118	7.5	6.0	−20	2.9	6.4	120		5.8			4.0		2.3	5.2	126
Shaanxi	1.8	3.9	120	5.1	7.4	44	1.6	3.6	128	2.7	5.0	87	1.0	1.6	68	1.1	2.2	100
Gansu	1.6	4.0	143	3.9	7.2	82	1.7	2.9	76	3.4	5.9	73	1.8	2.1	12	1.2	3.2	168
Qinghai	2.1	3.7	76				2.6	3.8	46		7.0					1.6	3.1	91
Ningxia	1.5	4.7	204	5.9	8.4	41	1.6	3.1	95	3.4	7.9	134	0.8			0.9	1.7	89
Xinjiang	1.6	6.2	284	2.6	8.9	241	1.3	5.4	302	2.2	7.3	236	1.5	3.0	102	1.3	4.2	236
Min	*0.9*	*3.3*	*271*	*0.7*	*5.0*	*573*	*0.7*	*1.7*	*149*	*1.0*	*3.8*	*298*	*0.5*	*0.6*	*17*	0.9	1.4	63
Average	*2.5*	*5.4*	*112*	*4.0*	*6.7*	*69*	*1.8*	*5.0*	*169*	*2.8*	*6.0*	*114*	*1.1*	*1.8*	*69*	1.7	3.3	95
Max	*5.1*	*7.4*	*45*	*7.5*	*8.9*	*18*	*3.8*	*6.4*	*69*	*5.5*	*7.9*	*45*	*2.2*	*4.0*	*83*	4.1	7.0	68

Appendix B

Table B1. Region-wise analysis of changes in grain output in China, 1978–2013.

Regions	Decomposition of Changes in Harvest				Total Change	Normalized Decomposition				Contribution
	A	S	M	Y		A	S	M	Y	
EC	**−5.5**	**−11.1**	**0.4**	**47.2**	**31.1**	**−17.7**	**−35.8**	**1.4**	**152.1**	**10.6**
Shanghai	−0.2	−1.8	−0.1	0.6	−1.5	−15.4	−121.0	−6.6	43.0	−0.5
Jiangsu	−2.0	−3.2	0.7	15.9	11.3	−18.0	−28.5	5.8	140.7	3.9
Zhejiang	−1.5	−9.7	−0.6	5.2	−6.6	−22.3	−146.7	−9.2	78.2	−2.3
Anhui	−1.1	2.9	0.2	15.9	18.0	−5.9	16.2	1.1	88.7	6.1
Jiangxi	−0.7	0.7	0.3	9.6	9.8	−7.0	6.9	2.9	97.3	3.4
MC	**−4.1**	**−0.9**	**4.5**	**54.9**	**54.4**	**−7.5**	**−1.7**	**8.2**	**101.0**	**18.6**
Henan	−1.0	5.9	3.4	29.9	38.1	−2.6	15.3	8.8	78.5	13.0
Hubei	−1.5	−4.4	0.1	13.5	7.8	−18.9	−56.6	1.2	174.4	2.6
Hunan	−1.6	−2.4	1.0	11.4	8.5	−18.8	−28.4	12.2	134.9	2.9
NC	**−3.6**	**−2.1**	**13.9**	**64.1**	**72.3**	**−5.0**	**−2.9**	**19.2**	**88.7**	**24.7**
Beijing	−0.2	−1.7	0.1	1.0	−0.9	−21.9	−191.0	5.8	107.0	−0.3
Tianjin	−0.1	−0.8	0.2	1.3	0.6	−18.8	−135.3	27.1	227.0	0.2
Hebei	−1.2	−3.5	3.1	19.0	17.5	−6.6	−19.9	17.8	108.7	6.0
Shanxi	−0.5	−0.3	2.8	4.4	6.4	−7.3	−4.9	43.7	68.5	2.2
Neimenggu	0.2	8.0	7.6	10.1	25.9	0.9	30.8	29.1	39.1	8.9
Shandong	−1.9	−3.8	0.2	28.3	22.8	−8.5	−16.7	0.9	124.3	7.8
NE	**−1.3**	**19.1**	**24.0**	**38.4**	**80.2**	**−1.6**	**23.9**	**29.9**	**47.9**	**27.4**
Liaoning	−0.8	−1.8	4.7	8.1	10.2	−7.9	−17.5	46.4	79.1	3.5
Jilin	−0.5	5.7	5.5	14.3	25.0	−2.2	22.8	22.0	57.4	8.5
Heilongjiang	0.1	15.2	13.7	16.0	45.0	0.1	33.8	30.5	35.6	15.4
NW	**−1.3**	**−1.3**	**4.3**	**21.7**	**23.3**	**−5.6**	**−5.5**	**18.3**	**92.9**	**8.0**
Shaanxi	−0.7	−3.2	1.1	7.0	4.2	−17.7	−75.9	25.6	168.0	1.4
Gansu	−0.3	0.2	1.5	5.1	6.5	−4.3	3.1	22.6	78.6	2.2
Qinghai	−0.1	−0.4	0.1	0.6	0.1	−117.1	−325.3	78.3	464.2	0.0
Ningxia	−0.1	0.2	1.2	1.2	2.6	−3.1	9.4	46.2	47.5	0.9
Xinjiang	−0.1	1.8	0.5	7.8	10.0	−0.8	18.2	4.5	78.0	3.4
SC	**−3.4**	**−18.5**	**0.2**	**24.1**	**2.5**	**−134.9**	**−740.0**	**9.6**	**965.3**	**0.9**
Fujian	−0.7	−4.0	−0.3	4.4	−0.6	−117.0	−620.6	−41.6	679.1	−0.2
Guangdong *	−1.7	−11.0	0.4	11.0	−1.3	−135.8	−875.5	32.1	879.2	−0.4
Guangxi	−0.9	−3.5	0.1	8.7	4.4	−20.9	−80.5	2.4	199.1	1.5
SW	**−3.9**	**1.8**	**0.1**	**31.2**	**29.3**	**−13.2**	**6.3**	**0.4**	**106.5**	**10.0**
Sichuan *	−2.7	−3.8	0.6	21.3	15.4	−17.9	−24.9	4.1	138.7	5.2
Guizhou	−0.6	2.2	−0.7	2.9	3.9	−15.9	57.9	−18.0	75.9	1.3
Yunnan	−0.5	3.5	0.2	6.3	9.6	−4.9	36.7	2.1	66.1	3.3
Xizang	0.0	−0.1	0.0	0.6	0.5	−7.7	−18.0	−5.0	130.7	0.2

A—area sown effect; S—spatial distribution effect; M—crop-mix effect; Y—pure yield effect.

References

1. Anderson, K.; Strutt, A. Food security policy options for China: Lessons from other countries. *Food Policy* **2014**, *49*, 50–58. [CrossRef]
2. Dev, S.M.; Zhong, F. Trade and stock management to achieve national food security in India and China? *China Agric. Econ. Rev.* **2015**, *7*, 641–654. [CrossRef]
3. Fan, S.; Rue, C. Achieving food and nutrition security under rapid transformation in China and India. *China Agric. Econ. Rev.* **2015**, *7*, 530–540. [CrossRef]
4. Zhu, J.; Li, T.X.; Lin, D.Y.; Zhong, F.N. Analysis of China's nine-year consecutive grain production growth: Contribution and future potential of inter-crop structural adjustment. *Issues Agric. Econ.* **2013**, *11*, 36–43. (In Chinese)
5. Jiang, C.Y. Food security in China: Situations and prospects. *Rev. Econ. Res.* **2012**, *40*, 12–35. (In Chinese)
6. Yang, H.; Li, X.B. Cultivated land and food supply in China. *Land Use Policy* **2000**, *17*, 73–88. [CrossRef]
7. Song, X.Q.; Wu, Z.F. Modelling and mapping trends in grain production growth in China. *Outlook Agric.* **2013**, *42*, 255–263. [CrossRef]
8. Xu, S.W.; Wu, J.Z.; Song, W.; Li, Z.Q.; Li, Z.M.; Kong, F.T. Spatial-temporal changes in grain production, consumption and driving mechanism in China. *J. Integr. Agric.* **2013**, *12*, 1889–1902. [CrossRef]
9. Jin, T. Effects of cultivated land use on temporal-spatial variation of grain production in China. *J. Nat. Resour.* **2014**, *29*, 911–919. (In Chinese)
10. Yang, H. Growth in China's grain production 1978–1997: A disaggregate analysis. *World Dev.* **1999**, *27*, 2137–2154. [CrossRef]
11. Xiao, L.; Yang, X.; Cai, H.; Zhang, D. Cultivated land changes and agricultural potential productivity in mainland China. *Sustainability* **2015**, *7*, 11893–11908. [CrossRef]
12. Wei, X.; Zhang, Z.; Wang, P.; Tao, F. Recent patterns of production for the main cereal grains: Implications for food security in China. *Reg. Environ. Chang.* **2016**. [CrossRef]
13. Zhou, Z.Y. Achieving food security in China: Past three decades and beyond. *China Agric. Econ. Rev.* **2010**, *9*, 251–275. [CrossRef]
14. Tan, S.H. Impacts of cultivated land conversion on environmental sustainability and grain self-sufficiency in China. *China World Econ.* **2008**, *16*, 75–92. [CrossRef]
15. Cater, C.A.; Zhong, F.; Zhu, J. Advances in Chinese agriculture and its global implication. *Appl. Econ. Perspect. Policy* **2012**, *34*, 1–36. [CrossRef]
16. Fan, S.; Agcaoili-Sombilla, M. Why projections on China's future food supply and demand differ. *Aust. J. Agric. Resour. Econ.* **1997**, *41*, 169–190. [CrossRef]
17. Zhu, J.; Hare, D.; Zhong, F.N.; Zhou, Z.Y. Grain promotion and food consumption: Analysis of Chinese provincial data. *Appl. Econ. Perspect. Policy* **2015**, *2*, 332–345. [CrossRef]
18. Li, T.X.; Zhu, J.; Baležentis, T.; Cao, L.J.; Yu, W.S.; Hong, W. Cropping pattern adjustment in China's grain production and its impact on land and water use. *Transform. Bus. Econ.* **2016**. submitted.
19. Liu, S.F. The Research of Rice Spatial Distribution: From 1978–2004. Ph.D. Thesis, Nanjing Agricultural University, Nanjing, China, 2007. (In Chinese)
20. Yang, C. The Research of Spatial Changes and Regional Optimization in the Production of Major Grain Crops in China. Ph.D. Thesis, Zhejiang University, Hangzhou, China, 2009. (In Chinese)
21. Chen, Y.; Li, X.; Jing, W. Changes and effecting factors of grain production in China. *Chin. Geogr. Sci.* **2011**, *21*, 676–684. [CrossRef]
22. Zheng, X.Y.; Xu, Z.; Ying, R. Regional heterogeneity in the changes of grain production in the context of urbanization and structural adjustment in China. *China Soft Sci. Mag.* **2014**, *11*, 71–86. (In Chinese)
23. Ang, B.W. Decomposition analysis for policymaking in energy: Which is the preferred method? *Energy Policy* **2004**, *32*, 1131–1139. [CrossRef]
24. Xu, X.Y.; Ang, B.W. Index decomposition analysis applied to CO_2 emission studies. *Ecol. Econ.* **2013**, *93*, 313–329. [CrossRef]
25. Ang, B.W.; Huang, H.C.; Mu, A.R. Properties and linkages of some index decomposition analysis methods. *Energy Policy* **2009**, *37*, 4624–4632. [CrossRef]
26. Kang, J.; Zhao, T.; Liu, N.; Zhang, X.; Xu, X.; Lin, T. A multi-sectoral decomposition analysis of city-level greenhouse gas emissions: Case study of Tianjin, China. *Energy* **2014**, *68*, 562–571. [CrossRef]

27. Robaina-Alves, M.; Moutinho, V. Decomposition of energy-related GHG emissions in agriculture over 1995–2008 for European countries. *Appl. Energy* **2014**, *114*, 949–957. [CrossRef]
28. Brizga, J.; Feng, K.; Hubacek, K. Drivers of CO_2 emissions in the former Soviet Union: A country level IPAT analysis from 1990 to 2010. *Energy* **2013**, *59*, 743–753. [CrossRef]
29. Baležentis, A.; Baležentis, T.; Streimikiene, D. The energy intensity in Lithuania during 1995–2009: A LMDI approach. *Energy Policy* **2011**, *39*, 7322–7334. [CrossRef]
30. Lin, J. Rural reforms and agricultural growth in China. *Am. Econ. Rev.* **1992**, *82*, 34–51.
31. Zhou, Z.Y.; Tian, W.M. Evolving trends of grain production in China. *Australas. Agribus. Rev.* **2006**, *14*, 1–10.
32. Nath, P.; Luan, Y.B.; Yang, W.M.; Yang, C.; Chen, W.; Li, Q.; Cui, X.F. Changes in arable land demand for food in India and China: A potential threat to food security. *Sustainability* **2015**, *7*, 5371–5397. [CrossRef]
33. Yu, W.S.; Jensen, H.G. China's agricultural policy transition: Impacts of recent reforms and future scenarios. *J. Agric. Econ.* **2010**, *61*, 343–368. [CrossRef]
34. Ito, J.; Ni, J. Capital deepening, land use policy, and self-sufficiency in China's grain sector. *China Econ. Rev.* **2013**, *24*, 95–107. [CrossRef]
35. Huang, J.K.; Yang, J.; Rozelle, S. China's agriculture: Drivers of change and implications for China and the rest of world. *Agric. Econ.* **2010**, *41*, 47–55. [CrossRef]
36. Veeck, G. China's food security: Past success and future challenges. *Eurasian Geogr. Econ.* **2013**, *54*, 42–56.
37. Holst, R.; Yu, X.H.; Grün, C. Climate change, risk and grain yields in China. *J. Integr. Agric.* **2013**, *12*, 1279–1291. [CrossRef]
38. Wu, J.Z.; Zhang, J.H.; Wang, S.G.; Kong, F.T. Assessment of food security in China: A new perspective based on production-consumption coordination. *Sustainability* **2016**, *8*, 183. [CrossRef]
39. Li, J.; Li, Z. Physical limitations and challenges to grain security in China. *Food Secur.* **2014**, *6*, 159–167. [CrossRef]
40. Xu, F.; Zhong, Q.B. The transformation of low-and middle-yield farmland is the effective path to the realization of the grain security in China. *Manag. World* **2010**, *12*, 39–47. (In Chinese)
41. Liu, N.; Li, X.; Waddington, S.R. Soil and fertilizer constraints to wheat and rice production and their alleviation in six intensive cereal-based farming systems of the Indian sub-continent and China. *Food Secur.* **2014**, *6*, 629–643. [CrossRef]
42. Li, G.; Zhao, Y.; Cui, S. Effects of urbanization on arable land requirements in China, based on food consumption patterns. *Food Secur.* **2013**, *5*, 439–449. [CrossRef]
43. Khan, S.; Hanjra, M.A.; Mu, J. Water management and crop production for food security in China: A review. *Agric. Water Manag.* **2009**, *93*, 349–360. [CrossRef]
44. Jiang, Y. China's water scarcity. *J. Environ. Manag.* **2009**, *90*, 3185–3196. [CrossRef] [PubMed]
45. Zhong, F.N. Understanding issues regarding food security and rising labor costs in China. *Issues Agric. Econ.* **2016**, *1*, 4–9. (In Chinese)
46. Ni, H.X.; Yu, K.Y.; Lv, X.D.; Liu, W.B.; Ma, J.L.; Zhang, Y.X.; Li, W.W.; Li, L.K. Research on food security and the control of "non-essential" agricultural import in China. *Issues Agric. Econ.* **2016**, *7*, 53–59. (In Chinese)
47. Gale, H.F.; Hansen, J.; Jewison, M. *China's Growing Demand for Agricultural Imports*; USDA-ERS Economic Information Bulletin Number 136; U.S. Department of Agriculture (USDA): Washington, DC, USA, 2015. Available online: http://ssrn.com/abstract=2709118 (accessed on 16 November 2016).
48. Fan, Q.; Qi, D.; Li, S. Study on the reform and transformation of corn temporary storage system in China. *Issues Agric. Econ.* **2016**, *8*, 74–81. (In Chinese)
49. Chen, J.S. An analysis of China's rural economic situation in 2012 and outlook for 2013. *Chin. Rural Econ.* **2013**, *2*, 4–11. (In Chinese)
50. Wang, J.M.; Xiao, H.B. The nature and prospects of the continuously growth of China's grain output in eight years. *Issues Agric. Econ.* **2013**, *2*, 22–30. (In Chinese)
51. Zhang, H.Z. Feeding the Chinese: Wither the Self-Sufficiency Policy? *IPP Review*. 18 May 2016. Available online: http://www.ippreview.com/index.php/Home/Blog/single/id/143.html (accessed on 16 November 2016).
52. Zhang, X.; Guo, Q.; Shen, X.; Yu, S.; Qiu, G. Water quality, agriculture and food safety in China: Current situation, trends, interdependencies, and management. *J. Integr. Agric.* **2015**, *14*, 2365–2379. [CrossRef]
53. Zhang, J.H. China's success in increasing per capita food production. *J. Exp. Bot.* **2011**, *5*, 1–5. [CrossRef] [PubMed]

54. Luan, J.; Qiu, H.J.; Jing, Y.; Liao, S.P.; Han, W. Decomposition of factors contributed to the increase of China's chemical fertilizer use and projections for future fertilizer use in China. *J. Nat. Resour.* **2013**, *28*, 1869–1878. (In Chinese)
55. Jiao, X.; Yang, L.; Wu, X.; Li, H.; Cheng, L.; Zhang, C.; Yuan, L.; Jiang, R.; Jiang, B.; Rengel, Z.; et al. Grain production versus resource and environmental costs: Towards increasing sustainability of nutrient use in China. *J. Exp. Bot.* **2016**. [CrossRef] [PubMed]
56. Shi, Q.H.; Wang, H.; Chen, F.; Chu, Q.Q. The spatial-temporal distribution characteristics and yield potential of medium-low yielded farmland in China. *Chin. Agric. Sci. Bull.* **2010**, *26*, 369–373. (In Chinese)
57. Zhang, Y.; Zhang, J.H.; Tang, G.R.; Chen, M.; Wang, L.C. Virtual water in the international trade of agricultural products of China. *Sci. Total Environ.* **2016**, *1*, 557–558. [CrossRef] [PubMed]