Assessing the Water Parallel Pricing System against Drought in China: A Study Based on a CGE Model with Multi-Provincial Irrigation Water

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Abstract: The reform of water management in China is still in progress, and the pricing of water resources is undertaken in parallel, with a divide between irrigation water and pipe water associated with different users: The supply of irrigation water is regulated by local government and that of pipe water is operated by the production sector of pipe water. Based on a literature review and an interview survey of farmers, this study incorporated the water parallel pricing system of China within a computable general equilibrium (CGE) model, where the drought of 2000 is simulated. The 16 provincial irrigation water supplies and their subsidies were also estimated and introduced into this CGE model. The results demonstrated that the effects on the macro-economy were insignificant. However, the effects
on agricultural production, particularly on farming production mainly cultivated in northern areas, were significant. Most farming production sectors employed more capital and labor to prevent losses in output from drought. Agricultural labor was shifted from non-farming agricultural production sectors into farming. Both urban and rural households suffered severe losses in welfare and food consumption, even though they benefited from the additional income. Moreover, rural households suffering the worst losses were located in both northern and southern areas.

**Keywords:** water parallel pricing system; multi-provincial irrigation water; CGE model; drought; China

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1. Introduction

Irrigation is an essential factor allowing China to be able to support the largest population in the world with only 6% of the world’s renewable water resources and 9% of the world’s arable land, guaranteeing agricultural production, food security and also economic and social stability [1]. However, it is projected that the 1 °C rise in air temperature expected by 2020 will increase in the need for irrigation water by 6%–10% in East Asia [2]. Indeed, this problem is already emerging in Northern China generally where temperatures have become higher [3] and more droughts have occurred than in the past [4]. Moreover, the share of agricultural water declined from 97% to 65%, while the share of industrial water increased from 2% to 22% during the period of 1949–2004 [5] and to 24% in 2011 [6]. Accordingly, drought will make irrigation more expensive [7]. Water availability will play a significant limiting role in future agricultural production and economic growth. The combined effects between higher crop water requirements (due to climate change) and increasing demand for non-agricultural water use (due to socio-economic development) should be paid more attention [8].

Water pricing plays as a key role in coordinating water use and economic growth. However, water prices in China are determined by top-down administrative commands rather than by the market. Moreover, the system of water resources management is notoriously fragmented and involves a series of government agencies from both vertical and horizontal levels [9]. To promote industrialization, the Ministry of Water Resources (MWR) prioritizes water allocation to urban-industrial uses over irrigation, which has resulted in serious competition for water between agriculture and industry [10]. After introducing the pricing method based on the marginal opportunity costs [11], water tariffs imposed by the government almost cover at least the operation and maintenance costs of most water supply utilities, even in several rural communities [12]. However, from the water parallel pricing system, it can be observed that the charges of irrigation water are related to the irrigated area instead of the volume of water that the progressive volumetric pricing has introduced in urban areas [13,14]. As a result, the main divide of water resources in China is between irrigation water, which is used in the agricultural production sectors, and pipe water, which is consumed by the urban-industrial sectors.

Based on a literature review and an interview survey of farmers in Jilin and Liaoning provinces, China, attempts have focused on incorporating the water parallel pricing system within a computable general equilibrium (CGE) model. This paper is organized around the following three objectives.
The first objective is to discuss the water parallel pricing system based on an interview survey, and to calculate irrigation water and its subsidy at the multi-provincial level, which are used to construct a social accounting matrix (SAM). The second objective is to introduce the water parallel pricing into CGE model, where the irrigation water and its subsidy from different provinces are employed to production function. The third objective is to simulate the drought of 2000, which was the most widespread in years, under the water parallel pricing system, and the effect of this drought on agricultural production and rural households are measured.

2. Background to the Drought of 2000 and the Water Parallel Pricing System

2.1. The Drought of 2000

The drought of 2000 was the most serious in nearly 15 years and the total drought affected rate in the cultivated areas reached 17.14%. The water employed in agriculture in 2000 (only 378.35 billion m³) was less than that utilized in the preceding (386.92 billion m³ in 1999) and subsequent years (382.57 billion m³ in 2001) [15]. The detailed affected levels are presented in Figure 1, where provinces with the drought affected rates greater than 50% were Jilin, Liaoing and Qinghai, followed by Shanxi, Inner Mongolia and Ningxia and finally, Gansu, Shaanxi, Anhui and Heilongjiang.

![Map of mainland China](image)

**Figure 1.** Drought-affected level in each province of year 2000. Data source: China Rural Statistics Yearbook 2001 [15]. Note: “Affected” defines those cultivated areas where yields are reduced by more than 30% [16].
2.2. The Water Parallel Pricing System and Water Price Distortion

2.2.1. The Water Parallel Pricing System Observed from an Interview Survey

We conducted an interview survey of some farmers in Jilin and Liaoning provinces, where the drought usually becomes more serious than in other provinces. Those farmers described the current management system of water resources as presented in Figures 2 and 3.

![Figure 2](image-url)

**Figure 2.** Surface water distributions between irrigation water and pipe water.

![Figure 3](image-url)

**Figure 3.** Reservoir irrigation systems at village level.
Figure 2 presents a simplified depiction of the structure of the water distribution between pipe water and irrigation water. There is a water pumping station near rivers or lakes constructed by the government. This pumping station transports water from rivers or lakes to the main canal, where water is distributed as pipe water by a main pipe and as irrigation water by a sub-canal. The main pipe is operated by the state-owned water production and distribution company, and the sub-canal is regulated by several village offices. The pipe water users, which mainly include the industrial and service sectors as well as households, must pay the price to the water company according to the amount of water they used. In contrast, farmers must pay the irrigation cost to the village office according to the size of their irrigated areas. As a result, pipe water and irrigation water are formulated by volumetric and non-volumetric pricing (or called area pricing), respectively, which has generated the water parallel pricing system.

In rural areas, water authorities directly collect payment from farmers who utilize the water for irrigation. Figure 3 presents the basic structure of the reservoir irrigation system at the village level. This reservoir, especially for those with large-scale irrigated areas, is basically funded by the local government. Thus, the local government imposes an irrigation cost to obtain a return on initial investment and to maintain the daily operation of the irrigation system. Specifically, the local government manages the main valve of the reservoir. Farmers must pay the irrigation cost for operating the sub-valve when they need water for irrigation. The irrigation cost is formulated according to the size of the irrigated area (Yuan per mu) and is changed in relation to the weather and cultivated crops. Indeed, this irrigation cost only reflects the variable cost of the total irrigation cost. In contrast, the fixed cost of the infrastructure is supported by the government, acting as a subsidy for farmers to lower costs.

2.2.2. Water Price Distortion and Equilibrium Irrigation Water Inputs

In this study, we selected 15 provinces and also an “other provinces” entity as the main crop-producing areas in China. The irrigation cost of ten crops cultivated in those provinces was collected from the official database, the National Agricultural Production Cost and Revenue Information Summary 2008 [17]. Accordingly, we estimated the irrigation water input costs employing the Equation (1).

\[
I_{irrigation\ input\ cost} (\text{yuan})_{ij} = Irrigation\ cost \left( \frac{\text{yuan}}{\text{mu}} \right)_{ij} \times \text{Cultivated\ area (mu)}_{ij}
\]

(1)

where \(i\) = crops; \(j\) = provinces, same as in Equations (2)–(4).

To present the price distortion between irrigation water and pipe water, the volumetric pricing method (water use (Yuan) divided by water withdrawal (m\(^3\))) was employed to derive the average prices of irrigation water and pipe water. However, China’s official database does not contain detailed information for irrigation water use and withdrawal; Rather, it provides data for agricultural water, which indicates the water consumed by all agricultural sectors, including farming, forestry, animal husbandry, fishery and the agriculture services. Furthermore, according to the Input-Output Tables of China 2007 [18] and the China Regional Input-Output Tables 2007 [19], where the production sector of pipe water is represented by the water production and distribution sector, pipe water is also consumed by the agricultural sectors, although this consumption is not very high. In fact, the use of pipe water for irrigation is limited to those rural areas very near to urban areas. The main portion of irrigation water
still comes from the local irrigation system. Moreover, the water withdrawal data are given by the China Statistical Yearbook on the Environment 2008 [20] (see Table 1).

Table 1. Water volumetric pricing and provincial water price distortions in 2007.

<table>
<thead>
<tr>
<th>Provincial Level</th>
<th>Water Uses (100 Million Yuan)</th>
<th>Water Withdrawals (100 million m³)***</th>
<th>Water Prices (Yuan/m³) ****</th>
<th>Subsidy Rates ****</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agricultural *</td>
<td>Industrial, Service and Households **</td>
<td>Agricultural</td>
<td>Industrial and Residential</td>
</tr>
<tr>
<td>National level</td>
<td>166.73</td>
<td>1199.87</td>
<td>3599.51</td>
<td>2219.16</td>
</tr>
<tr>
<td>Guangdong</td>
<td>7.13</td>
<td>255.24</td>
<td>224.84</td>
<td>237.67</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>4.73</td>
<td>48.79</td>
<td>151.35</td>
<td>83.52</td>
</tr>
<tr>
<td>Hainan</td>
<td>1.95</td>
<td>5.56</td>
<td>35.84</td>
<td>10.85</td>
</tr>
<tr>
<td>Yunnan</td>
<td>6.61</td>
<td>12.72</td>
<td>105.95</td>
<td>44.08</td>
</tr>
<tr>
<td>Guangxi</td>
<td>5.89</td>
<td>27.31</td>
<td>208.39</td>
<td>102.01</td>
</tr>
<tr>
<td>Henan</td>
<td>18.20</td>
<td>26.03</td>
<td>120.07</td>
<td>89.21</td>
</tr>
<tr>
<td>Jilin</td>
<td>4.72</td>
<td>38.41</td>
<td>67.53</td>
<td>33.25</td>
</tr>
<tr>
<td>Anhui</td>
<td>6.68</td>
<td>68.21</td>
<td>120.56</td>
<td>111.49</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>15.22</td>
<td>54.86</td>
<td>214.75</td>
<td>76.62</td>
</tr>
<tr>
<td>Hebei</td>
<td>15.66</td>
<td>33.78</td>
<td>151.59</td>
<td>50.91</td>
</tr>
<tr>
<td>Hubei</td>
<td>6.20</td>
<td>70.38</td>
<td>132.65</td>
<td>126.09</td>
</tr>
<tr>
<td>Chongqing</td>
<td>2.42</td>
<td>21.53</td>
<td>18.75</td>
<td>58.67</td>
</tr>
<tr>
<td>Sichuan</td>
<td>11.62</td>
<td>42.19</td>
<td>118.71</td>
<td>95.27</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>11.34</td>
<td>19.52</td>
<td>141.77</td>
<td>38.27</td>
</tr>
<tr>
<td>Shandong</td>
<td>10.40</td>
<td>105.38</td>
<td>159.71</td>
<td>59.83</td>
</tr>
<tr>
<td>Other provinces</td>
<td>37.95</td>
<td>369.97</td>
<td>1627.03</td>
<td>1001.43</td>
</tr>
</tbody>
</table>

Notes: Source: * The estimated irrigation water input costs plus the pipe water inputs; ** Input-Output Tables of China 2007 [18] and China Regional Input-Output Tables 2007 [19]; *** China Statistic Yearbook on Environment 2008 [20]; **** Estimated by authors.

By relying on these data, we estimated the agricultural water price and the pipe water price, assuming that the agricultural water price is equal to the irrigation water price. In detail, the agricultural water use was defined to be equal to the sum of sectoral irrigation water input costs plus the pipe water used in agricultural water sectors. It was also assumed that different sectors in the same provinces share the same agricultural water price and pipe water price. As presented in Table 1, the two water prices were significantly different across provinces.

The differences between the irrigation water price (represented by the agricultural water price) and pipe water price can be regarded as the subsidy on irrigation water. Accordingly, the equilibrium irrigation water input costs and their subsidies were estimated according to Equations (2) and (3), and the results are exhibited in Tables 2 and 3:
Equilibrium irrigation water input costs (\(\text{yuan}\))

\[
\text{Equilibrium irrigation water input costs (\(\text{yuan}\))} = \text{Irrigation water input costs (\(\text{yuan}\))} \times \frac{\text{Pipe water price (\(\text{yuan/m}^3\))}}{\text{Irrigation water price (\(\text{yuan/m}^3\))}}
\]  

(2)

Subsidy for irrigation water (\(\text{yuan}\))

\[
\text{Subsidy for irrigation water (\(\text{yuan}\))} = \text{Irrigation water input costs (\(\text{yuan}\))} - \text{Equilibrium irrigation water input costs (\(\text{yuan}\))}
\]  

(3)

It should be noted that the sectoral equilibrium irrigation water input costs of “other provinces” are equal to the differences between the national level and the sum of the given 15 provinces.

The subsidy rates recorded in the last column of Table 1 was derived using Equation (4):

\[
\text{Subsidy rate for irrigation water}\_{ij} = \frac{\text{Subsidy for irrigation water (\(\text{yuan}\))}_{ij}}{\text{Equilibrium irrigation water input costs (\(\text{yuan}\))}_{ij}}
\]  

(4)

Table 2. Equilibrium irrigation water input costs at the provincial and sectoral levels.

<table>
<thead>
<tr>
<th>Unit: 10 thousand Yuan</th>
<th>Paddy</th>
<th>Wheat</th>
<th>Corn</th>
<th>Vegetables</th>
<th>Fruits</th>
<th>Oil Seeds</th>
<th>Sugarcane</th>
<th>Potato</th>
<th>Sorghum</th>
<th>Other Crops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>National level</td>
<td>5,523,673</td>
<td>1,979,392</td>
<td>2,705,227</td>
<td>5,227,817</td>
<td>521,447</td>
<td>514,332</td>
<td>84,459</td>
<td>376,607</td>
<td>72,921</td>
<td>1,220,047</td>
<td>18,225,922</td>
</tr>
<tr>
<td>Guangdong</td>
<td>333,811</td>
<td>244</td>
<td>35,676</td>
<td>1,089,802</td>
<td>30,373</td>
<td>86,123</td>
<td>58,651</td>
<td>43,323</td>
<td>85</td>
<td>57,686</td>
<td>1,735,773</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>670,855</td>
<td>1511</td>
<td>2299</td>
<td>86,829</td>
<td>25,978</td>
<td>12,353</td>
<td>715</td>
<td>10,137</td>
<td>377</td>
<td>44,426</td>
<td>855,479</td>
</tr>
<tr>
<td>Hainan</td>
<td>30,561</td>
<td>0</td>
<td>1317</td>
<td>139,560</td>
<td>5118</td>
<td>656</td>
<td>188</td>
<td>3044</td>
<td>0</td>
<td>2820</td>
<td>183,064</td>
</tr>
<tr>
<td>Yunnan</td>
<td>83,997</td>
<td>6572</td>
<td>14,851</td>
<td>152,402</td>
<td>2056</td>
<td>2423</td>
<td>6793</td>
<td>10,465</td>
<td>151</td>
<td>25,972</td>
<td>305,681</td>
</tr>
<tr>
<td>Guangxi</td>
<td>212,919</td>
<td>267</td>
<td>36,867</td>
<td>231,290</td>
<td>12,332</td>
<td>8881</td>
<td>7769</td>
<td>7890</td>
<td>298</td>
<td>20,365</td>
<td>538,879</td>
</tr>
<tr>
<td>Henan</td>
<td>23,692</td>
<td>176,274</td>
<td>6099</td>
<td>103,139</td>
<td>12,597</td>
<td>15,306</td>
<td>20</td>
<td>2172</td>
<td>80</td>
<td>10,909</td>
<td>350,288</td>
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<tr>
<td>Jilin</td>
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<td>643</td>
<td>140,650</td>
<td>169,510</td>
<td>20,434</td>
<td>15,781</td>
<td>0</td>
<td>6626</td>
<td>14,001</td>
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<tr>
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<td>56,341</td>
<td>3882</td>
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<td>38,600</td>
<td>29,198</td>
<td>211</td>
<td>7304</td>
<td>139</td>
<td>59,715</td>
<td>702,226</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>923,240</td>
<td>35,320</td>
<td>60,049</td>
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<td>21,532</td>
<td>7010</td>
<td>0</td>
<td>8766</td>
<td>6176</td>
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<tr>
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<td>28,133</td>
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<td>12,579</td>
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<td>1951</td>
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</tr>
<tr>
<td>Hubei</td>
<td>240,074</td>
<td>17,472</td>
<td>41,331</td>
<td>33,334</td>
<td>22,735</td>
<td>31,578</td>
<td>152</td>
<td>10,544</td>
<td>436</td>
<td>44,795</td>
<td>442,452</td>
</tr>
<tr>
<td>Chongqing</td>
<td>30,822</td>
<td>4090</td>
<td>10,220</td>
<td>5161</td>
<td>1194</td>
<td>2152</td>
<td>29</td>
<td>7782</td>
<td>315</td>
<td>7040</td>
<td>68,804</td>
</tr>
<tr>
<td>Sichuan</td>
<td>233,749</td>
<td>64,057</td>
<td>116,539</td>
<td>40,314</td>
<td>4592</td>
<td>17,707</td>
<td>524</td>
<td>20,133</td>
<td>2040</td>
<td>25,879</td>
<td>525,535</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>7743</td>
<td>24,544</td>
<td>405,269</td>
<td>125,405</td>
<td>6041</td>
<td>13,347</td>
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<td>15,993</td>
<td>8606</td>
<td>57,285</td>
<td>664,234</td>
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<tr>
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<td>343,945</td>
<td>310,213</td>
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<td>140,928</td>
<td>7481</td>
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<td>25,249</td>
<td>2351</td>
<td>110,911</td>
<td>2,365,998</td>
</tr>
<tr>
<td>Other provinces</td>
<td>1,982,039</td>
<td>1,238,813</td>
<td>1,491,833</td>
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<td>163,458</td>
<td>251,758</td>
<td>9406</td>
<td>190,515</td>
<td>35,914</td>
<td>533,221</td>
<td>6,210,537</td>
</tr>
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</table>

Note: Sources: Estimated by authors.
Table 3. Subsidy for irrigation water at the provincial and sectoral levels.

<table>
<thead>
<tr>
<th>Unit: 10 Thousand Yuan</th>
<th>Paddy</th>
<th>Wheat</th>
<th>Corn</th>
<th>Vegetables</th>
<th>Fruits</th>
<th>Oil Seeds</th>
<th>Sugarcane</th>
<th>Potato</th>
<th>Sorghum</th>
<th>Other Crops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>National level</td>
<td>−5,046,675</td>
<td>−1,808,246</td>
<td>−2,471,323</td>
<td>−4,775,801</td>
<td>−476,361</td>
<td>−469,861</td>
<td>−77,156</td>
<td>−544,044</td>
<td>−66,616</td>
<td>−1,114,557</td>
<td>−16,650,041</td>
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<td>Guangdong</td>
<td>−323,951</td>
<td>−237</td>
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<td>−29,475</td>
<td>−83,579</td>
<td>−56,919</td>
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<td>−83</td>
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<td>−1,684,504</td>
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<td>−5151</td>
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<td>−1899</td>
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<td>−7355</td>
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<td>−1044</td>
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<td>−132,132</td>
<td>−159,244</td>
<td>−19,196</td>
<td>−14,926</td>
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<td>−6225</td>
<td>−13,153</td>
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<td>Heilongjiang</td>
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<td>−54,107</td>
<td>−266,843</td>
<td>−19,402</td>
<td>−6316</td>
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<td>−135,339</td>
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<td>Hebei</td>
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<td>−10,621</td>
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<td>−5627</td>
<td>−16,474</td>
<td>−24,444</td>
<td>−847,383</td>
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<td>Hubei</td>
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<td>−37,869</td>
<td>−30,542</td>
<td>−28,831</td>
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<td>−9660</td>
<td>−400</td>
<td>−41,043</td>
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<td>Chongqing</td>
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<td>−2649</td>
<td>−6620</td>
<td>−3343</td>
<td>−773</td>
<td>−1394</td>
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<td>−5041</td>
<td>−204</td>
<td>−4560</td>
<td>−44,566</td>
</tr>
<tr>
<td>Sichuan</td>
<td>−182,070</td>
<td>−49,495</td>
<td>−90,774</td>
<td>−31,401</td>
<td>−3577</td>
<td>−13,792</td>
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<td>−15,682</td>
<td>−1589</td>
<td>−20,157</td>
<td>−409,346</td>
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<tr>
<td>Inner Mongolia</td>
<td>−6529</td>
<td>−20,696</td>
<td>−341,724</td>
<td>−105,742</td>
<td>−5904</td>
<td>−11,254</td>
<td>0</td>
<td>−13,485</td>
<td>−7257</td>
<td>−48,363</td>
<td>−560,084</td>
</tr>
<tr>
<td>Shandong</td>
<td>−53,281</td>
<td>−331,224</td>
<td>−298,739</td>
<td>−3,138,956</td>
<td>−135,715</td>
<td>−7204</td>
<td>0</td>
<td>−24,315</td>
<td>−2264</td>
<td>−106,808</td>
<td>−2,276,487</td>
</tr>
<tr>
<td>Other provinces</td>
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<td>−1,204,498</td>
<td>−1,396,554</td>
<td>−300,656</td>
<td>−147,055</td>
<td>−235,914</td>
<td>−6351</td>
<td>−178,806</td>
<td>−33,548</td>
<td>−497,783</td>
<td>−5,840,655</td>
</tr>
</tbody>
</table>

Note: Sources: Estimated by authors.

3. A CGE Model with the Water Parallel Pricing System

3.1. Previous CGE Model Focusing on China’s Water Resources

The CGE Model as a good economic method for policy evaluation has been applied in many areas of water resource management and water pricing in China. The key question for employing the CGE model in these areas is how to make a connection between water resources and the whole social-economic system [21]. The CGE models for water issues (water-CGE model) are generally developed from the classical CGE models, such as ORANI [22], GTAP [23,24] and TERM [25,26]. There are quite a few water-CGE models in the literature. For example, Diao and Roe (2003) [27] developed an inter-temporal CGE model for Morocco focusing on water and trade policies. Gómez, Tirado and Rey-Maquieira (2004) [28] analyzed the welfare gains by improved allocation of water rights for the Balearic Islands. Horridge, Madden and Wittwer (2005) [29] modeled the 2002–2003 Australian drought by employing the TERM and developed an estimation formula that computed the productivity loss for each agricultural industry in each region. Calzadilla, Rehdanz, and Tol (2008) [23] considered the impact of increasing irrigation efficiency on global economic system based on the new version of GTAP-W. Watson and Davies (2011) [30] examined the effects of medium-run, exogenously projected population and economic growth on the water demand in the economically large and diverse region of the South Platte River Basin in Colorado, Wittwer and Dixon (2012) [26] made an analysis of the economic benefits of infrastructure upgrades or the economic costs of water buybacks based on TERM-H2O CGE modeling.

For water-CGE modeling studies in China, water resources are regarded as a constraint on production in estimating the marginal price of water by simulating the change in water supply [31], or acts as the
factor defined in the production function to evaluate the effects of water scarcity [32]. Great potential in agricultural water saving was demonstrated in a case study of Jiangxi Province which defined water production and supply as a sector and water resources as factors with consideration of the subsidy of productive water [33]. Water saving could be achieved by controlling the export of farming products [34] or by raising water prices [35]. Chou, Hsu, Huang et al. (2001) [22] constructed a WATERGEM model based on ORANI, where municipal water, surface water and ground water were involved; Berrittella, Rehdanz and Tol (2006) [36] defined a “non-market solution” and “market solution” by contrasting three alternative groups to estimate the impacts of the South-North Water Transfer Project on the economy of China and the rest of the world. Feng et al. (2007) [37] used a recursive dynamic CGE model to assess the economic implications of the same project. Yu and Shen (2014) [38] summarized the water-CGE studies and indicated that there are four types of formulating the water in CGE model: (1) Water as a constrain condition in production and/or consumption (e.g., [31]); (2) Water as a factor (e.g., [32]); (3) Water as an intermediate input (e.g., [33]); and (4) Water as a factor and as an intermediate input according to different users (integrated formulation, e.g., [30]).

The reform of China’s water management is still in progress, and the pricing system is inadequate to the representation of the commodity attributes of water [38]. The price distortion between agricultural water and non-agricultural water is usually neglected in previous water-CGE models of China. Moreover, little attention has been paid to China’s fragmented water management system, which is the main reason for the parallel pricing and separated supply for irrigation and pipe water. Previous CGE modeling studies involved China’s pricing system for water resources are rarely found in the literature.

3.2. Data and Modeling Framework

The water parallel pricing system is defined in both the dataset and model. This dataset essentially has the form of the 2007 Social Accounting Matrix (SAM) for China, which was contributed by Ge and Tokunaga (2011) [39]. We introduced the 16 province’s equilibrium irrigation water inputs (from Table 2) and their subsidies (from Table 3) and also the production sector of pipe water into the SAM to construct the SAM with the irrigation water from 16 provinces (SAM-16P, see S1 in Supplementary Material File; for a simplified diagram, see Table 4).

This model also refers to some agricultural CGE models to address the connection between agriculture and water, stated by Zhong, Okiyama and Tokunaga (2014) [40], Akune, Okiyama and Tokunaga (2011) [41], Okiyama and Tokunaga (2010) [42] and Tokunaga et al. (2003) [43]. The detailed mathematical functions of this static CGE model with irrigation water from 16 provinces (SCGE-16P) are presented in Appendix.

The production module consists of 34 sectors, which were divided into two categories: (i) Agricultural sectors including farming and non-farming, allocated across agricultural labor, croplands and irrigation water from 16 provinces; (ii) Other sectors including industrial, construction and services, where pipe water are the inputs. It should be noted that non-farming agricultural sectors only employ agricultural labor but not croplands and irrigation water; and other non-agricultural sectors only employ non-agricultural labor and capital. The nested constant elasticity of substitution (CES) production structure is applied to all production sectors. Most of parameters in the SCGE-16P as in the standard CGE model were derived from calibration, with the exception of substitution elasticity ($\sigma$) [44].
Table 4. Simplified social accounting matrix (SAM)-16P. Note: AGR = Agricultural sectors as activities/commodities, including paddy, wheat, corn, vegetable, fruit, oil seed, sugarcane, potato, sorghum and other crops and also animal husbandry, forestry, fishery and agriculture services; OTH = Other sectors as activities/commodities; WAP = Pipe water production sector as one of activities/commodities; 16WAR = 16 Provinces’ irrigation water as factor inputs; 16LAND = 16 Provinces’ croplands as factor inputs; 16AGRLB = 16 Provinces’ agricultural labor as factor inputs; NAGRLB = Non-agricultural labor as a factor input; CAP = Capital as a factor input; 16HHDURAL = 16 provinces’ rural households; HHDURBN = Urban households; GOV = Government; ENT = Enterprise; S-I = Savings and Investment; DTAX = Direct tax; INDTAX = Indirect tax; 16SUBWAR = 16 Provinces’ subsidy for irrigation water; TAR = Tariff; ROW = Rest of the world.

<table>
<thead>
<tr>
<th>Unit: 0.1 billion yuan</th>
<th>Activities and Commodities</th>
<th>Factors</th>
<th>Institutions</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AGR</td>
<td>OTH</td>
<td>WAP</td>
<td>16WAR</td>
<td>16LAND</td>
</tr>
<tr>
<td><strong>Activities and Commodities</strong></td>
<td>AGR</td>
<td>6877</td>
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<td>0</td>
<td>6013</td>
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<td>503,647</td>
<td>590</td>
<td>19,106</td>
<td>65,968</td>
</tr>
<tr>
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<td>9</td>
<td>837</td>
<td>41</td>
<td>52</td>
<td>270</td>
</tr>
<tr>
<td><strong>Factors</strong></td>
<td>16WAR</td>
<td>1823</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16LAND</td>
<td>157</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16AGRLB</td>
<td>26,564</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAGRLB</td>
<td>618</td>
<td>82621</td>
<td>244</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAP</td>
<td>1115</td>
<td>115,819</td>
<td>229</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Institutions</strong></td>
<td>16HHDURAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHDURBN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOV</td>
<td>1823</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DTAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INDTAX</td>
<td>48</td>
<td>38,396</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16SUBWAR</td>
<td>-1665</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAR</td>
<td>73</td>
<td>1360</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROW</td>
<td>2328</td>
<td>71693</td>
<td>0</td>
<td>1623</td>
<td>122</td>
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<tr>
<td><strong>Total</strong></td>
<td>51,294</td>
<td>841,886</td>
<td>1179</td>
<td>1823</td>
<td>157</td>
</tr>
</tbody>
</table>
Previous CGE models have provided a useful reference work for this study. Based on the CGE model with the croplands of 16 provinces [39,45], we incorporated irrigation water and pipe water by modeling the water parallel pricing system by means of integrated formulation where irrigation water acts as one of the factor inputs in the farming sectors and pipe water is consumed by all production sectors as an intermediate input and by households through their demand functions. Compared to previous CGE models, this model incorporates irrigation subsidy to indicate the price distortion between irrigation water and pipe water; irrigation water input and its subsidy are disaggregated into 16 groups for each of the 16 provinces. This gives the pipe water consumption of rural households. Thus, the water parallel pricing system is introduced into this model, in which irrigation water price is given at the level for which farmers are willing to pay and the subsidy is included. The supply of irrigation water is regulated by local government. Pipe water price is equal to the marginal cost of production, and pipe water supply is operated by its production sector. Therefore, the water parallel pricing system is represented by the parallel pricing processes of irrigation water and pipe water.

In China’s CGE modeling studies, the Cobb-Douglas function has been widely applied to represent the substitution between labor and capital in agricultural production (e.g., [31,32]); while in other production, the CES function is employed and its elasticity of this substitution has been estimated (e.g., [46–48]). For the substitution between labor and capital (σ_F), agricultural sectors have the Cobb-Douglas function, while non-agricultural sectors have the CES function with the elasticity given by Zhao and Wang (2008) [46]. The substitution between non-agricultural labor and agricultural labor (σ_{LB}), as well as that among regional agricultural labor (σ_{RLB}), are referred to Ge, Lei and Tokunaga (2014) [45]. Furthermore, farming sectors employ the combinations of cropland and irrigation water (the land-water bundles) from 16 provinces following the Cobb-Douglas assumption [45], and the irrigation subsidy is included in irrigation water price (see Figure 4). We set σ_{RLW} = 0.2 to denote that water pricing not a valid means of significantly reducing agricultural water consumption under water parallel pricing system [49,50]. Pipe water is combined with value-added input within the production function of non-farming agricultural sectors and other sectors, which faithfully reflects the characteristics of water-use efficiency in China. Water-use efficiency is highly relevant to value-added input, especially in industry, and therefore “water-use per unit of industrial value added” is used to represent water-use efficiency [6] (see Figure 5). We set σ_{VAW} = 0.5 to represent a more direct influence of water pricing policy on the industrial production [13]. The pipe water input in the farming sectors along with the irrigation water of “Other provinces” becomes the composite water demand of “Other provinces”. The reason for this setting is that those rural areas using pipe water for irrigation are very close to urban areas and thus were classified within “Other provinces”. We set σ_{WARP} = 30 to assume that there is no difference between pipe water and irrigation water for farming production.
Figure 4. Nested constant elasticity of substitution (CES) production structure of farming sectors. Notes: Province 1 = Guangdong; Province 2 = Jiangxi; Province 3 = Hainan; Province 4 = Yunnan; Province 5 = Guangxi; Province 6 = Henan; Province 7 = Jilin; Province 8 = Anhui; Province 9 = Heilongjiang; Province 10 = Hebei; Province 11 = Hubei; Province 12 = Chongqing; Province 13 = Sichuan; Province 14 = Inner Mongolia; Province 15 = Shandong; Province 16 = Other Provinces.

Figure 5. Cont.
The total supply of irrigation water is exogenous to presenting the resource endowment owned by the government, and so the government receives total payments of the irrigation water supply from 16 provinces as a source of income. Total subsidies of irrigation water are also entered into the income function of the government with a negative value. However, pipe water supply is equal to the sum of the sectoral demand defined by a market clearing function.

Households are grouped by urban and the 16 province’s rural households (corresponding to the water, agricultural labor and land provinces). Their income comes from the payments of agricultural and non-agricultural labor, capital return, cropland’s return and the transfers from government and enterprises and also foreign countries. Their consumption behavior follows the Cobb-Douglas assumption. The Hicksian equivalent variation (EV) measures the changes in household welfare: if EV is positive, the simulation increases welfare; and if it is negative, the simulation decreases welfare.

SCGE-16P as an open-economy model follows a small-country assumption regarding that the world prices of imports and exports are exogenous. The domestic prices of imports and exports are in Chinese Yuan (RMB). Similar to most CGE models, domestic production of each commodity is divided into domestic and export products through a constant elasticity of transformation (CET) function (\( \sigma_E \), obtained from Zhai and Hertel (2005) [47], is presented in Figures 4 and 5). The domestic consumption of each commodity is composed of domestic and import products based on the Armington assumption (1969) [51] (\( \sigma_M \), obtained from Willenbockel (2006) [48], is presented in Figures 4 and 5). Moreover, domestic consumption is separated by households, government and investment following the Cobb-Douglas assumption, respectively. Total investment is the sum of the savings obtained from households, enterprises and government, respectively. In particular, the model structure of farming products within the SCGE-16P is presented in Figure 6.
Other assumptions are the same as those for the standard CGE model [44]. Moreover, all prices of commodities and factors in the base year are assumed to equal one. We excluded the non-agricultural labor market to follow Walras’ law, and the wage of non-agricultural labor is exogenously fixed as the numeraire price index. Sensitivity analysis, where abnormalities were not observed from the results, can be obtained from the authors upon request for the sake of brevity. This model was conducted within the GAMS (Generalized Algebraic Modeling System) software, and the GAMS codes can be found in another one of Supplementary Material File, S2.

4. Simulation Results and Discussion


To simulate the drought of 2000, the modeling of farming production is suitable for considering the changes in cropland supply and irrigation water supply for different crops in different provinces. The changes in agricultural water represent the changes in irrigation water supply due to data limitation. Moreover, the year 2007 served as the baseline to the drought of 2000, and the simulated rates of
Table 5. Simulated rates for the regional supplies of croplands and irrigation water.

<table>
<thead>
<tr>
<th>Provincial Level</th>
<th>Simulating Cropland Supply</th>
<th>Simulating Irrigation Water Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cultivated Area of Farming 2007, Unit: 1000 ha *</td>
<td>Affected Rate of 2000 Drought **</td>
</tr>
<tr>
<td>Guangdong</td>
<td>4363.10</td>
<td>1.551%</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>5245.10</td>
<td>11.096%</td>
</tr>
<tr>
<td>Hainan</td>
<td>754.30</td>
<td>0.000%</td>
</tr>
<tr>
<td>Yunnan</td>
<td>5801.90</td>
<td>1.953%</td>
</tr>
<tr>
<td>Guangxi</td>
<td>5594.40</td>
<td>8.641%</td>
</tr>
<tr>
<td>Henan</td>
<td>14,087.80</td>
<td>10.048%</td>
</tr>
<tr>
<td>Jilin</td>
<td>4944.00</td>
<td>54.819%</td>
</tr>
<tr>
<td>Anhui</td>
<td>8853.90</td>
<td>24.984%</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>11,898.50</td>
<td>23.999%</td>
</tr>
<tr>
<td>Hebei</td>
<td>8652.70</td>
<td>18.173%</td>
</tr>
<tr>
<td>Hubei</td>
<td>7030.00</td>
<td>19.383%</td>
</tr>
<tr>
<td>Chongqing</td>
<td>3134.70</td>
<td>5.291%</td>
</tr>
<tr>
<td>Sichuan</td>
<td>9278.20</td>
<td>7.940%</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>6761.50</td>
<td>37.197%</td>
</tr>
<tr>
<td>Shandong</td>
<td>10,724.40</td>
<td>18.892%</td>
</tr>
<tr>
<td>Other provinces</td>
<td>46,339.40</td>
<td>17.632%</td>
</tr>
</tbody>
</table>

Notes: Data source: * China Agricultural Yearbook 2008 [52]; ** China Agricultural Yearbook 2001 [53]; *** China Statistic Yearbook on Environment 2008 [20]; **** China Water Resources Bulletin 2000 [54]; ***** Estimated by authors.

Table 5 reflects the fact that the drought of 2000 primarily occurred in the northern part of China, with Jilin being the most affected province. In Jilin, agricultural water declined by 27.4% compared with its 2007 level. Inner Mongolia and Henan were the second and third most affected provinces because their agricultural water declined by 20.1% and 16.5%, respectively. However, it should be noted that there were seven provinces in the southern areas in which the agricultural water supplies in 2000 exceeded those in 2007, including Guangdong, Jiangxi, Hainan, Guangxi, Anhui, Chongqing and the “Other provinces”. Thus, this year was not the worst year of drought for these provinces.

4.2. Effects of the 2000 Drought on the Agricultural Economy

The simulation predicted an insignificant effect on the nominal and real values of the national gross domestic product (GDP). The worst effect occurred in the total output of farming products and also agricultural outputs, which decreased by 0.078% and 0.052%, respectively. Total consumption, including food consumption, was also negatively affected. One projected positive value was the consumer price index, which was the primary reason for the decrease in consumption. The effects on the irrigation water prices of the 16 provinces were closely related to the changes in their irrigation water supply: A decrease in irrigation water supply increases price and vice versa (see Table 6).
Table 6. Changes in the macro economy and price indexes.

<table>
<thead>
<tr>
<th>Changes in Macro Indexes</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal GDP, %</td>
<td>0.013</td>
</tr>
<tr>
<td>Real GDP, %</td>
<td>−0.001</td>
</tr>
<tr>
<td>Total output of farming, %</td>
<td>−0.078</td>
</tr>
<tr>
<td>Total output of agriculture, %</td>
<td>−0.052</td>
</tr>
<tr>
<td>Total consumption, %</td>
<td>−0.012</td>
</tr>
<tr>
<td>Total food consumption, %</td>
<td>−0.068</td>
</tr>
<tr>
<td>Total change in welfare of households, 10 million Yuan</td>
<td>−116.036</td>
</tr>
<tr>
<td>Consumer price index, %</td>
<td>0.028</td>
</tr>
<tr>
<td>Capital return, %</td>
<td>0.009</td>
</tr>
<tr>
<td>Exchange rate, %</td>
<td>0.010</td>
</tr>
<tr>
<td>Pipe water price, %</td>
<td>0.006</td>
</tr>
</tbody>
</table>

| Guangdong                                    | −5.43       |
| Jiangxi                                      | −19.87      |
| Hainan                                       | −23.68      |
| Yunnan                                       | 9.68        |
| Guangxi                                      | −12.96      |
| Henan                                        | 38.64       |
| Jilin                                        | 51.80       |
| Anhui                                        | −9.79       |
| Heilongjiang                                 | 11.18       |
| Hebei                                        | 1.50        |
| Hubei                                        | 26.20       |
| Chongqing                                    | −32.06      |
| Sichuan                                      | 11.46       |
| Inner Mongolia                               | 38.59       |
| Shandong                                     | 6.03        |
| Other provinces                              | −14.74      |

Notes: (1) Sources: derived from simulation; (2) “Food” includes the 10 crops and the food products provided by food industries, including the following six types: meat, milk, vegetable oil, gain, sugar, and other food.

The three most affected crops in terms of output were sorghum, wheat and oil seed, which decreased by 2.278%, 0.407% and 0.295%, respectively, as they are mainly cultivated in the northern area of China. Their imports thus increased more significantly than those of other crops. Obviously, the decline in their inputs of composite land and water was the main reason for their decrease in output and their increases in the inputs of capital and labor. Therefore, at the national level, drought significantly reduced the output and export of crops, leading to increased imports. As a result, their producer prices increased significantly; the greatest increases were observed for sorghum, wheat and corn, whose prices rose by 0.974%, 0.385% and 0.338%, respectively. Furthermore, agricultural labor was reallocated from the non-farming agricultural production sectors into farming, with the exceptions of production of sorghum, oil seed and other crops, whose imports increased instead (see Table 7).
Table 7. Effects on agricultural production sectors.

<table>
<thead>
<tr>
<th></th>
<th>Producer Prices</th>
<th>Outputs</th>
<th>Exports</th>
<th>Imports</th>
<th>Capital Inputs</th>
<th>Composite Agricultural Labor Inputs</th>
<th>Non-Agricultural Labor Inputs</th>
<th>Composite Land and Water Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddy</td>
<td>0.156</td>
<td>−0.114</td>
<td>−0.636</td>
<td>0.645</td>
<td>0.172</td>
<td>0.132</td>
<td>0.172</td>
<td>−2.875</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.385</td>
<td>−0.407</td>
<td>−1.741</td>
<td>1.454</td>
<td>0.349</td>
<td>0.306</td>
<td>0.348</td>
<td>−8.882</td>
</tr>
<tr>
<td>Corn</td>
<td>0.338</td>
<td>−0.084</td>
<td>−1.255</td>
<td>0.512</td>
<td>0.403</td>
<td>0.360</td>
<td>0.402</td>
<td>−5.864</td>
</tr>
<tr>
<td>Vegetable</td>
<td>0.223</td>
<td>−0.196</td>
<td>−0.958</td>
<td>0.371</td>
<td>0.044</td>
<td>0.004</td>
<td>0.043</td>
<td>−6.252</td>
</tr>
<tr>
<td>Fruit</td>
<td>0.066</td>
<td>−0.064</td>
<td>−0.265</td>
<td>0.099</td>
<td>0.098</td>
<td>0.058</td>
<td>0.098</td>
<td>−4.365</td>
</tr>
<tr>
<td>Oil seed</td>
<td>0.129</td>
<td>−0.295</td>
<td>−0.722</td>
<td>0.061</td>
<td>−0.113</td>
<td>−0.153</td>
<td>−0.113</td>
<td>−4.075</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>0.075</td>
<td>−0.024</td>
<td>0.139</td>
<td>0.077</td>
<td>0.040</td>
<td>0.077</td>
<td>0.077</td>
<td>−2.600</td>
</tr>
<tr>
<td>Potato</td>
<td>0.189</td>
<td>−0.150</td>
<td>−0.791</td>
<td>0.327</td>
<td>0.045</td>
<td>0.005</td>
<td>0.045</td>
<td>−4.469</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.974</td>
<td>−2.278</td>
<td>−5.595</td>
<td>2.648</td>
<td>−1.252</td>
<td>−1.292</td>
<td>−1.252</td>
<td>−9.220</td>
</tr>
<tr>
<td>Other crops</td>
<td>0.044</td>
<td>−0.017</td>
<td>−0.140</td>
<td>0.071</td>
<td>0.029</td>
<td>−0.012</td>
<td>0.028</td>
<td>−1.848</td>
</tr>
<tr>
<td>Animal Husbandry</td>
<td>0.061</td>
<td>−0.030</td>
<td>−0.213</td>
<td>0.048</td>
<td>0.006</td>
<td>−0.033</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>Forestry</td>
<td>0.038</td>
<td>−0.017</td>
<td>−0.116</td>
<td>0.052</td>
<td>0.020</td>
<td>−0.020</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>Fishery</td>
<td>0.042</td>
<td>−0.021</td>
<td>−0.134</td>
<td>0.023</td>
<td>0.014</td>
<td>−0.023</td>
<td>0.014</td>
<td></td>
</tr>
</tbody>
</table>

Note: Sources: Derived from simulation.

Both urban and rural households were projected to suffer significant reductions in their welfare, total consumption and food consumption, despite the fact that most of them benefited from additional income. The higher consumer price indexes, especially the higher prices of agricultural products, were the main reasons for these reductions. Moreover, rural households from Henan, Sichuan, Hubei, Guangdong, Inner Mongolia, Yunnan and Jilin experienced the worst declines in welfare, with the decreases amounting to more than 10 million Yuan. These rural households were part of both northern and southern areas of China. Furthermore, significant negative effects on food consumption to all rural households were found, particularly in Hubei, Jilin, Sichuan, Inner Mongolia, Guangdong and Yunnan, with the decreases amounting to more than 0.1%. This demonstrates that rural households that were experiencing declines in welfare were marked by an analogous change in their food consumption. In particular, the losses of food consumption in rural households were more serious than those in urban households at the national level (see Table 8).

Figure 7 presents a chart summarizing the impacts of the drought of 2000 on rural households. When the drought occurred and reduced the supplies of irrigation water and cropland, agricultural outputs decreased, and then, the prices of agricultural products increased. Rural households lowered their food consumption so that their utility levels and also their welfare decreased. Decreasing supplies of cropland and irrigation water increased the return of cropland. Meanwhile, labor wages were also higher because of the increasing demand of labor; thus, rural households benefited from higher income. However, additional income could not compensate for their losses in consumption.
### Table 8. Changes in welfare, income and consumption of urban and rural households.

<table>
<thead>
<tr>
<th>Province</th>
<th>Welfare</th>
<th>Income</th>
<th>Consumption</th>
<th>Food Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangdong</td>
<td>-3.754</td>
<td>0.033</td>
<td>-0.026</td>
<td>-0.103</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>-0.638</td>
<td>0.064</td>
<td>-0.007</td>
<td>-0.099</td>
</tr>
<tr>
<td>Hainan</td>
<td>0.125</td>
<td>0.080</td>
<td>0.009</td>
<td>-0.077</td>
</tr>
<tr>
<td>Yunnan</td>
<td>1.985</td>
<td>0.037</td>
<td>-0.024</td>
<td>-0.103</td>
</tr>
<tr>
<td>Guangxi</td>
<td>-0.571</td>
<td>0.061</td>
<td>-0.006</td>
<td>-0.091</td>
</tr>
<tr>
<td>Henan</td>
<td>-9.280</td>
<td>-0.053</td>
<td>-0.069</td>
<td>-0.087</td>
</tr>
<tr>
<td>Jilin</td>
<td>-1.970</td>
<td>0.008</td>
<td>-0.041</td>
<td>-0.127</td>
</tr>
<tr>
<td>Anhui</td>
<td>0.566</td>
<td>0.053</td>
<td>0.005</td>
<td>-0.086</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>-0.492</td>
<td>0.036</td>
<td>-0.008</td>
<td>-0.089</td>
</tr>
<tr>
<td>Hebei</td>
<td>1.941</td>
<td>0.048</td>
<td>0.017</td>
<td>-0.041</td>
</tr>
<tr>
<td>Hubei</td>
<td>-5.489</td>
<td>0.011</td>
<td>-0.049</td>
<td>-0.145</td>
</tr>
<tr>
<td>Chongqing</td>
<td>0.718</td>
<td>0.083</td>
<td>0.016</td>
<td>-0.066</td>
</tr>
<tr>
<td>Sichuan</td>
<td>-7.767</td>
<td>0.018</td>
<td>-0.048</td>
<td>-0.124</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>-2.393</td>
<td>-0.022</td>
<td>-0.055</td>
<td>-0.124</td>
</tr>
<tr>
<td>Shandong</td>
<td>1.674</td>
<td>0.036</td>
<td>0.009</td>
<td>-0.050</td>
</tr>
<tr>
<td>Other provinces</td>
<td>14.365</td>
<td>0.059</td>
<td>0.014</td>
<td>-0.069</td>
</tr>
</tbody>
</table>

#### Note: Sources: Derived from simulation.

#### Figure 7. Flow chart of the impact of drought 2000 on rural households.

### 5. Conclusions and Policy Recommendation

The basic purpose of a CGE analysis is to provide several possible solutions for policy recommendation regarding a series of assumptions. The main originalities of this study focused on two aspects to construct the SCGE-16P: (1) Extending the given SAM by introducing irrigation water and
its irrigation subsidy and then segmenting them into 16 provincial levels; (2) Introducing the water parallel pricing system into the CGE model, where the price distortion between irrigation water and pipe water was defined, and the supply of irrigation water and that of pipe water were managed by the government and the pipe water production sector, respectively. In the simulation of the 2000 drought, the macroeconomic results indicated that the effects on nominal and real GDP were negative but insignificant. However, the decline in the output of some crops was significant and varied. All crop outputs and exports decreased, particularly for sorghum, wheat and oil seed, which are mainly cultivated in the northern areas, and then their imports increased. Furthermore, most farming production sectors employed more capital and labor to sustain output because of the decline in the supplies of cropland and irrigation water. As a result, agricultural labor was redistributed from non-farming agricultural production sectors into farming. Households suffered significant losses in welfare, total consumption and food consumption. Rural households from both northern and southern areas experienced the most significant declines in welfare, including in Henan, Sichuan, Hubei, Guangdong, Inner Mongolia, Yunnan and Jilin. Furthermore, the close relationship between food consumption and welfare was exemplified for both urban and rural areas.

The purpose of the water pricing reform is to allocate water resources to different sectors with more efficiency, especially between agricultural sectors and industrial sectors. To promote this reform, both irrigation water and pipe water should be formulated with volumetric pricing according to the marginal cost level. To protect the losses of both northern and southern households from drought, their basic level of food consumption should be guaranteed by additional supports, such as providing new subsidy and promoting employment to make up their losses in income and consumption. Moreover, it is necessary to shift additional agricultural labor to the non-farming agricultural sectors to prevent losses in output. In the northern area, more water-efficient irrigation technologies should be introduced into the production of water-intensive crops. The production of less water-intensive crops should be extended to this area. Other policy supports should consider limiting urban expansion on high-quality land, promoting capital investments into basic agricultural inputs (fertilizer and machinery), extension services and agri-business development [55]. Furthermore, water-saving technology should be improved in the urban-industrial sectors; thus, more water could be redistributed to agricultural sectors.

It would be interesting to make a comparison between the real impacts of drought and the simulation results. However, the 2000 drought was a short-term event, which only continued few months varied across different regions, and the detailed seasonal data describing the real impacts are not available in official database but only annual data recorded at the end of 2000 [15,53,54]. The only available data in official database about this drought are the drought-affected areas, which were already considered in the simulation design. Moreover, the relatively work of the drought 2000 are also rare found in previous studies. On the other hand, the SCGE-16P model constructed in this study was expended from the standard CGE model, where many assumptions setting are too strict to reflect the reality. So the simulation results derived from this model just provided the “perfect market reaction”, which might have some discrepancies between model responses and actual responses because of two reasons: Firstly, the simulation of 2000 drought in design only considered those drought-affected areas with more 30% decline in yield as interpreted in the yearbook, but those areas with less 30% decline were ignored, which were much larger than the areas in our design; Secondly, as well known, China’s market-oriented reform is still underway, and so there are many barriers impeding the market force at the institutional level and
at the regional level. Consequently, it is possible that the observed output impacts would be more significant than the results generated from model simulation. In other words, the simulation just provided a theoretical response to the drought under the strict market condition rather than an actual response. This theoretical response would play an important role for government to improve the market-oriented reform and water management system, especially in the period of a serious drought.

Besides, several parameters ($\sigma_E$, $\sigma_M$, $\sigma_F$ and $\sigma_{LB}$) used in this study were set according to previous studies. Some other parameters ($\sigma_{RLW}$, $\sigma_{VAW}$ and $\sigma_{WARP}$), due to data limitation, were based on assumption instead of estimation, which might not be precise enough to describe the detailed condition of economic system. More accurate values of these parameters need to be estimated for future study by using econometric approach to improve the quality of model simulation.

**Acknowledgments**

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**Author Contributions**

Shuai Zhong, Mitsuru Okiyama and Suminori Tokunaga conceived and designed the initial work of study and simulation; Lei Shen, Jinghua Sha, Litao Liu and Jingjing Yan provided many very helpful suggestions to improve its analysis, discussed the results and commented on the manuscript; Shuai Zhong collected the data, constructed the model and wrote the paper.

**Conflicts of Interest**

The authors declare no conflict of interest.

**Appendix: SCGE Model with Irrigation Water from 16 Provinces (SCGE-16P)**

**A1. Model Equations**

**A1.1. Production Block**

**A1.1.1. Provinces’ Agricultural Labor in Cobb-Douglas Function**

$$LFR_{agc, prov} = \beta LFR_{agc, prov} \times PLF_{agc} \times LF_{agc} / PLFR_{prov}$$  \hspace{1cm} (A1)
A1.1.2. Composite Agricultural Labor in Cobb-Douglas Function

\[ LF_{agc} = bFLR_{agc} \times \prod_{prov} \frac{LFR_{agc,prov}}{\prod_{prov} \frac{aLFR_{agc,prov}}{bFLR_{agc,prov}}} \]  \hspace{1cm} \text{(A2)}

A1.1.3. Non-agricultural Labor in CES Function

\[ LE_{agc} = \left( \frac{L_{agc}}{aL_{agc}} \right) \times \left( \frac{\gamma L_{agc}}{PLE} \right) \times \left[ \gamma L_{agc} \times PLE \times \left( 1 - \frac{\alpha L_{agc}}{1 - \alpha L_{agc}} \right) \right] \times \left( 1 - \gamma L_{agc} \times PLF_{agc} \times \left( 1 - \alpha L_{agc} \right) \right) \]  \hspace{1cm} \text{(A3)}

A1.1.4. Composite Agricultural Labor in CES Function

\[ LF_{agc} = \left( \frac{L_{agc}}{aL_{agc}} \right) \times \left( \frac{1 - \gamma L_{agc}}{PLF_{agc}} \right) \times \left[ \gamma L_{agc} \times PLE \times \left( 1 - \frac{\alpha L_{agc}}{1 - \alpha L_{agc}} \right) \right] \times \left( 1 - \gamma L_{agc} \times PLF_{agc} \times \left( 1 - \alpha L_{agc} \right) \right) \]  \hspace{1cm} \text{(A4)}

A1.1.5. Zero-profit Condition in CES Function for the Labor

\[ PL_{agc} \times L_{agc} = PLF_{agc} \times LF_{agc} + PLE \times LE_{agc} \]  \hspace{1cm} \text{(A5)}

A1.1.6. Irrigation Water Demand of “Other Provinces” for Farming Production Sectors

\[ WAR_{cro,OTH}^{cro} = \left( \frac{WAROTH_{cro}}{aWARP_{cro}} \right) \times \left( \frac{\gamma WARP_{cro}}{PWR_{OTH}^{cro}} \right) \times \left( \frac{\sigma WARP_{cro}}{1 - \alpha WARP_{cro}} \right) \times \left( \frac{\sigma WARP_{cro}}{1 - \alpha WARP_{cro}} \right) \]  \hspace{1cm} \text{(A6)}

A1.1.7. Pipe Water Demand of “Other Provinces” for Farming Production Sectors

\[ WAP_{cro} = \left( \frac{WAROTH_{cro}}{aWARP_{cro}} \right) \times \left( \frac{1 - \gamma WARP_{cro}}{P_{WAP}^{cro}} \right) \times \left( \frac{\sigma WARP_{cro}}{1 - \alpha WARP_{cro}} \right) \times \left( \frac{\sigma WARP_{cro}}{1 - \alpha WARP_{cro}} \right) \]  \hspace{1cm} \text{(A7)}

A1.1.8. Zero-profit Condition in CES Function for the Composite Water Demand of “Other Provinces” for Farming Production Sectors

\[ WAROTH_{cro} \times PWROTH_{cro} = PWR_{OTH}^{cro} \times WAR_{cro,OTH}^{cro} + P_{WAP}^{cro} \times WAP_{cro} \]  \hspace{1cm} \text{(A8)}
A1.1.9. Composite Water Demand of “Other Provinces” for Farming Production Sectors

\[
WAR_{\text{cro}, \text{OTH}} = \left( \frac{LW_{\text{cro}, \text{OTH}}}{aLW_{\text{cro}, \text{OTH}}} \right) \times \left[ \frac{\gamma LW_{\text{cro}, \text{OTH}}}{(1 + ts\text{wr}_{\text{cro}, \text{OTH}}) \times PW\text{R}_\text{cro}} \right] \sigma LW_{\text{cro}, \text{OTH}}
\]

\[
\times \left\{ \gamma LW_{\text{cro}, \text{OTH}} \sigma LW_{\text{cro}, \text{OTH}} \left[ (1 + ts\text{wr}_{\text{cro}, \text{OTH}}) \times PW\text{R}_\text{cro} \right] (1 - \sigma LW_{\text{cro}, \text{OTH}}) \right\}
\]

A1.1.10. Cropland Demand of “Other Provinces” for Farming Production Sectors

\[
LD_{\text{cro}, \text{OTH}} = \left( \frac{LW_{\text{cro}, \text{OTH}}}{aLW_{\text{cro}, \text{OTH}}} \right) \times \left( 1 - \frac{\gamma LW_{\text{cro}, \text{OTH}}}{PLD_{\text{OTH}}} \right) \sigma LW_{\text{cro}, \text{OTH}}
\]

\[
\times \left\{ \gamma LW_{\text{cro}, \text{OTH}} \sigma LW_{\text{cro}, \text{OTH}} \left[ (1 + ts\text{wr}_{\text{cro}, \text{OTH}}) \times PW\text{R}_\text{cro} \right] (1 - \sigma LW_{\text{cro}, \text{OTH}}) \right\}
\]

A1.1.11. Zero-profit Condition in CES Function for the Land-Water Bundles of “Other Province” for Farming Production Sectors

\[
LW_{\text{cro}, \text{OTH}} \times PLW_{\text{cro}, \text{OTH}}
\]

\[
= (1 + ts\text{wr}_{\text{cro}, \text{OTH}}) \times WAR\text{POTH}_\text{cro} \times PW\text{R}_\text{cro} + PLD_{\text{OTH}} \times LD_{\text{cro}, \text{OTH}}
\]

A1.1.12. Irrigation Water Demand of 16 Provinces except “Other Provinces” for Farming Production Sectors

\[
WAR_{\text{cro, prov}} = \left( \frac{LWR_{\text{cro, prov}}}{aLWR_{\text{cro, prov}}} \right) \times \left[ \frac{\gamma LW_{\text{cro, prov}}}{(1 + ts\text{wr}_{\text{cro, prov}}) \times PW\text{R}_{\text{prov}}} \right] \sigma LW_{\text{cro, prov}}
\]

\[
\times \left\{ \gamma LW_{\text{cro, prov}} \sigma LW_{\text{cro, prov}} \left[ (1 + ts\text{wr}_{\text{cro, prov}}) \times PW\text{R}_{\text{prov}} \right] (1 - \sigma LW_{\text{cro, prov}}) \right\}
\]

A1.1.13. Cropland Demand of 16 Provinces except “Other Provinces” for Farming Production Sectors

\[
LD_{\text{cro, prov}} = \left( \frac{LWR_{\text{cro, prov}}}{aLW_{\text{cro, prov}}} \right) \times \left( 1 - \frac{\gamma LW_{\text{cro, prov}}}{PLD_{\text{prov}}} \right) \sigma LW_{\text{cro, prov}}
\]

\[
\times \left\{ \gamma LW_{\text{cro, prov}} \sigma LW_{\text{cro, prov}} \left[ (1 + ts\text{wr}_{\text{cro, prov}}) \times PW\text{R}_{\text{prov}} \right] (1 - \sigma LW_{\text{cro, prov}}) \right\}
\]

\[
PLWR_{cro,prov} \times LWR_{cro,prov} = (1 + tswr_{cro,prov}) \times PWR_{prov} \times WAR_{cro,prov} + PLD_{prov} \times LD_{cro,prov}
\]  
(A14)

A1.1.15. Demand of Land-water Bundle of 16 Provinces in Cobb-Douglas Function for Farming Production Sectors

\[
LWR_{cro,prov} = \beta L W_{cro,prov} \times PL W_{cro} \times LW_{cro} / PLWR_{cro,prov}
\]  
(A15)

A1.1.16. Composite Land-Water Demand in Cobb-Douglas Function for Farming Production Sectors

\[
L W_{cro} = b F L W_{cro} \times \left( \prod_{prov} L WR_{cro,prov} \right)^{\beta L W_{cro,prov}}
\]  
(A16)

A1.1.17. Capital Demand in Cobb-Douglas Function for Agricultural Production Sectors

\[
K_{agc} = \beta F K_{agc} \times P V A_{agc} \times V A_{agc} / PK
\]  
(A17)

A1.1.18. Composite Labor Demand in Cobb-Douglas Function for Agricultural Production Sectors

\[
L_{agc} = \beta F L_{agc} \times P V A_{agc} \times V A_{agc} / P L_{agc}
\]  
(A18)

A1.1.19. Composite Land-Water Demand in Cobb-Douglas for Farming Production Sectors

\[
L W_{cro} = \beta F L W_{cro} \times P V A_{cro} \times V A_{cro} / PL W_{cro}
\]  
(A19)

A1.1.20. Value-Added Demand in Cobb-Douglas Function for Farming Production Sectors

\[
V A_{cro} = b F_{cro} \times \left( K_{cro}^{\beta F K_{cro}} \times L_{cro}^{\beta F L_{cro}} \times L W_{cro}^{\beta L W_{cro}} \right)
\]  
(A20)


\[
V A_{ncro} = b F_{ncro} \times \left( K_{ncro}^{\beta F K_{ncro}} \times L_{ncro}^{\beta F L_{ncro}} \right)
\]  
(A21)

A1.1.22. Capital Demand in CES Function for the Production of Other Sectors

\[
K_{inse} = \left( \frac{V A_{inse}}{a F_{inse}} \times \frac{1 - \gamma F_{inse}}{PK} \right)^{\alpha F_{inse}} \times \left( \frac{\gamma F_{inse}^{\sigma F_{inse}}}{\alpha F_{inse}} \times P L_{inse}^{(1 - \alpha F_{inse})} \right) \frac{\sigma F_{inse}}{(1 - \alpha F_{inse})}
\]  
\[
+ (1 - \gamma F_{inse})^{\alpha F_{inse}} \times PK^{(1 - \alpha F_{inse})}
\]  
(A22)

A1.1.23. Non-agricultural Labor Demand in CES Function for the Production of Other Sectors

\[
L E_{inse} = \left( \frac{V A_{inse}}{a F_{inse}} \times \frac{\gamma F_{inse}}{PL_{inse}^{\alpha F_{inse}}} \right)^{\sigma F_{inse}} \times \left( \frac{\gamma F_{inse}^{\sigma F_{inse}}}{\alpha F_{inse}} \times P L E^{(1 - \alpha F_{inse})} \right) \frac{\sigma F_{inse}}{(1 - \alpha F_{inse})}
\]  
\[
+ (1 - \gamma F_{inse})^{\alpha F_{inse}} \times PK^{(1 - \alpha F_{inse})}
\]  
(A23)
A1.1.24. Zero-profit Condition in CES Function for Value Added of Other Sectors

\[ PVA_{\text{ncpinse}} \times VA_{\text{ncpinse}} = PK \times K_{\text{inse}} + PLE \times LE_{\text{inse}} \] (A24)

A1.1.25. Value-Added Demand in CES Function for Non-farming Agricultural and Other Sectors

\[
\begin{align*}
V_{A\text{ncpinse}} &= \left( \frac{VA_{W\text{ncpinse}}}{\sigma_{VA_{W\text{ncpinse}}}} \right) \times \left[ \frac{\gamma_{VA_{W\text{ncpinse}}}}{(1 + tv_{A\text{ncpinse}}) \times PVA_{\text{ncpinse}}} \right] \\
&\times \left[ (1 - \gamma_{VA_{W\text{ncpinse}}}) \times P_{WAP} \right] \\
&+ (1 - \gamma_{VA_{W\text{ncpinse}}}) \times \left[ (1 + tv_{A\text{ncpinse}}) \times PVA_{\text{ncpinse}} \right] \left[ (1 - \sigma_{VA_{W\text{ncpinse}}}) \right]
\end{align*}
\] (A25)

A1.1.26. Pipe Water Demand in CES Function for Non-farming Agricultural and Other Sectors

\[
\begin{align*}
W_{A\text{ncpinse}} &= \left( \frac{VA_{W\text{ncpinse}}}{\sigma_{VA_{W\text{ncpinse}}}} \right) \times \left[ \frac{1 - \gamma_{VA_{W\text{ncpinse}}}}{P_{WAP}} \right] \\
&\times \left[ (1 - \gamma_{VA_{W\text{ncpinse}}}) \times P_{WAP} \right] \\
&+ (1 - \gamma_{VA_{W\text{ncpinse}}}) \times \left[ (1 + tv_{A\text{ncpinse}}) \times PVA_{\text{ncpinse}} \right] \left[ (1 - \sigma_{VA_{W\text{ncpinse}}}) \right]
\end{align*}
\] (A26)

A1.1.27. Zero-profit Condition in CES Function for the Pipe Water Demand and Value-added Demand of Non-farming Agricultural and Other Sectors

\[ PVA_{W\text{ncpinse}} \times VA_{W\text{ncpinse}} = P_{WAP} \times W_{A\text{ncpinse}} + (1 + tv_{A\text{ncpinse}}) \times PVA_{\text{ncpinse}} \times VA_{\text{ncpinse}} \] (A27)

A1.1.28. Intermediate Demand Except Water in Leontief Function

\[ I_{O_{\text{mwa,sec}}} = i_{iio_{\text{mwa,sec}}} \times XD_{\text{sec}} \] (A28)

A1.1.29. Value-Added Demand in Leontief Function for Farming Sectors

\[ VA_{\text{cro}} = i_{a_{\text{cro}}} \times XD_{\text{cro}} \] (A29)

A1.1.30. Composite Value-Added Demand in Leontief Function for Non-farming Agricultural and Other Sectors

\[ VA_{\text{ncpinse}} = i_{a_{\text{ncpinse}}} \times XD_{\text{ncpinse}} \] (A30)

A1.1.31. Relationship between the Producer Price, the Price of Value-Added and the Price of Intermediate Inputs for Production Sectors

\[ PD_{\text{cro}} = i_{a_{\text{cro}}} \times PVA_{\text{cro}} \times (1 + tv_{\text{cro}}) + \sum_{nwa} P_{\text{nwa}} \times i_{iio_{\text{nwa,cro}}} \] (A31)
### A1.1.32. Relationship between the Producer Price, the Price of Value-Added and the Price of Intermediate Inputs for Non-farming Agricultural and Other Sectors

\[ P_{D_{ncpinse}} = ivt_{ncpinse} \times PVAW_{ncpinse} \times (1 + ivt_{ncpinse}) + \sum_{nwa} P_{nwa} \times \iiota_{nwa,ncpinse} \]  
\( (A32) \)

### A1.2. Trade Block

#### A1.2.1. Import Demand in Armington Function

\[ M_{sec} = \left( \frac{X_{sec}}{a_{sec}} \right) \times \left( \frac{\gamma_{sec}}{PM_{sec}} \right)^{\alpha_{sec}} \times \left\{ \frac{\gamma_{sec}^{\alpha_{sec}} \times PM_{sec}^{(1 - \alpha_{sec})}}{\left(1 - \alpha_{sec}\right)} + \left(1 - \gamma_{sec}\right)^{\alpha_{sec}} \times PDD_{sec}^{(1 - \alpha_{sec})} \right\}^{\frac{\alpha_{sec}}{\left(1 - \alpha_{sec}\right)}} \]  
\( (A33) \)

#### A1.2.2. Domestic Product Demand in Armington Function

\[ XDD_{sec} = \left( \frac{X_{sec}}{a_{sec}} \right) \times \left(1 - \gamma_{sec}\right)^{\alpha_{sec}} \times \left\{ \frac{\gamma_{sec}^{\alpha_{sec}} \times PM_{sec}^{(1 - \alpha_{sec})}}{\left(1 - \alpha_{sec}\right)} + \left(1 - \gamma_{sec}\right)^{\alpha_{sec}} \times PDD_{sec}^{(1 - \alpha_{sec})} \right\}^{\frac{\alpha_{sec}}{\left(1 - \alpha_{sec}\right)}} \]  
\( (A34) \)

#### A1.2.3. Zero-profit Condition in Armington Function

\[ P_{sec} \times X_{sec} = PM_{sec} \times M_{sec} + PDD_{sec} \times XDD_{sec} \]  
\( (A35) \)

#### A1.2.4. Export Demand in CET Function

\[ E_{sec} = \left( \frac{XD_{sec}}{aT_{sec}} \right) \times \left(1 - \gammaT_{sec}\right)^{\sigmaT_{sec}} \times \left\{ \frac{(1 - \gammaT_{sec})^{\sigmaT_{sec}} \times PE_{sec}^{(1 - \sigmaT_{sec})}}{\left(1 - \sigmaT_{sec}\right)} + \gammaT_{sec}^{\sigmaT_{sec}} \times PDD_{sec}^{(1 - \sigmaT_{sec})} \right\}^{\frac{\sigmaT_{sec}}{\left(1 - \sigmaT_{sec}\right)}} \]  
\( (A36) \)

#### A1.2.5. Domestic Product Demand in CET Function

\[ XDD_{sec} = \left( \frac{XD_{sec}}{aT_{sec}} \right) \times \left(\frac{\gammaT_{sec}}{PDD_{sec}}\right)^{\sigmaT_{sec}} \times \left\{ \frac{(1 - \gammaT_{sec})^{\sigmaT_{sec}} \times PE_{sec}^{(1 - \sigmaT_{sec})}}{\left(1 - \sigmaT_{sec}\right)} + \gammaT_{sec}^{\sigmaT_{sec}} \times PDD_{sec}^{(1 - \sigmaT_{sec})} \right\}^{\frac{\sigmaT_{sec}}{\left(1 - \sigmaT_{sec}\right)}} \]  
\( (A37) \)

#### A1.2.6. Zero-profit Condition in CET Function

\[ PD_{sec} \times XD_{sec} = PE_{sec} \times E_{sec} + PDD_{sec} \times XDD_{sec} \]  
\( (A38) \)

#### A1.2.7. Import Price

\[ PM_{sec} = (1 + tm_{sec}) \times ER \times \frac{PmZ_{sec}}{m_{sec}} \]  
\( (A39) \)
A1.2.8. Export Price

\[ PE_{sec} = ER \times pW_eZ_{sec} \]  
(A40)

A1.3. Blocks of Households and Enterprise

A1.3.1. Household Consumption

\[
P_{sec} \times C_{sec,hou} = \alpha H_{sec,hou} \times \left[ (1 - ty_{hou}) \times (1 - mps_{hou}) \times Y_{hou} - PCINDEX \times \sum_{insd} TRI_{insd,hou} \right] \]  
(A41)

A1.3.2. Initial Utility Level of Households

\[
U_{UUZ,hou} = \prod_{sec} C_{sec,hou} \alpha H_{sec,hou} \]  
(A42)

A1.3.3. Proposed Change in Utility Level of Households

\[
U_{UU,hou} = \prod_{sec} C_{sec,hou} \alpha H_{sec,hou} \]  
(A43)

A1.3.4. Initial Level of Equivalent Variation Level

\[
EP_{Z,hou} = UU_{UUZ,hou} / \prod_{sec} (\alpha H_{sec,hou} / 1)^{\alpha H_{sec,hou}} \]  
(A44)

A1.3.5. Proposed Change in the Level of Equivalent Variation

\[
EP_{,hou} = UU_{UU,hou} / \prod_{sec} (\alpha H_{sec,hou} / 1)^{\alpha H_{sec,hou}} \]  
(A45)

A1.3.6. Equivalent Variation to Measure the Welfare Changing of Households

\[
EV_{,hou} = EP_{,hou} - EP_{Z,hou} \]  
(A46)

A1.3.7. Income of Households and Enterprise

\[
y_{insdng,prov} = PK \times KS_{insdng,prov} + PLFR_{insdng,prov} \times LSF_{insdng,prov} + PLE \times LSE_{insdng,prov} + PLD_{prov} \times LDS_{insdng,prov} + PCINDEX \times \sum_{insd} TRI_{insd,prov} + ER \times NFD_{insdng,prov} \]  
(A47)

A1.3.8. Savings of Household and Enterprise

\[
SP_{insdng} = mps_{insdng} \times (1 - ty_{insdng}) \times Y_{insdng} \]  
(A48)
A1.4. Saving/Investment

A1.4.1. Total Saving

\[ S = \sum_{insdng} SP_{insdng} + SG + ER \times SF \]  
(A49)

A1.4.2. Sectoral Investment of Bank

\[ P_{sec} \times I_{sec} = \alpha I_{sec} \times S \]  
(A50)

A1.5. Government Block

A1.5.1. Government Saving

\[ SG = mpg \times TAXR \]  
(A51)

A1.5.2. Interest Payments to Government

\[ IG = \alpha IG \times S \]  
(A52)

A1.5.3. Total Subsidy for Irrigation Water

\[ TSDWR = \sum_{cro, prov} tswr_{cro, prov} \times PWR_{prov} \times WAR_{cro, prov} \]

\[ + \sum_{cro} tswr_{cro,*OTH} \times PWRPOTH_{cro} \times WARPOTH_{cro} \]  
(A53)

Note: the set “prov” in this equation (A53) only covers pre-15 provinces.

A1.5.4. Government Consumption

\[ P_{sec} \times CG_{sec} = \alpha CG_{sec} \times \left[ TAXR + TSDWR + IG + ER * RGF + \sum_{prov} PWR_{prov} \times IRWAG_{prov,*GOV^*} \right] \]

\[ - \left( PCINDEX \times \sum_{insdng} TRI_{insdng} + ER * EGF + SG \right) \]  
(A54)

A1.5.5. Total Tax Revenue

\[ TAXR = \sum_{cro} tv_a_{cro} \times \left( PL_{cro} \times L_{cro} + PK \times K_{cro} + PLW_{cro} \times LW_{cro} \right) \]

\[ + \sum_{ncro} tv_a_{ncro} \times \left( PL_{ncro} \times L_{ncro} + PK \times K_{ncro} \right) + \sum_{inse} tv_a_{inse} \times \left( PLE \times LE_{inse} + PK \times K_{inse} \right) \]

\[ + \sum_{sec} tv_a_{sec} \times pwMz_{sec} \times ER \times M_{sec} + \sum_{insdng} tv_{insdng} \times Y_{insdng} \]  
(A55)
A1.6. Market Condition

A1.6.1. Consumer Price Index

\[ \text{PCINDEX} = \frac{\sum \text{P}_{\text{sec}} \times \text{CZ}_{\text{sec}}}{\sum \text{P}_{Z_{\text{sec}}} \times \text{CZ}_{\text{sec}}} \]  \hspace{1cm} (A56)

A1.6.2. Non-agricultural Labor Markets

\[ \sum \text{LE}_{\text{sec}} = \sum \text{LSE}_{\text{insdng}} \]  \hspace{1cm} (A57)

A1.6.3. Agricultural Labor Markets of 16 Provinces

\[ \sum \text{LFR}_{\text{age,prov}} = \sum \text{LSFR}_{\text{insd,prov}} \]  \hspace{1cm} (A58)

A1.6.4. Capital Markets

\[ \sum \text{K}_{\text{sec}} = \sum \text{KS}_{\text{insdng}} + \text{KSRW} \]  \hspace{1cm} (A59)

A1.6.5. Cropland Markets of 16 Provinces

\[ \sum \text{LD}_{\text{cro,prov}} = \sum \text{LDS}_{\text{prov,insd}} \]  \hspace{1cm} (A60)

A1.6.6. Irrigation Markets of 16 Provinces

\[ \sum \text{WAR}_{\text{cro,prov}} = \sum \text{IRWAG}_{\text{insd,prov}} \]  \hspace{1cm} (A61)

A1.6.7. Commodity Markets except Pipe Water

\[ X_{\text{nwa}} = \sum_{\text{hou}} C_{\text{nwa,hou}} + I_{\text{nwa}} + CG_{\text{nwa}} + \sum_{\text{sec}} IO_{\text{nwa,sec}} \]  \hspace{1cm} (A62)

A1.6.8. Commodity Markets of Pipe Water

\[ X_{\text{WAP}} = \sum_{\text{hou}} C_{\text{WAP,hou}} + I_{\text{WAP}} + CG_{\text{WAP}} + \sum_{\text{sec}} WAP_{\text{sec}} \]  \hspace{1cm} (A63)

A1.6.9. Balance of International Payments

\[ \sum_{\text{sec}} pWmZ_{\text{sec}} \times M_{\text{sec}} + (PK/ER) \times KSRW + (PK/ER) \times EGF \]
\[ = \sum_{\text{sec}} pWeZ_{\text{sec}} \times E_{\text{sec}} + SF + \sum_{\text{insdng}} NFD_{\text{insdng}} + RGF \]  \hspace{1cm} (A64)
A1.6.10. Nominal Gross Domestic Products (NGDP)

\[
NGDP = \sum_{\text{nwa,sec}} P_{\text{nwa,sec}} \times IO_{\text{nwa,sec}} + \sum_{\text{sec}} P_{\text{WAP,sec}} \times WAP_{\text{sec}} + \sum_{\text{sec,hou}} P_{\text{sec,hou}} \times C_{\text{sec,hou}} \\
+ \sum_{\text{sec}} P_{\text{sec}} \times CG_{\text{sec}} + \sum_{\text{sec}} P_{\text{sec}} \times I_{\text{sec}} + \sum_{\text{sec}} PE_{\text{sec}} \times E_{\text{sec}} - \sum_{\text{sec}} PM_{\text{sec}} \times M_{\text{sec}}
\]  
(A65)

A1.6.11. Real Gross Domestic Products (RGDP)

\[
RGDP = \sum_{\text{nwa,sec}} PZ_{\text{nwa,sec}} \times IO_{\text{nwa,sec}} + \sum_{\text{sec}} PZ_{\text{WAP,sec}} \times WAP_{\text{sec}} + \sum_{\text{sec,hou}} PZ_{\text{sec,hou}} \times C_{\text{sec,hou}} \\
+ \sum_{\text{sec}} PZ_{\text{sec}} \times CG_{\text{sec}} + \sum_{\text{sec}} PZ_{\text{sec}} \times I_{\text{sec}} + \sum_{\text{sec}} PEZ_{\text{sec}} \times E_{\text{sec}} - \sum_{\text{sec}} PMZ_{\text{sec}} \times M_{\text{sec}}
\]  
(A66)

A2. Model Variables

A2.1. Sets

- **sec**: Activities and commodities
- **prov**: 16 provinces
- **age**: Agricultural sectors including farming and non-farming
- **cro**: Farming sectors
- **ncro**: Non-farming agricultural sectors
- **ncpinse**: Non-farming agricultural, construction, industrial and service sectors
- **inse**: Construction, industrial and service sectors
- **nwa**: Non-water sectors
- **insd**: Domestic institutions including government, enterprise and households
- **insdng**: Domestic institutions except government
- **hou**: Urban and rural households

A2.2. Variables

- **PK**: Return to capital
- **PL_{sec}**: Wage rate of composite labor
- **PL_{agc}**: Wage rate of composite agricultural labor
- **PLFR_{prov}**: Wage rate of provincial agricultural labor
- **PLE**: Wage rate of non-agricultural labor (fixed as the numeraire)
- **PLD_{prov}**: Return to cropland of 16 provinces
- **PWR_{prov}**: Irrigation water price of 16 provinces
- **PWPOT_{cro}**: Price of composite water of “Other provinces”
- **PLWR_{cro,prov}**: Price of provincial land-water bundle of 16 provinces
- **PLW_{cro}**: Price of land-water bundle
- **PVA_{sec}**: Price level of value-added
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PVAW_{ncp}$</td>
<td>Price level of composite demand of water and value-added</td>
</tr>
<tr>
<td>$P_{sec}$</td>
<td>Price level of domestic sales of composite commodities</td>
</tr>
<tr>
<td>$PD_{sec}$</td>
<td>Price level of domestic output of firm</td>
</tr>
<tr>
<td>$PDD_{sec}$</td>
<td>Price of domestic output delivered to home market</td>
</tr>
<tr>
<td>$PM_{sec}$</td>
<td>Import price with tariffs in local currency</td>
</tr>
<tr>
<td>$PE_{sec}$</td>
<td>Price of exports in local currency</td>
</tr>
<tr>
<td>$PCINDEX$</td>
<td>Consumer price index (commodities)</td>
</tr>
<tr>
<td>$ER$</td>
<td>Exchange rate (RMB against U.S. dollar)</td>
</tr>
<tr>
<td>$X_{sec}$</td>
<td>Domestic sales of composite commodity</td>
</tr>
<tr>
<td>$XD_{sec}$</td>
<td>Gross domestic production (output) level firm</td>
</tr>
<tr>
<td>$XDD_{sec}$</td>
<td>Domestic production delivered to home markets</td>
</tr>
<tr>
<td>$E_{sec}$</td>
<td>Export demand</td>
</tr>
<tr>
<td>$M_{sec}$</td>
<td>Import demand</td>
</tr>
<tr>
<td>$K_{sec}$</td>
<td>Capital demand</td>
</tr>
<tr>
<td>$L_{sec}$</td>
<td>Composite labor demand</td>
</tr>
<tr>
<td>$LF_{agc}$</td>
<td>Composite agricultural labor demand</td>
</tr>
<tr>
<td>$LE_{sec}$</td>
<td>Non-agricultural labor demand</td>
</tr>
<tr>
<td>$LFR_{prov,agc}$</td>
<td>Agricultural labor demand at provincial level</td>
</tr>
<tr>
<td>$WAP_{sec}$</td>
<td>Pipe water demand</td>
</tr>
<tr>
<td>$LD_{cro,prov}$</td>
<td>Cropland demand of farming sectors of 16 provinces</td>
</tr>
<tr>
<td>$WAR_{cro,prov}$</td>
<td>Irrigation demand of farming sectors of 16 provinces</td>
</tr>
<tr>
<td>$WARPOTH_{cro}$</td>
<td>Composite water demand of “Other provinces” for farming sector</td>
</tr>
<tr>
<td>$LWR_{cro,prov}$</td>
<td>Demand of provincial land-water bundle of 16 provinces</td>
</tr>
<tr>
<td>$LW_{sec}$</td>
<td>Demand of land-water bundle</td>
</tr>
<tr>
<td>$VA_{sec}$</td>
<td>Value-added demand</td>
</tr>
<tr>
<td>$VAW_{ncp}$</td>
<td>Composite demand of pipe water and value-added</td>
</tr>
<tr>
<td>$IO_{nwa,sec}$</td>
<td>Intermediate input demand</td>
</tr>
<tr>
<td>$C_{sec,hou}$</td>
<td>Consumer households’ demand for commodities and leisure</td>
</tr>
<tr>
<td>$CG_{sec}$</td>
<td>Government commodity demand</td>
</tr>
<tr>
<td>$UU_{hou}$</td>
<td>Proposed change in utility level of households</td>
</tr>
<tr>
<td>$EP_{hou}$</td>
<td>Proposed change in the level of equivalent variation</td>
</tr>
<tr>
<td>$EV_{hou}$</td>
<td>Equivalent variation to measure the welfare changing of households</td>
</tr>
<tr>
<td>$I_{sec}$</td>
<td>Investment demand</td>
</tr>
<tr>
<td>$IG_{sec}$</td>
<td>Interests payment to government</td>
</tr>
<tr>
<td>$TAXR$</td>
<td>Total tax revenue of government</td>
</tr>
<tr>
<td>$TSDWR$</td>
<td>Total subsidies on irrigation water</td>
</tr>
<tr>
<td>$SP_{insd}$</td>
<td>Households and enterprise savings</td>
</tr>
<tr>
<td>$Y_{insd}$</td>
<td>Income level of households and enterprise</td>
</tr>
<tr>
<td>$NGDP$</td>
<td>Nominal gross domestic products of macro economy</td>
</tr>
<tr>
<td>$RGDP$</td>
<td>Real gross domestic products of macro economy</td>
</tr>
<tr>
<td>$1RWAG_{insd,prov}$</td>
<td>Supply of provincial irrigation water of 16 provinces (exogenous)</td>
</tr>
<tr>
<td>$LD_{insd,prov}$</td>
<td>Domestic cropland endowment of 16 provinces (exogenous)</td>
</tr>
</tbody>
</table>
\( TRI_{\text{ind, insd}} \) Transfers between institutions (exogenous)

\( SF \) Foreign savings (exogenous)

\( LSE_{\text{ind}} \) Total non-agricultural labor supply (exogenous)

\( LSFR_{\text{ind, prov}} \) Total agricultural labor supply of 16 provinces (exogenous)

\( KS_{\text{insd, reg}} \) Total capital supply (exogenous)

\( pWeZ_{\text{sec}} \) Initial world price level of exports (exogenous)

\( pWmZ_{\text{sec}} \) Initial world price level of exports (exogenous)

\( NFD_{\text{insd, reg}} \) Net revenue of factor from foreign market (exogenous)

\( KSRW \) Foreign capital demand in local current (exogenous)

\( RGF \) Foreign revenue of government (exogenous)

\( EGF \) Foreign expenditure of government (exogenous)

\( CZ_{\text{sec, hou}} \) Initial households’ consumer demand for commodities and leisure (exogenous)

\( UUZ_{\text{sec, hou}} \) Initial utility level of households (exogenous)

\( EPZ_{\text{hou}} \) Initial level of equivalent variation (exogenous)

\( PZ_{\text{sec}} \) Initial price level of domestic sales of composite commodities (exogenous)

\( PMZ_{\text{sec}} \) Initial import price with tariffs in local currency (exogenous)

\( PEZ_{\text{sec}} \) Initial Price of exports in local currency (exogenous)

### A2.3. Parameters

\( \sigma_{LW_{\text{cro, prov}}} \) Elasticity of substitution between cropland and irrigation water of 16 provinces

\( \alpha_{LW_{\text{cro, prov}}} \) Efficiency parameter for land-water bundle of 16 provinces

\( \gamma_{LW_{\text{cro, prov}}} \) CES distribution parameter for land-water bundle of 16 provinces

\( \sigma_{L_{\text{sec}}} \) Elasticity of substitution between agricultural and non-agricultural labor

\( \sigma_{A_{\text{sec}}} \) Substitution elasticity of Armington function

\( \sigma_{T_{\text{sec}}} \) Substitution elasticity of CET function

\( \gamma_{L_{\text{sec}}} \) CES distribution parameter for composite labor

\( \gamma_{A_{\text{sec}}} \) CES distribution parameter for Armington function

\( \gamma_{T_{\text{sec}}} \) CES distribution parameter for CET function

\( \beta_{LW_{\text{cro, prov}}} \) Cobb-Douglas power of provincial water-land bundle of 16 provinces

\( \beta_{LFR_{\text{agc, prov}}} \) Cobb-Douglas power of provincial agricultural labor of 16 provinces

\( \beta_{FL_{sec}} \) Cobb-Douglas power of composite labor in value-added bundle

\( \beta_{FK_{sec}} \) Cobb-Douglas power of capital in value-added bundle

\( \beta_{FLW_{\text{cro}}} \) Cobb-Douglas power of composite land-water in value-added bundle

\( b_{FLWR_{sec}} \) Scale parameter for composite provincial water-land bundle

\( b_{FLFR_{sec}} \) Efficiency parameter for provincial agricultural labor

\( \sigma_{WARP_{\text{cro}}} \) Elasticity of substitution between the pipe water and irrigation water of “Other provinces”

\( \gamma_{WARP_{\text{cro}}} \) CES distribution parameter for the pipe water and irrigation water of “Other provinces”

\( \alpha_{WARP_{\text{cro}}} \) Efficiency parameter for the pipe water and irrigation water of “Other provinces”
$\sigma V A W_{ncpinse}$ Elasticity of substitution between the pipe water and value-added
$\gamma V A W_{ncpinse}$ CES distribution parameter for the pipe water and value-added
$\alpha V A W_{ncpinse}$ Efficiency parameter for the pipe water and value-added
$\alpha I_{sec}$ Efficiency parameter for composite labor
$b F_{sec}$ Efficiency parameter for value-added bundle
$\sigma F_{inse}$ Elasticity of substitution between capital and non-agricultural labor
$\gamma F_{inse}$ CES distribution parameter for the capital and non-agricultural labor
$\alpha F_{inse}$ Efficiency parameter for the capital and non-agricultural labor
$\alpha A_{sec}$ Efficiency parameter of Armington function of commodity
$\alpha T_{sec}$ Efficiency parameter of CET function of commodity
$iva_{sec}$ Technical coefficients of Leontief function for value-added
$iio_{nwa,sec}$ Technical coefficients of Leontief function
$\alpha H_{sec,hou}$ Power in nested-ELES household utility function
$mps_{insdng}$ Domestic institutions’ marginal propensity to save
$mpg$ Government's marginal propensity to save
$ty_{insdng}$ Tax rate on domestic institution’s income including households and enterprise
$tm_{sec}$ Tariff rate for each import
$tswr_{cro,prov}$ Subsidy rates for irrigation water of 16 provinces
$\alpha I_{sec}$ Cobb-Douglas power in the bank’s utility function
$tva_{sec}$ Net production tax on value-added
$\alpha G_{sec}$ Cobb-Douglas power of the government utility function (commodities)
$\alpha IG$ Cobb-Douglas power of the interests payment of government

References


