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Decomposing the Decoupling of Water Consumption and Economic Growth in China's Textile Industry

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Abstract: Unprecedented economic achievement in China's textile industry (TI) has occurred along with rising water consumption. The goal of industrial sustainable development requires the decoupling of economic growth from resource consumption. This paper examines the relationship between water consumption and economic growth, and the internal influence mechanism of China's TI and its three sub-sectors: the manufacture of textiles (MT) sector, the Manufacture of Textile Wearing Apparel, Footwear, and Caps (MTWA) sector, and the manufacture of chemical fibers (MCF) sector. A decoupling analysis was performed and the Laspeyres decomposition method was applied to the period from 2001 to 2014. We showed that six of the fourteen years analyzed (2003, 2006, 2008, 2009, 2011, and 2013) exhibited a strong decoupling effect and three of the fourteen years (2005, 2007, and 2010) exhibited a weak decoupling effect. Overall, China's TI experienced a good decoupling between economic growth and water consumption from 2002 to 2014. For the three sub-sectors, the MTWA sector experienced a more significant positive decoupling than the MT and MCF sectors. The decomposition results confirm that the industrial scale factor is the most important driving force of China's TI water consumption increase, while the water efficiency factor is the most important inhibiting force. The industrial structure adjustment does not significantly affect water consumption. The industrial scale and water use efficiency factors are also the main determinants of change in water consumption for the three sub-sectors.

Keywords: textile industry; water consumption; economic growth; decoupling; decomposition

1. Introduction

Water is not only a significant natural resource for maintaining ecological balance, but also a scarce, strategic resource in economic development [1]. Since the Industrial Revolution, economic development has increasingly relied on water resources. Increasing consumption of fresh water causes water shortages [2]. Recently, this situation has become more and more severe in China, causing great impact on production and overall quality of life [3]. In recent years, the Chinese government has paid greater attention to the water issues in some key industries, such as the steel industry, the paper-making industry, the textile industry (TI), and the electricity generation industry [4].

China is the largest textile producer in the world. The TI is a traditional pillar industry in China and recognized as a precious keystone for China's domestic economies [5,6]. The TI has not only created tremendous growth in some economic indicators, such as profit level, productivity, and selling rate of production, but has also made considerable contribution to market prosperity, the development of the regional economy, and the promotion of employment and social stability [7]. The gross industrial output value of China's TI was approximately 168.42 million CNY in 2014, and the average annual growth rate was 13.96% from 2001 to 2014 (converted to 2014 constant prices) [8,9].

However, the TI is also one of the industries that consumes enormous quantities of fresh water in China. Water is an important input for the manufacture of fibers, yarns, and cloths. Dyeing, printing, and chemical fiber pulp production are typical processes that consume great amounts of water and discharge enormous amounts of waste water [10]. The TI consumed approximately 8647.30 Mt fresh water in 2014, ranking seventh among 41 key industries. Nevertheless, water repetitiveness and water productivity of China's TI are 63.66% and 51.34 Mt/million CNY, respectively, which are much lower than the average value of the major investigated industries (i.e., 89.46% and 94.12 Mt/million CNY) [8,9]. Hence, the sustainable development of China's TI has been restricted by tremendous consumption and relatively low utilization efficiency of water resources. In view of the whole life cycle of textile products, water is a significant factor affecting the production and development of the TI [11].

The TI was listed as one of the pilot industries aimed at creating the ecological civilization of China in 2014. China's State Council issued the Action Plan for Prevention and Control of Water Pollution on April 2, 2015 [4], which requires an improvement in industrial water savings in water-intensive industries (e.g., the TI, steel industry, and electricity generation industry) and the promotion of industrial water recycling. The government also released the 13th Five-Year Plan of the Textile Industry in September 2016. It pointed out that China would strengthen the ecologically sustainable development of the TI and promote advanced water-saving processing technologies and facilities. The phased goals of water consumption and waste water emission in China's TI are that by 2020, water withdrawal of the added value of the unit industry of the textile industry will decrease by 23%, and the total emission of major pollutants will decrease by 10% [12]. The decoupling between water consumption and economic growth will promote the realization of the goal of water saving in China's TI.

The theory of decoupling, first proposed by Ernst Ulrich von Weizsäcker [13], leverages the analysis of the relationship between environmental resource pressure and economic growth. In the field of resources and the environment "decoupling" is defined as the process of economic growth as well as material consumption rate that are not synchronized [14,15]. The decoupling degree is defined by a system of decoupling indicators, and over the history of decoupling theory, the concept has undergone three development iterations, from a simple two-pronged classification system to the advanced quantitative grading scale that we use today. In the first stage, the Organization for Economic Co-operation and Development (OECD) [16] proposed the use of decoupling indicators to divide "decoupling" into "absolute decoupling" and "relative decoupling" based on the driving force–environmental pressure–environmental condition indicator system. Then, Vehmas [17] investigated a set of more detailed criteria for describing the decoupling state, which expanded decoupling categorization to include states of strong decoupling, weak decoupling, strong coupling, weak coupling, expansive coupling, and recessive coupling. Eventually, Tapio [18,19] introduced the concept of decoupling elasticity and the intermediate variables to measure the decoupling state, improving the measurement of decoupling state both in terms of criteria and methodology. According to the theory, the decoupling state can first be divided into coupling, decoupling, and negative decoupling. It is then subdivided into eight categories by decoupling the elasticity value: weak decoupling, strong decoupling, weak negative decoupling, strong negative decoupling, expansive negative decoupling, expansive coupling, recessive decoupling, and recessive coupling.

A number of studies have researched the decoupling relationship between economic growth and water consumption. Yu [20] set detailed criteria to evaluate the decoupling of grain production in relation to irrigation water in an agriculture field and studied the decoupling relationship from the perspective of China's nineteen large agriculture provinces, revealing that only the Guizhou Province has achieved absolute decoupling. Zhu et al. [21] performed research on the decoupling relationship between water utilization and economic growth based on the data of two provinces in China (Yunnan and Guizhou), which both faced a shortage problem of available water resources. They found that the decoupling state was far from ideal and concluded that the root cause of this discrepancy was the slow growth rate of the economy, low efficiency of water utilization and the unreasonable structure of water utilization. Wu [22] analyzed the decoupling economic growth in relation to the water consumption of China from 1953 to 2010 and explained the inner principle systematically. Zhang and Yang [23] used the water footprint method to study the decoupling relationship among water consumption, water environmental pressure, and crop production. Their research shows that strong decoupling occurs more often between the water consumption and crop production, while weak decoupling mostly occurs between the environmental pressure and crop production. Gilmont [24] focused on the case of Israel and found that semi-arid economies are facing challenges of an ever-widening gap between total national water use and local water withdrawn from natural resources, showing that decoupling includes two types: with an economy that is no longer water sufficient or an economy which is able to make up for the over-exploitation of natural water. Gilmont [25] also figured out how the virtual water flows decouple with food imports based on the food trade. The results show that the production intensity of many major crops produced in the Middle East and North Africa (MENA) region are much higher than the global average blue water level, expressing the fact that trade can not only reduce the blue water of MENA, but also enable the network to reduce global blue water. Wang et al. [26] developed the environmental pressure (including water resource) decoupling analysis to obtain the corresponding decoupling state in Tianjin, China, and put forward policy suggestions to promote further sustainable development. Zhang et al. [27] evaluated the resource decoupling (energy and water consumption) and environmental impact (wastewater, SO_2, and CO_2) from the economic growth in China. They obtained the results that the decoupling state of resource consumption is worse than the wastewater and SO_2 decoupling, but is much better than CO_2 decoupling. From the literature presented, research on the decoupling of economic growth and water consumption is still limited in many regions and nations. Additionally, current studies generally agree with this idea and analysis of the decoupling state, and fail to perform further decomposition to investigate the driving factors of water consumption.

Considering that the contradiction between water supply and water demand is becoming more and more severe in China's TI, a comprehensive study of the interactions between water consumption and economic growth and its inherent influence mechanism is particularly important for the sustainable development in the future. Therefore, we investigated the relationship between water consumption and economic growth of China's textile industry with decoupling methodology. The influencing factors of the relationship were also analyzed with the Laspeyres decomposition method. The results from these analyses will fill the gap in the scientific research on decoupling between water consumption and economic growth. Furthermore, trying to solve the water shortage problem arising from the large water consumption industries is also of great value to the self-development of the TI, and even the healthy development of China's industrial economy.

This paper is organized as follows: Section 2 offers an overview of the main methodology and data this paper uses to investigate the relationship between water consumption and the economic growth of the TI; and Section 3 evaluates the water usage situation of the TI and its three sub-industries; then it analyzes and discusses the decoupling states, eventually turning out to be a report of the main results of decomposition analysis. Section 4 concludes the study.

2. Methodology and Data

2.1. Decoupling Method

The equation of decoupling elasticity is written as follows:

$$D_{Y-WC} = \frac{\%\Delta WC}{\%\Delta Y} = \frac{(WC^t - WC^{t-1})/WC^{t-1}}{(Y^t - Y^{t-1})/Y^{t-1}} = \frac{WC^t/WC^{t-1} - 1}{Y^t/Y^{t-1} - 1} \quad (1)$$

The meanings of variables of Equation (1) are shown in Table 1.

Table 1. Description of variables of decoupling. TI: textile industry.

Variable	Variable Description	Units	Data Sources
D_{Y-WC}	Decoupling elasticity of water consumption and economic growth of TI	/	*China's Environmental Yearbook* [8]; *Annual Statistic Report on Environment in China* [9]
WC	The water consumption of TI	Mt	
$\%\Delta WC$	The growth rate of water consumption of TI	%	
$\%\Delta Y$	The economic growth rate of TI	%	
WC^t	The water consumption of TI in year t	Mt	
WC^{t-1}	The water consumption of TI in year $t-1$	Mt	
Y^t	The economic output of TI in year t	million CNY	
Y^{t-1}	The economic output of TI in year $t-1$	million CNY	

The decoupling state can be divided into eight types (see Table 2) according to decoupling theory, ranging from the most desirable state of "strong decoupling" to the least desirable "strong negative decoupling". A result indicating weak decoupling, though not as favored as strong decoupling, is still satisfactory compared to the other degrees which are though not as favorable.

Table 2. Criteria for decoupling degrees.

Degrees of Decoupling/Coupling	Relationship between Economic Growth and Water Consumption
Expansive negative decoupling	$\Delta WC > 0,\ \Delta Y > 0,\ D_{Y-WC} \in (1.2, +\infty)$
Strong negative decoupling	$\Delta WC > 0,\ \Delta Y < 0,\ D_{Y-WC} \in (-\infty, 0)$
Weak negative decoupling	$\Delta WC < 0,\ \Delta Y < 0,\ D_{Y-WC} \in [0, 0.8]$
Weak decoupling	$\Delta WC > 0,\ \Delta Y > 0,\ D_{Y-WC} \in [0, 0.8]$
Strong decoupling	$\Delta WC < 0,\ \Delta Y > 0,\ D_{Y-WC} \in (-\infty, 0)$
Recessive decoupling	$\Delta WC < 0,\ \Delta Y < 0,\ D_{Y-WC} \in (1.2, +\infty)$
Expansive coupling	$\Delta WC > 0,\ \Delta Y > 0,\ D_{Y-WC} \in [0.8, 1.2]$
Recessive coupling	$\Delta WC < 0,\ \Delta Y < 0,\ D_{Y-WC} \in [0.8, 1.2]$

ΔWC: the variation of water consumption; ΔY: the variation of the economic output; $D_{Y\text{-}WC}$: decoupling elasticity of water consumption and economic growth.

2.2. Laspeyres Decomposition Method

Decomposition analysis is a useful tool to identify the contribution of different factors that affect one variable. The Laspeyres decomposition method is a commonly used index decomposition analysis (IDA) [28–31] to make time-series analyses based on aggregate information of each sector. This method was firstly proposed by Howarth et al. [32] and Park [33], and shows the degree to which they explained variable changes caused by the fluctuations of one explanatory variable when other explanatory variables remain invariant. It is more suitable for a comparison among similar objects while large residual terms existing in the algorithm reduce the accuracy of the decomposition. Later, Sun made some modifications to this model and proposed the complete Laspeyres decomposition model [34,35]. According to the principle of jointly-created and equal distribution, this method distributes those un-decomposed residual terms equally to each factor, eliminating the effect of residual terms that exist in the traditional index decomposition method. Based on this complete decomposition model, to study the water consumption of the TI we set up a decomposition model, as follows:

$$WC = \sum_i WC_i = \sum_i Y \times \frac{Y_i}{Y} \times \frac{WC_i}{Y_i} = \sum_i Y \times S_i \times WI_i \quad (2)$$

The definition of all variables in Equation (2) is shown in Table 3.

Table 3. The definition of the variables in Equation (2).

Variable	Variable Description	Units	Data Sources
WC	The water consumption of TI	Mt	*China's Environmental Yearbook* [8]; *Annual Statistic Report on Environment in China* [9]
WC_i	The water consumption of sub-sector i	Mt	
Y	The economic output of TI, on behalf of the industry scale factor	million CNY	
Y_i	The economic output of sub-sector i	million CNY	
S_i	The proportion of sub-sector i's output, on behalf of the industry structure factor	%	
WI_i	The water consumption intensity of sub-sector i, on behalf of the water resources use efficiency factor	Mt/million CNY	

Equation (2) expresses all of the factors that influence the water consumption of the TI: Y, S, and WI. Hence, the variation of the total consumption of water from year $t-1$ to year t can be viewed as the sum of the contributions from all factors:

$$\Delta WC = WC^t - WC^{t-1} = \sum_i Y^t \times S_i^t \times WI_i^t - \sum_i Y^{t-1} \times S_i^{t-1} \times WI_i^{t-1} = \Delta WC_Y + \Delta WC_S + \Delta WC_{WI} \quad (3)$$

In Equation (3), ΔWC_Y represents the industry scale factor, showing the economic output of the TI, and the influence of the total production value on water consumption, equivalent. ΔWC_S is the industry structure factor, which refers to the ratio between the economic output of each specific sector and the gross production value of the TI, reflecting the effect of the relative proportion of economic output of each sub-sector. ΔWC_{WI} is defined as the water use efficiency factor, or the water consumption per unit of economic output, which measures the effect of the water utilization efficiency. These three factors can be calculated by the following equations:

$$\Delta WC_Y = \sum_i \Delta Y \times S_i^{t-1} \times WI_i^{t-1} + \frac{1}{2}\sum_i \Delta Y\left(S_i^{t-1} \times \Delta WI_i + WI_i^{t-1} \times \Delta S_i\right) + \frac{1}{3}\sum_i \Delta Y \times \Delta S_i \times \Delta WI_i \quad (4)$$

$$\Delta WC_S = \sum_i Y^{t-1} \times \Delta S_i \times WI_i^{t-1} + \frac{1}{2}\sum_i \Delta S_i\left(Y^{t-1} \times \Delta WI_i + WI_i^{t-1} \times \Delta Y\right) + \frac{1}{3}\sum_i \Delta Y \times \Delta S_i \times \Delta WI_i \quad (5)$$

$$\Delta WC_{WI} = \sum_i Y^{t-1} \times S_i^{t-1} \times \Delta WI_i + \frac{1}{2}\sum_i \Delta WI_i\left(Y^{t-1} \times \Delta S_i + S_i^{t-1} \times \Delta Y\right) + \frac{1}{3}\sum_i \Delta Y \times \Delta S_i \times \Delta WI_i \quad (6)$$

The contribution of the water consumption of sector i in year t can be calculated by the following equations [36]:

$$\Delta WC_{Y_i} = \Delta Y \times S_i^{t-1} \times WI_i^{t-1} + \frac{1}{2}\Delta Y\left(S_i^{t-1} \times \Delta WI_i + WI_i^{t-1} \times \Delta S_i\right) + \frac{1}{3}\Delta Y \times \Delta S_i \times \Delta WI_i \quad (7)$$

$$\Delta WC_{S_i} = Y^{t-1} \times \Delta S_i \times WI_i^{t-1} + \frac{1}{2}\Delta S_i\left(Y^{t-1} \times \Delta WI_i + WI_i^{t-1} \times \Delta Y\right) + \frac{1}{3}\Delta Y \times \Delta S_i \times \Delta WI_i \quad (8)$$

$$\Delta WC_{WI_i} = Y^{t-1} \times S_i^{t-1} \times \Delta WI_i + \frac{1}{2}\Delta WI_i\left(Y^{t-1} \times \Delta S_i + S_i^{t-1} \times \Delta Y\right) + \frac{1}{3}\Delta Y \times \Delta S_i \times \Delta WI_i \quad (9)$$

In Formulae (4)–(9), ΔY represents the change in economic output of TI from year $t-1$ to year t, ΔS_i represents the change in the proportion of sub-sector i's output from year $t-1$ to year t, and ΔWI_i represents the change of the water consumption intensity of sub-sector i from year $t-1$ to year t.

2.3. Data

According to the GB/T(Recommendatory National Standard of China) 4754-2011 Standard Industrial Classification of China, the TI is taken into account by dividing it into three sub-sectors, named as the manufacture of textiles (MT) sector, the manufacture of Manufacture of Textile Wearing Apparel, Footwear, and Caps (MTWA) sector, and the manufacture of chemical fibers (MCF) sector. Thus, the gross production value and total water consumption of the TI is the summation of MT, MTWA, and MCF. The data used in this paper is obtained from the National Bureau of Statistics of China and the Ministry of Environmental Protection of China. The study period refers to the years 2001–2014. In this paper, the gross industrial output value of the TI is used as its economic output and the total industrial water consumption as the gross industrial water resource consumption.

The gross industrial output value (converted to 2014 constant prices) and water consumption of China's TI are collected from the China Environment Yearbook (2002–2006) [8] and the China Environmental Statistics Annual Report (2006–2014) [9]. Data in the period of 2001–2005 were collected from the China Environment Yearbook, and data in the period of 2006–2014 were released in the Annual Statistic Report on Environment in China. Because there was a misprint in the industrial water consumption data for MCF in 2012, we used the average value (4035.43 Mt) of industrial water consumption data in 2011 and 2013 instead.

3. Results and Discussion

3.1. Water Consumption of the TI and Sub-Sectors

The gross industrial water consumption of the TI and its three sub-sectors during the period 2001–2014 is shown in Figure 1. This reveals that the gross water consumption of the TI during the period 2001–2010 shows an upward tendency and in general, is accompanied by several fluctuations. It increased from 6271.74 Mt in 2001 to 9463.01 Mt in 2010; the average annual growth rate is approximately 4.68%. The water consumption of the TI during the period 2011–2014 follows a wavy pattern and shows a general upward trend. Among these four years, 2013 consumed the least amount of water at 7854.22 Mt, while 2014 consumed the largest amount at 8647.30 Mt.

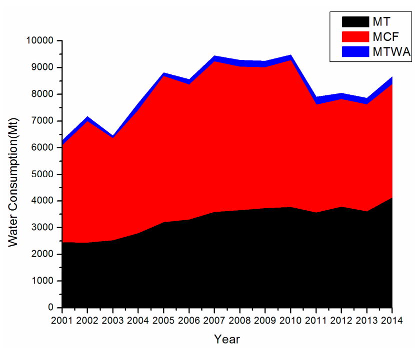

Figure 1. The water consumption of China's TI and its three sub-sectors. MT: the manufacture of textiles; MCF: the manufacture of chemical fibers; MTWA: Manufacture of Textile Wearing Apparel, Footwear, and Caps.

Among the three sub-sectors, the largest proportion of water consumption is ascribed to the MCF, followed by the MT and the MTWA. The water consumption of the MTWA is much smaller than the total amount of the MCF and the MT. During the period 2001–2014, the MT was the lowest in 2002, when it comprised approximately 33.81% of the total water consumption in 2002, but it started to show an upward trend and reached a peak of approximately 47.42% of the total in 2014. The MTWA accounts for the lowest percentage of water consumption among these three sub-sectors; its amount varies from 2% to 3% over the entire period. The MCF consumed the largest percentage of water among the three sectors; the change of the gross water consumption of the TI is apparently related to the change of the water consumption by the MCF. The water consumption of the MCF shows an upward trend during the period 2001–2009, but it starts to fall after 2011. It accounts for the highest proportion of water consumption in 2002, which was approximately 63.54%, and the lowest in 2014, at approximately 49.26%.

3.2. Analysis of Decoupling Models

3.2.1. Decoupling Water Consumption from the Production Value of the TI

Table 4 shows the decoupling elasticity of China's TI from 2002 to 2014. As is reported in Table 4, China's TI experienced expansive negative decoupling in 2002 and 2014, expansive coupling in 2004, weak decoupling in 2005, 2007 and 2010, strong negative decoupling in 2012, and strong decoupling in the remaining years (2003, 2006, 2008, 2009, 2011, and 2013).

Table 4. Decoupling results of the TI during the period 2002–2014.

Year	$\%\Delta WC$	$\%\Delta Y$	D_{Y-WC}	Degree of Decoupling
2002	14.23	7.15	1.99	Expansive negative decoupling
2003	−10.11	7.66	−1.32	Strong decoupling
2004	18.79	18.67	1.01	Expansive coupling
2005	15.01	22.86	0.66	Weak decoupling
2006	−2.79	26.64	−0.10	Strong decoupling
2007	10.28	18.85	0.55	Weak decoupling
2008	−1.72	40.73	−0.04	Strong decoupling
2009	−0.34	6.38	−0.05	Strong decoupling
2010	2.43	12.40	0.20	Weak decoupling
2011	−16.59	25.39	−0.65	Strong decoupling
2012	1.88	−3.09	−0.61	Strong negative decoupling
2013	−2.33	4.84	−0.48	Strong decoupling
2014	10.10	0.75	13.45	Expansive negative decoupling

$\%\Delta WC$: the growth rate of water consumption; $\%\Delta Y$: the economic growth rate; $D_{Y\text{-}WC}$: decoupling elasticity of water consumption and economic growth.

The decoupling state was unstable during the "Tenth Five-Year" period (2001–2005). This was in part caused by the growing exports of textiles and clothing after China's accession to the WTO in 2001. China's textile industrial capacity increased rapidly in this period. However, large quantities of water were consumed for the industrial production of exported textiles and clothing because of poor awareness of sustainable development and water-saving technologies.

During the "Eleventh Five-Year" period (2006–2010), the textile industry showed great improvement in water conservation. Advanced water-saving technologies were widely applied in the printing of textiles and clothing. For example, during this period, the fresh water withdrawn for printing and dyeing fabric decreased from 4.0 t water per 100 m to 2.5 t water per 100 m. Meanwhile, the water recycling rate of the printing and dyeing industry increased from 7% to 15% [5]. The Chinese government proposed a series of policies related to industry entry regulation and technical innovation in this period. The Law of the People's Republic of China on Prevention and Control of Water Pollution initiated in 2008 (revised edition) [37] is a typical policy. This law proposed a strict regulation to control the amount of pollutants factories can discharge and required the enterprises to replace the laggard equipment and technology with advanced ones. It effectively promoted the improvement of industrial production technologies, equipment and production efficiency. Besides, the adoption of industrial symbiosis approach and eco-industrial park program has effectively promoted the collaboration between enterprises in improving their economic and environmental performance, such as water saving and management [38,39]. Therefore, the water consumption of China's TI was largely reduced.

In 2010, the Chinese government issued Opinions on Further Strengthening Industrial Water Saving Work of the Ministry of Industry and Information Technology (MIIT) (China's MIIT [2010] No. 218) [40] and the Decision of the CPC (The Communist Party of China) Central Committee and the State Council on Accelerating the Development of Water Conservancy Reform (December 31, 2010) [41], leading to the greatest decrease of water consumption from 2010 to 2011 when it reached 16.59%. These policies ensure the social and economic developments with the water resource carrying capacity are in harmony from the perspective of the system. However, since 2011, the decoupling states showed several fluctuations, with strong decoupling and strong negative decoupling occurring alternatively. It can be concluded that the main reasons for this are the transfer of backward production capacity in central and western regions, the failure of adjustment and optimization of regional distribution, and the change in the demand of scale economy-driven water resources during the process of the "East-to-West Mulberry Transfer" program.

However, in view of the specific value of those strong decoupling states, nearly all absolute values of the strong decoupling elasticity are smaller than 1, except for the value in 2003 (−1.32). This reveals that the economic output of TI did not perform with a strong decoupling in terms of water consumption, which means further improvement is still required. Specifically, the decoupling state in 2012 was very unsatisfactory, characterized by strong negative decoupling, which was, to a large extent, caused by the increase of water consumption and the recession of economic output. Furthermore, expansive negative decoupling occurred in 2014 and the elasticity was 13.45, the largest value during the study period. The increase of industrial water consumption was relatively high that year likely due to the combined effects of economic development and resource utilization efforts.

3.2.2. Decoupling Water Consumption from the Production Value of the Three Sub-Sectors

The decoupling elasticities of the three sub-sectors are shown in Tables 5–7. During the study period, none of the three sub-sectors reached a stable decoupling of water consumption in relation to the economic growth. However, in comparison, the decoupling state of the MT is steadier, followed by the MTWA, while the MCF experienced significant changes.

Table 5. Decoupling results of the MT during the period 2002–2014.

Year	$\%\Delta WC$	$\%\Delta Y$	D_{Y-WC}	Degree of Decoupling
2002	−0.54	1.73	−0.31	Strong decoupling
2003	3.45	12.12	0.28	Weak decoupling
2004	10.57	20.67	0.51	Weak decoupling
2005	14.96	24.15	0.62	Weak decoupling
2006	3.01	24.03	0.13	Weak decoupling
2007	8.65	10.77	0.80	Expansive coupling
2008	1.85	59.56	0.03	Weak decoupling
2009	2.13	9.45	0.23	Weak decoupling
2010	1.27	8.22	0.15	Weak decoupling
2011	−5.40	24.32	−0.22	Strong decoupling
2012	6.04	−3.33	−1.81	Strong negative decoupling
2013	−4.69	5.10	−0.92	Strong decoupling
2014	14.19	−2.84	−5.00	Strong negative decoupling

$\%\Delta WC$: the growth rate of water consumption; $\%\Delta Y$: the economic growth rate; $D_{Y\text{-}WC}$: decoupling elasticity of water consumption and economic growth.

Table 6. Decoupling results of the MTWA during the period 2002–2014.

Year	%Δ*WC*	%Δ*Y*	D_{Y-WC}	Degree of Decoupling
2002	−2.34	20.36	−0.11	Strong decoupling
2003	−49.91	15.22	−3.28	Strong decoupling
2004	178.01	10.75	16.56	Expansive negative decoupling
2005	−49.99	12.74	−3.92	Strong decoupling
2006	53.44	77.05	0.69	Weak decoupling
2007	7.08	−0.37	−18.90	Strong negative decoupling
2008	13.95	7.51	1.86	Expansive negative decoupling
2009	−2.22	14.81	−0.15	Strong decoupling
2010	−16.09	−10.44	1.54	Recessive decoupling
2011	43.75	37.83	1.16	Expansive coupling
2012	−17.99	10.40	−1.73	Strong decoupling
2013	1.47	6.41	0.23	Weak decoupling
2014	18.70	11.72	1.60	Expansive negative decoupling

%Δ*WC*: the growth rate of water consumption; %Δ*Y*: the economic growth rate; $D_{Y\text{-}WC}$: decoupling elasticity of water consumption and economic growth.

Table 7. Decoupling results of the MCF during the period 2002–2014.

Year	%Δ*WC*	%Δ*Y*	D_{Y-WC}	Degree of Decoupling
2002	24.98	19.24	1.30	Expansive negative decoupling
2003	−15.66	−5.82	2.69	Recessive decoupling
2004	20.23	15.56	1.30	Expansive negative decoupling
2005	18.75	22.36	0.84	Expansive coupling
2006	−7.51	18.76	−0.40	Strong decoupling
2007	11.46	54.85	0.21	Weak decoupling
2008	−4.57	6.28	−0.73	Strong decoupling
2009	−1.92	−7.18	0.27	Weak negative decoupling
2010	4.09	38.72	0.11	Weak decoupling
2011	−26.44	25.83	−1.02	Strong decoupling
2012	−0.35	−5.96	0.06	Weak negative decoupling
2013	−0.35	3.50	−0.10	Strong decoupling
2014	5.92	9.27	0.64	Weak decoupling

%Δ*WC*: the growth rate of water consumption; %Δ*Y*: the economic growth rate; $D_{Y\text{-}WC}$: decoupling elasticity of water consumption and economic growth.

As is shown in Table 5, in terms of MT, the growth rate of its water consumption is lower than the economic growth rate in all years, except for 2012 and 2014. Strong decoupling occurred in three years (2002, 2011, and 2013), expansive coupling occurred in 2007, and 2012 and 2014 showed strong negative decoupling, with weak decoupling occurring in the remaining years. Specifically, except for the year 2007, the weak decoupling occurred in the period 2003–2010, a fact which can be explained by the low-scale effect of China's MT economies. Though the total scale of the MT was large, the MT was mainly composed of small and medium-sized enterprises. Extensive economic growth of the MT resulted in the fact that it relies heavily on water. The water-saving technology and equipment had not been updated in this period. On October 19, 2012, China's Ministry of Environmental Protection issued the new "Textile Dyeing and Finishing Industrial Water Pollutant Discharge Standard" (GB4287-2012). This new standard required the COD (Chemical Oxygen Demand) concentration of waste water discharged directly by printing and dyeing enterprises to be below 100 mg/L and the indirect emissions to be below 200 mg/L. As a result, the preprocessor facilities of most enterprises at that time could not meet the standard. Many companies moved into the industrial zone and more money was wasted on rebuilding their factories. Also, little attention was given to the improvement of water-saving technologies and the purchase of advanced production equipment [42].

Regarding the MTWA, Table 6 shows that expansive negative decoupling occurred in 2004, 2008 and 2014, weak decoupling occurred in 2006 and 2013, 2007 shows strong negative decoupling, 2010 shows recessive decoupling, expansive coupling occurred in 2011, and strong decoupling occurred in the remaining years (2002, 2003, 2005, 2009, and 2012). Compared with the other two sub-industries, MTWA showed the highest number of years that reached ideal "strong decoupling", totaling 38.46% of the years in the study period. This is because the average water consumption per unit product in the production of MTWA was overall less than other sectors. Thus, the burden to save water and reduce emissions was much lighter. However, the MTWA experienced large fluctuations, especially in 2004 and 2007, with the decoupling elasticity reaching 16.56 and −18.90, respectively. The absolute values are much larger than those of other years, due to the acceleration of transformation and upgrade of MTWA. The industrial scale of the MTWA expanded rapidly, while the large-scale infrastructure construction and equipment development led to the larger consumption of water resources. Moreover, the growth rate of water consumption during three most recent years (2012–2014) of the study period increased from −17.99% in 2012 to 18.70% in 2014. Meanwhile, the decoupling condition also became worse, turning from strong decoupling in 2012 to the expansive negative decoupling in 2014. By this token, under the new circumstances of the global textile industry and trade, the industrial scale of the MTWA became larger and the amount of export transactions also increased. However, these conditions also led to the growing water consumption by the TI. The water-saving space is also limited by the diminishing marginal water conservation capacity.

According to the results in Table 7, the MCF showed expansive negative decoupling in 2002 and 2004, and recessive decoupling in 2003. Expansive coupling occurred in 2005, and strong decoupling occurred in 2006, 2008, 2011, and 2013. Weak decoupling occurred in 2007, 2010, and 2014. Weak negative decoupling occurred in 2009 and 2012. From 2002 to 2005, the decoupling state was poor. This was mainly because of the expansion of polyester and chemical fiber capacities while the products and technology research input was inadequate. Isomorphism of products was a serious problem. The utilization of chemical fiber filament and staple fiber capacity was 60%–70% and the rate of operation of polyester capacity was less than 70% [43]. During the period 2006–2010, the recycling technologies of textile fibers improved greatly. The reused textile fibers surpassed 4 Mt in 2010. Viscose fiber, which uses the renewable, biodegradable bamboo pulp and hemp stalk pulp as raw material, realized the industrialization production [5]. The recycled fiber processing volume proportion increased from 9.6% in 2010 to 11.3% in 2015. The green development policies contributed the decoupling results from 2011 to 2014. However, due to the structural surplus of capacity, the structural contradiction, the uncoordinated development of industrial chains, the large raw material gap, and relatively small scales of most enterprises of China's chemical fiber industry, there is still a wide gap between China and advanced countries in terms of overall technological levels. All of these factors lead to the poor competitiveness of the MCF [12].

3.3. Analysis of Factors Influencing Water Utilization Efficiency

3.3.1. The Decomposition Analysis of the Water Consumption in the TI

Table 8 shows the results of the decomposition analysis of the water consumption of China's TI from 2002 to 2014. The central columns show the contribution values of the three factors (Y, S, and WI) that cause the change of water consumption in TI. The last column lists the cumulative contribution values, which reflect the water consumption variations of TI in year *t*; the units are in Mt of water. The values in the parentheses signify the percentages of the given factors' contributions to the cumulative value.

Table 8. The decomposition results of the TI during the period 2002–2014. Unit: Mt, 100%.

Year	ΔWC_Y	ΔWC_S	ΔWC_{WI}	ΔWC
2002	462.78 (51.87)	332.68 (37.29)	96.77 (10.85)	892.23 (100)
2003	502.67 (−69.44)	−450.49 (62.23)	−776.12 (107.21)	−723.93 (100)
2004	1203.59 (99.44)	−80.39 (−6.64)	87.16 (7.20)	1210.36 (100)
2005	1692.88 (147.46)	−6.93 (−0.60)	−537.90 (−46.85)	1148.05 (100)
2006	2068.06 (−842.66)	−354.52 (144.45)	−1958.96 (798.21)	−245.42 (100)
2007	1567.55 (178.27)	1159.46 (131.86)	−1847.71 (−210.13)	879.30 (100)
2008	3264.79 (−2014.31)	−1174.55 (724.67)	−2252.32 (1389.63)	−162.08 (100)
2009	573.00 (−1810.53)	−606.43 (1916.17)	1.78 (−5.64)	−31.65 (100)
2010	1100.67 (490.47)	956.18 (426.09)	−1832.44 (−816.56)	224.41 (100)
2011	2000.75 (−127.47)	8.21 (−0.52)	−3578.49 (228.00)	−1569.53 (100)
2012	−250.10 (−168.91)	−96.25 (−65.00)	494.41 (333.91)	148.06 (100)
2013	376.17 (−200.81)	−39.62 (21.15)	−523.88 (279.66)	−187.33 (100)
2014	61.76 (7.79)	223.90 (28.23)	507.43 (63.98)	793.08 (100)

ΔWC_Y: the industry scale factor; ΔWC_S: the industry structure factor; ΔWC_{WI}: the water use efficiency factor; ΔWC: the variation of the total consumption of water of TI.

According to the data reported in Table 8 and Figure 2, the industry scale is revealed to be the largest inducement for the increase of China's TI water consumption. During the period considered, the contribution value of the scale factor is, as a whole, greater than the contribution values of the other two factors. Except for 2012, changes in water consumption based on the scale factor generated positive effects—that is, the scale factor drives TI water consumption. The average contribution value of the scale factor was approximately 1124.97 Mt over the 13-year study period. Over this time period the largest contribution value was approximately 3264.79 Mt in 2008. The rate of contribution was only 7.79% in 2014, while in other years the absolute values of the rates were greater than 50%. The reason is that by the essence of labor-intensive industries, China's TI relies on the advantage of human capital to flourish in the long-term. Its continuous expansion, at an industrial scale, and demand due to international trade, caused the increased water consumption [5,43].

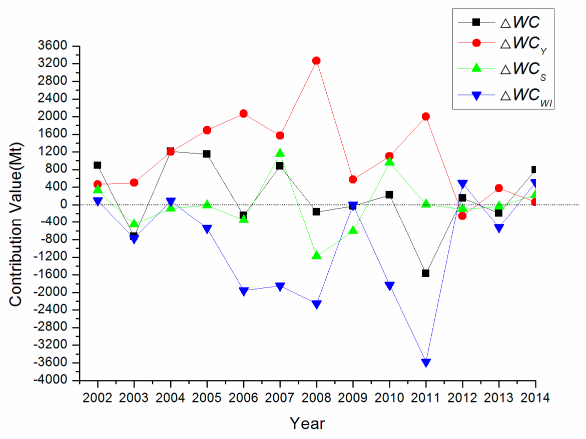

Figure 2. The contribution value of factors influencing water consumption in the TI. ΔWC: the cumulative contribution values; ΔWC_Y: the contribution values of the industry scale factor; ΔWC_S: the contribution values of the industry structure factor; ΔWC_{WI}: the contribution values of the water use efficiency factor.

The industrial structure influences China's TI water consumption, which has an inhibitory effect on the increase of water consumption, although the effect is not significant. In contrast with the two other factors, the contribution values of the structural factor of positive and negative distribution are uneven, and from the numerical analysis, it can be seen that the structure factor on the change of water consumption is not large. The average contribution value is only −9.90 Mt, which is far less than the averages for the other two factors. This shows that the optimization and adjustment of the industrial structure for reducing textile industrial water consumption is not significant, and the high investment and the low added value of the industrial structure has not yet induced a significant change. The state of China's textile industry has been in the low part of the production process of the "Smiling curve" for a while now.

Water use efficiency is the largest contributor inhibiting the TI water consumption, which plays an important positive role in reducing water consumption. In the years 2002, 2004, 2009, 2012, and 2014, the contribution values of the efficiency factor of water consumption variation are positive; in the other years, the influences are negative. In other words, in most years the efficiency factor inhibits the water consumption. The average contribution value of the water efficiency factor is approximately −932.33 Mt over the 13-year study period. A large number of new water-saving technologies and consumption and waste water emission reductions were widely implemented during the 12th Five-Year Plan (2011–2015) period. These actions led to dyeing fabric fresh water withdrawals dropping from 2.5 t per 100 m to 1.8 t per 100 m and the rate of water reuse rising from 15% to 30%. Some binding targets, such as the decline of energy consumption per added-value, the decrease in water withdrawal and total pollutant emissions, have been successfully met. Additionally, the proportion of recycled fiber to total fiber processing increased from 9.6% in 2010 to 11.3% in 2015 [12].

3.3.2. The Decomposition Analysis of the Water Consumption in the Three Sub-Sectors

Figures 3–5 present the decomposition results of the TI's sub-sectors during the period of 2002–2014; the units are in Mt of water.

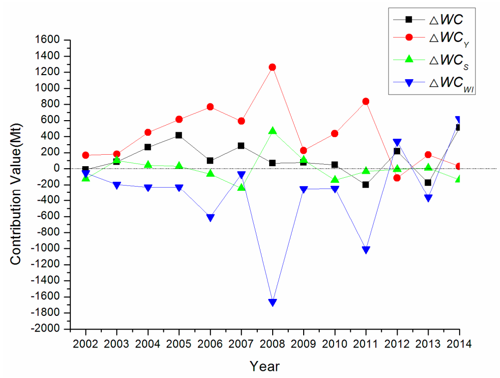

Figure 3. The contribution value of factors influencing water consumption in the MT. ΔWC: the cumulative contribution values; ΔWC_Y: the contribution values of the industry scale factor; ΔWC_S: the contribution values of the industry structure factor; ΔWC_{WI}: the contribution values of the water use efficiency factor.

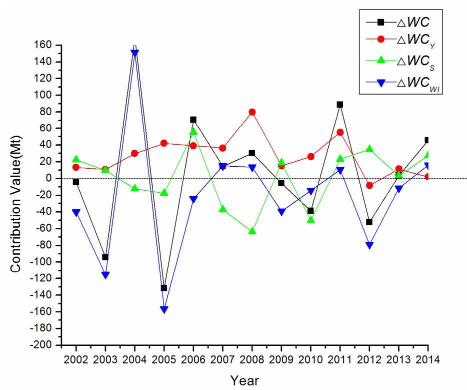

Figure 4. The contribution value of factors influencing water consumption in the MTWA. ΔWC: the cumulative contribution values; ΔWC_Y: the contribution values of the industry scale factor; ΔWC_S: the contribution values of the industry structure factor; ΔWC_{WI}: the contribution values of the water use efficiency factor.

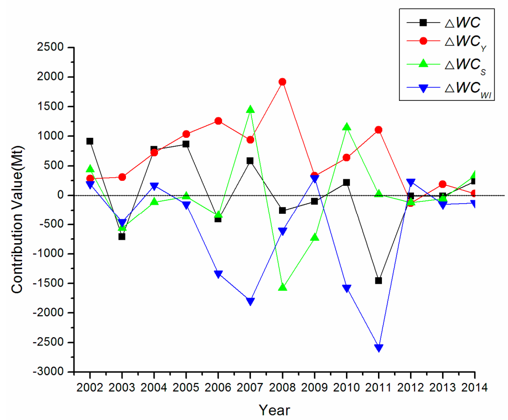

Figure 5. The contribution value of factors influencing water consumption in the MCF. ΔWC: the cumulative contribution values; ΔWC_Y: the contribution values of the industry scale factor; ΔWC_S: the contribution values of the industry structure factor; ΔWC_{WI}: the contribution values of the water use efficiency factor.

It can be seen from Figure 3 that the change in the trend of the contribution values of the three factors of the MT is consistent with that of the TI, which indicates the MT played a significant role in the water consumption problem of China's TI. Except for the year 2012, the contribution values of the scale factor are positive, and generally the numerical values are quite large. The average contribution value reaches approximately 432.82 Mt, which is to a large extent, increasing the water consumption. The contribution values of the structure factors are significantly smaller than those for the other two factors, which average a mere −0.36 Mt during the research period. Although the overall effect was not significant, several factors negatively contributed to the decoupling results. Except for the years 2012 and 2014, the contribution values of the efficiency factor are negative; the average contribution value is approximately −304.41 Mt, which has contributed significantly to the control of water consumption. Both the positive effects of the scale factor and the negative effects of the efficiency factor are rather significant. The efficiency factor's inhibitory effects offset the scale factor's enhancing effects on water consumption; consequently, any increase in industrial water consumption was effectively controlled. The reasons are that the capacity for independent innovation of the MT improved and continues to improve. A number of advanced technologies made substantive breakthroughs, and a group of independent studies and development of scientific and technological achievements and advanced equipment have been widely applied in the textile industry.

As is shown in Figure 4, the contribution values of the three factors and the cumulative contribution values of MTWA are all quite fluctuant. Before 2005 the cumulative contribution value was mainly dominated by the efficiency factor, and the scale and structure factors had a larger influence after 2005, the cumulative contribution value being a combination of the three factors. Except for the year 2012, the scale factor is characterized by a positive effect. The average contribution value for the scale factor is approximately 27.14 Mt, which stimulates the water consumption. During the period 2002–2014, there are eight years where the contribution values of the structure factor are positive. Furthermore, the numbers for the structure factor in the four-year period from 2011 to 2014 are positive, which led to an increase of the industrial water consumption, but the effect is not significant. The efficiency factor presents more of a negative effect during the study period, which inhibits water consumption, and its average contribution value is −21.04 Mt. Compared with the other two sub-sectors, the MTWA has a smaller industry scale and a lower production water consumption link, so its scale factor effects and efficiency factor effects are not particularly prominent among the three influence factors. Their contribution values are far less than those for the MT and the MCF sub-sectors.

According to the data reported in Figure 5, the variation trends of the contribution values of the MCF's scale factor and efficiency factor are consistent with those of the TI. The MCF's scale factor and efficiency factor decomposition results are slightly closer to the change trend of the TI, whereas the MCF's structure factor influence is significantly larger than the TI's. Except for the year 2012, the scale factor contribution values are all positive. The average contribution value reaches 665.00 Mt, which boosts the industry water consumption. The structure factor and efficiency factor contribution values are mostly negative and the average contribution values are −10.65 Mt and −606.88 Mt, respectively, which inhibits the consumption of water resources. Additionally, the inhibition of the efficiency factors is greater than the inhibitory effect of the structure factors. Although the MCF's structure factor on water consumption also has a certain inhibition effect, the MCF's high-end products in the effective supply is insufficient, phased, and the structural capacity is still in excess. The cumulative contribution value change is still unstable. For the 13-year period, nearly half of the years are positive, which is a major cause of the increased water consumption, and it also reveals the reason why the decoupling state of the MCF is poor.

4. Conclusions

Based on the economic output and water consumption of China's Textile Industry (TI) during the period 2001–2014, this paper calculates the decoupling elasticity of water consumption in relation to the economic growth of this industry and its three sub-sectors. Furthermore, the inner principle of decoupling water consumption in relation to economic growth is analyzed with a decomposition model. Several conclusions are obtained, as follows:

(1) During the period 2002–2014, strong decoupling occurred in six years (2003, 2006, 2008, 2009, 2011, and 2013), three years (2005, 2007, and 2010) show weak decoupling, two years (2002 and 2014) show expansive negative decoupling, in one year (2004) expansive coupling occurred, and in one year (2012) strong negative decoupling occurred. This condition is mainly attributed to the fulfillment of national water-saving policies and the improvement in water-saving technologies.
(2) For the three sub-sectors, the manufacture of textile sector (MT) shows weak decoupling in general. The Manufacture of Textile Wearing Apparel, Footwear, and Caps sector (MTWA) experienced strong decoupling in five years (2002, 2003, 2005, 2009, and 2012), and weak decoupling occurred in two years (2006, 2013) and as such, showed a better decoupling condition than the other two sub-sectors. The water consumption of the manufacture of chemical fibers sector (MCF) was the highest, while its economic output was lower than MT's, and the water efficiency was the lowest of the three.
(3) The factors influencing the decoupling condition between water consumption and economic growth of TI are mainly the industry scale and water efficiency factors, while the role of the industry structure factor is not significant. The industry scale factor is the largest stimulus to the increase of the water consumption by China's TI. The water efficiency factor is the largest contributor to decreased water consumption in the textile industry.
(4) The water consumption of MCF on China's TI results in a larger overall effect on water consumption, MT has a lesser effect, and the effect of MTWA is minimal. The industrial scale factor exerts a great effect on the increase of water consumption of the three sub-sectors, while the water efficiency factor is an inhibiting factor. The effect of the industry structure factor is not particularly significant.

To achieve the goal of sustainable development in China's TI, it is imperative to consider the effects of changing factors, including the industry scale, industrial structure and the efficiency factors, as a whole. Implementing water-saving management strategies and popularizing water-saving technologies comprise a sound strategy to accomplish the "strong decoupling" between economic growth and water consumption of China's TI. Specifically, more rigorous standards of water consumption and pollutant discharge for printing and dyeing should be proposed, and a strict regulatory system should be set up for newly-built factories to eliminate excess capacity and low capacity. Secondly, the government should encourage the production of the additional high values and optimize the industrial structure to increase the economic output and reduce water consumption. Finally, it is important to popularize advanced anhydrous production technologies and equipment. This can directly reduce water consumption and improve production efficiency.

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