Sustainability **2014**, *6*, 3301-3320; doi:10.3390/su6063301

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

An Extended Input Output Table Compiled for Analyzing Water Demand and Consumption at County Level in China

Xiangzheng Deng [1,*], Fan Zhang [2], Zhan Wang [1], Xing Li [2] and Tao Zhang [1]

[1] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; E-Mails: lizwang128@gmail.com (Z.W.); zhangtaomi_2008@163.com (T.Z.)

[2] School of Mathematics and Physics, China University of Geosciences (Wuhan), Wuhan 430074, China; E-Mails: zhangf.ccap@igsnrr.ac.cn (F.Z.); lixingcug@163.com (X.L.)

* Author to whom correspondence should be addressed; E-Mail: dengxz.ccap@gmail.com; Tel.: +86-10-6488-8990; Fax: +86-10-6485-6533.

Received: 6 March 2014; in revised form: 14 May 2014 / Accepted: 16 May 2014 / Published: 27 May 2014

Abstract: This paper attempts to propose hybrid methodology of compiling water resource extended input-output (IO) table at county level (According to administrative structure of China, a county is subordinate to its province, and provincial level is parallel to state level of other countries). By combining Non-Survey-based RAS-technique for possible iterated results and Partial-Survey-based current situation for actual ongoing resource-consumption, we aimed to depict a more accurate structure for water resource consumption and regional economic impact analysis at a county level in the arid area. Additionally, non-parameter methodology was adopted to interpolate missing data. Since human interventions continually have impacted on the natural environment that would finally lead to over-consumption of natural resources, we introduced water consumption caused by cultivation in the Primary Industry and water usage in other industries into a local input-output matrix of Shandan County in Gansu Province, China. Evidence of empirical analysis shows that the modified IO table can more accurately describe economic structure than weighted provincial average IO table does. Moreover, industrialization is ongoing with economic diversity and continually generating water use demand even though also stimulating imports of light industrial products according to the Partial-Survey reports. It demonstrates that industrialization and increasing household consumption drive a high speed of economic growth but with a high cost of water consumption through the Secondary and Tertiary Industries, even at a far rural area. Hence, water scarcity would be a constraint on sustainable development in regions such as Shandan County when taking economic valuation of natural water consumption into account.

Keywords: water resource consumption; water scarcity; input-output table; provincial level; county level; RAS-algorithm

1. Introduction

Water scarcity has become one of the largest and worldwide problems. Year by year, increasing water demand of economic and demographic growth has driven intensive water usage among all economic sectors in many regions [1]. Some researchers in ecology, environmental economics, and agricultural economics have been working on the relationship between water resource utilization and economic growth since the 1950s. Studies at the national scale tried to figure out economic impacts on resource usage and its counterfactual experiments through a Computable General Equilibrium (CGE) model for discussion of environmental changes [2]. Its adaptation to predict future economic impacts of regional climate changes as one of hot issues were internationally discussed [3]. Study on interregional and intraregional interdependence for sustainable development and economic growth has also been addressed by international trade analysis [4]. However, studies of small counties have been limited by difficulties of data collection and its methodological problems, all of which bring about modification of production function back to a local input-output (IO) model.

The input-output analysis in a local region has become more and more important since it can show the economic structure in a table that is more accurate and reliable than weighted provincial table by using an advanced input-output approach. However, there is still lack of research that can spatially depict the economic behavior according to the input-output table of a small region that is located at multi-counties' borders [5,6]. The reasons may include economic and geographical diversities among provinces, empirical weighted coefficients easily making huge deviation from the actual economic structure, and even more difficulties of data collection in a rural county. All these reasons can be attributed to extracting the local data of the regional economic structure from that of the economic structure at a higher level (e.g., national level or provincial level). Moreover, a regional production function can be very different from that at the provincial level since small economies are more dependent on imports, and it is necessary to adjust the regional production function in order to illustrate the regional final demand and original supply. Thus, it is of great significance to build regional IO tables from both economic and geographical viewpoints, especially for analyzing the water usage in a rural region.

Firstly, a regional IO table would show a correct logic transmission mechanism of an economic structure through the interdependence among sectoral inputs [7]. Since each county has its unique production function, it is necessary to avoid overestimation of economic output caused by tradeoff among those incompletion of sectors in different counties. For instance, if changes in economic outputs are driven by changes in water demand through the tertiary sectors at provincial level, we cannot say that economic impacts of water usage with a same percentage change in its subordinate county because the regional distinction should not be ignored. Moreover, hydrological data collections from observation stations at either urban area or rural area are expected with error distribution, which are usually charged by local water department at administration level in China [8]. In this research, by cooperating with relevant administration in Shandan County to get more accurate data of water consumption quantity, we can more accurately reveal the economic structure through economic impact analysis of water demand. Furthermore, compiling a regional environmentally extended-IO table is also crucially important to support persuasive policy for balancing economic development and environmental conservation at county level [9].

Secondly, data collection becomes more difficult when considering geographical diversities and multilevel administrations in a large drainage basin. For instance, in order to obtain more accurate results, we get statistic data at the county level rather than simply extract the weighted statistics provincial level. In this study, we have introduced water resource consumption in each sector so that we can calculate a balance sheet including direct and indirect economic impacts of water demand on sectoral output in order to identify how seriously the region would suffer from water scarcity on the whole. Thereby, relationships between sectoral output and water usage, as well as the sectoral economic interdependence would be derived through an extended input-output table. Thus, we would test that water scarcity would be a limiting factor of sectoral outputs when allowing production function proportional changes with proportional changes of water demand in the study area.

Furthermore, conventional IO tables ignore the interrelationship between economic activities and resource depletion. It is therefore necessary to build resource extended input-output tables for small-scale research in order to reveal economic impacts on utilization of natural resources, such as water and land. Though there have been a number of respectable research and international negotiations on natural resource utilization for supporting economic development demand at the national level [10], there are still few studies at the regional level. For example, Zhang (2011) did quantitative research on water usage in Beijing, and Titze (2011) did qualitative research on the industrial cluster in Germany through inter-regional and intra-regional analysis among basic prefectures [11,12].

This paper attempts to propose a hybrid methodology of compiling a water resource extended IO table at the county level for regional economic-resource analysis. Next part will give a literature review on IO table compilation, in which the methods and issues are summarized. The methodology of embedding water resource into the IO table is also followed. Thereafter, brief introduction of the study area and data collection is given. Our empirical results show the comparison evidence of the difference between county level IO table and provincial level IO table. The final part discussed some ongoing research of scientific issues in compiling IO tables.

2. Literature Review

Traditional IO analysis is an analytical framework to analyze economic structure, which is developed by Leontief in the late 1930s. It is a top-down economic technique to reveal a complex national economy with close relationships between various sectors in the economic structure. Research on interdependence of industries in an economy through market-based transactions is the fundamental purpose of input-output framework [13]. An extended Leontief model is used to analyze economic impact based on a social accounting matrix by adding new rows and columns to accommodate new inputs and outputs derived from adjusted production function [14].

Water supply as the input in a traditional input-output model was considered by Lofting and Mcgauhey in 1968. He pointed out that the water resource is an essential natural resource to support the demand of civilization, industrialization and urbanization and it should be taken into account in the IO analysis [15]. Faye Duchin, particularly, recommended that the input-output methodology as a powerful tool analyzed interrelations between economy development and natural environment [16]. An IO table embedded with the natural water consumption account is an efficient way to evaluate the economic value of water usage in various sectors at both national and regional scales [17]. There have been some studies on local water resource consumption. For example, Lange incorporated water uptake data in the dynamic input-output model to assess the environmental implications of Indonesia's second long-term development plan [18]. Kim *et al.* used a multi-region input-output approach to analyze water quality enhancing policies for Korea [19]. Esther Velazquez presented an input-output model to show the relationship between the sectoral water consumption and sectoral economic output in Andalusia [20]. Wang identified the relationships between production activities and their related water usage in Zhangye City through a regional input-output model [21].

However, there are still some methodological difficulties to get a reliable IO table for showing transformation of economic structure when missing statistical records have a time lag. On the one hand, some studies followed parameter-adjustment methods. For example, Stone (1961) introduced the RAS-algorithm to enhance the accuracy of the technical coefficients matrix [22,23]. Ghahramani studied missing data by using likelihood-based stochastic process [24]. On the other hand, non-parameter method also gives a tendency of data and depicted their time series vibration. For example, Kohn used the autoregressive integrated moving average model (ARIMA) to directly predict missing data [25]. Deng *et al.* presented non-parameter method for interpolating missing data from a spatial perspective of the density function following a normal distribution [26]. In order to reach a reliable IO table for further research, we generated a hybrid methodology in the next section [27].

3. Methodology

3.1. Water Consumption in Primary Industry

A water resource consumption extended input-output table at county level can be divided into three parts of the consumption in primary industry, secondary industry, and tertiary industry respectively [28]. As to water consumption in the primary industry, it is necessary to find out actual water usage in each sector because water is a specific natural resource to supply anthropogenic activities. For instance, sustainability of crops farming industry needs external investment of water resource, while traditional economic assumption advocated that forestry directly obtains water resource from precipitation and surface runoff in a climatic cycle [29]. However, it may be wrong because climatic changes would take future generation in a risk of resource scarcity. Thus, many famous economists research on an appropriate discount rate in order to explain tradeoff of the risk between current generation and future generation [30].

When considering water resource consumption in forestry sector, animal husbandry sector, and fishery, it is necessary but difficult to distinguish whether these sectors need "water resource" to support sustainable development. Since forest ecosystems and aquatic ecosystems depend on natural water resource, such as precipitation and surface runoff to a large extend to sustainable development without much human intervention, in these sectors, thus, water resource are regarded as FREE goods. It means that water resource has no economic value (price = 0) though these sectors consumed certain an amount of water resource. This can be explained that ecological water consumption would be considered as water resource supply to those particular sectors corresponding to related ecosystems, such as forest ecosystems, grassland ecosystems, and aquatic ecosystem. However, there is lack of robust methods to estimate the economic value of natural water resource.

Thereby, in order to construct a reliable regional input-output table, economic value of water has to be identified for estimating regional economic structure appropriately. For this purpose, land use for crops farming would be divided into two categories including irrigated land and non-irrigated land. Thereafter, irrigation coefficients can estimate water consumption in different land use types. Although it is difficult that estimate economic value of water of crop farming, we approached a new method of a calculation of economic value of water in different sectors.

Firstly, a difference of water consumption of irrigated land and non-irrigated land can be calculated. By taking the difference of gross economic output between these two types of land uses, we obtain economic output per unit of water resource consumption. Thereby, this is regarded as economic value of water of crops farming industry, which can be applied to calculate economic value of water demand for the output of crops farming industry:

$$\mathrm{WI}_{crop} = \frac{GO_{irrigated} - GO_{non-irrigated}}{WA_{irrigated} - WA_{non-irrigated}} \times WA$$

where WI is the economic value of water consumption of crop farming industry, the GO represents gross output of different land use types (irrigated and non-irrigated), the WA is the amount of water consumption of different land use types.

3.2. Water Usage in Other Industries

With regard to water usage in other industries, the Nonsurvey method of input-output analysis is used to calculate the water resource consumption of each sector, in which a total water resource is allocated to each sector by using the water usage coefficients. Numerous researches have been conducted to estimate industrial water usage coefficients of each sector through the input-output analysis. Those research data can be used as references to obtain the water usage in each sector. Since most sectors of the Secondary and the Tertiary Industry are situated in urban area, it can be assumed that economic value of water of a particular prefecture can be captured for estimating its economic value of water usage in each sector:

$$\mathrm{WI}_i = GO_i \times C_i \times P$$

where C_i is the water usage coefficients in each sector, P is the economic value of water, and the WI and GO are the economic value of water consumption and gross output.

3.3. Mathematical Approach

The methods to construct the input-output tables can be easily grouped into three categories, including the non-survey-based method, the survey-based method, and the hybrid method, and each of them has its own outstanding characteristics [31,32]. A traditional RAS approach aims to get an updated regional input-output matrix in the "target" year. In this study, we will adopt a hybrid method which is combined both the Nonsurvey based RAS-algorithm and the Partial-survey method in the "target" year of 2007. The mathematical approach is following:

$$x_i{}^n = \sum_{j=1}^{n} z_{ij}^n + f_i^n \quad (1)$$

At provincial level, $x_i{}^n$ is the total output of sector i and by f_i^n as the total demand for sector i's product, and the above general equation represents the distribution of sector *i* output, also, sales of the output of each of the n sector would be derived. The following Equation (2) would summarize their parallel relationship. In Equation (3), Z_i^n presents a row of the total intermediate demand matrix Z^n, which is a sum of each sectoral output times by its coefficient at provincial level.

$$X^n = Z^n + f^n \quad (2)$$

$$Z_i^n = a_{i1}^n x_{i1}^n + a_{i2}^n x_{i2}^n + \cdots + a_{ij}^n x_{ij}^n + \cdots + a_{in}^n x_{in}^n \quad (3)$$

In the original Leontief's input-output analysis suppose the final demand drives economic structure changes, and then, leading to the input-output table changes. The key factor here is the technical coefficient (a_{ij}^n) of each sector, which would represent proportional changes in each sector by final demand changes at provincial level. According to Stone's explanation, a_{ij}^n also indicates the economic phenomena of *substitution effect* and *fabrication effect* [32,33].

In this paper, when define the regional *substitution effect* for sector *i* in region *r* as $r_i^0 = \frac{1-(w_i^r/x_i^r)}{1-(w_i^n/x_i^n)}$; w_i^r is the total consumption by sector *i* in region *r* and x_i^r is gross input of sector *i* in *r* at county level. w_i^n is the total input by sector *i* and x_i^n is gross input of sector *i* at provincial level. In addition, when defining the regional *fabrication effect* for sector *j* in region *r* as $s_j^0 = \frac{1-(w_j^r/x_j^r)}{1-(w_j^n/x_j^n)}$; w_j^r is the total value-added payment by sector *j* in region *r* and x_j^r is gross output of sector *j* in *r* at county level. w_j^n is the total value-added payments by sector *j* and x_j^n is gross output of sector *j* at provincial level. The regional *fabrication effect* gives the possibility changes in the proportion of value-added water demand in a sector's output over iteration. Thereby, the expression of the technical coefficient (a_{ij}^{rr}) of each sector at the provincial level would also be derived in Equation (4), which also presents as initial value of the technical coefficient at county level.

$$a_{ij}^{rr} = r_i^0 a_{ij}^n s_j^0 \quad (4)$$

In this study, the final demand was transformed into economic value of water resource consumption at county level. WI_i^a, is introduced, which is iteratively caused by cultivation and human activities intervention into sectoral outputs in Equation (5) when defining Equation (6) as a row of the total iteratively intermediate demand matrix Z^{rr} at county level. Here, we designed local total final demand would be iterated and eventually burden on water consumption. In other words, we assumed other sectoral final demands would be driven by natural resource consumption.

$$x_i{}^{rr} = \sum_{j=1}^{n} z_{ij}^{rr} + WI_i^a \quad (5)$$

$$Z_i^{rr} = a_{i1}^{rr} x_{i1}^{rr} + a_{i2}^{rr} x_{i2}^{rr} + \cdots + a_{ij}^{rr} x_{ij}^{rr} + \cdots + a_{in}^{rr} x_{in}^{rr} \quad (6)$$

Stone (1961) reported the RAS technique, which is known as a "biproportional" matrix balancing technique in order to attempt at refinement an improvement of the transactions and coefficients. By updating coefficient matrix with a series of adjustment terms, an adjusted coefficient matrix would be derived by the following steps [32,33].

Define $u_i = \sum_{j=1}^{n} z_{ij}^{rr}$, and $v_j = \sum_{i=1}^{n} z_{ij}^{rr}$ as $u = \begin{bmatrix} u_1 \\ \vdots \\ u_n \end{bmatrix}, v = \begin{bmatrix} v_1 \\ \vdots \\ v_n \end{bmatrix}$; here u and v is the convention in literature, and v' represents the value-added vector. Then, an evolutionary equation would be reached in Equation (7), which is the original name of RAS-algorithm through a transaction as Equation (8).

$$A^{rr^2} = \hat{r}^1 A^{rr}(0)\hat{s}^1, \text{ by defining } A^{rr^1} = \hat{r}^1 A^{rr}(0) \tag{7}$$

$$Z^{rr^1} = A^{rr^1} X(1), \text{ by defining } Z^{rr^0} = A^{rr}(0)X(1) \tag{8}$$

where the $\hat{r}^1 = \begin{bmatrix} r_1^1 & 0 & 0 \\ 0 & r_i^1 & 0 \\ 0 & 0 & r_n^1 \end{bmatrix}, \hat{s}^1 = \begin{bmatrix} s_1^1 & 0 & 0 \\ 0 & s_j^1 & 0 \\ 0 & 0 & s_n^1 \end{bmatrix}$ when $r_i^1 = u_i(1)/u_i{}^0$ is the first of what will be a series of adjustment terms for the logic of the row adjustments; and when $s_j^1 = v_j(1)/v_j{}^0$ is the first of what will be a series of adjustment terms for the logic of the column adjustments; Note that, if the $r_i^1 < 1$, the elements in *i*th row of $A^{rr}(0)$ are all reduced when multiply by r_i^1, and *vice versa*; if the $s_j^1 < 1$, the elements in *j*th column of A^{rr^1} are all reduced when multiply s_j^1, and *vice versa*. By repetition of the RAS procedures over 1992–2007, a relative consistent technical coefficient matrix would be derived when the following Equation (9) can be held. It could also predict consistent-based structural changes in the future [33,34].

$$A^{rr^{2n}} = [\hat{r}^{n+1} \dots \hat{r}^1] A^{rr}(0) [\hat{s}^1 \dots \hat{s}^{n+1}] \tag{9}$$

Then, the total output would be given by the Leontief inverse (L^e) (or the total requirements matrix) multiplied by the final demand of water resource consumption (WI^a) in Equation (10) at the county level.

$$X^{rr} = (I - A^{rr})^{-1} WI^a = L^e WI^a \tag{10}$$

Additionally, Partial-Survey method as a supplement to the above RAS-algorithm, an updated accurate input-output table is reached. Although Survey method holds a higher theoretical accuracy but higher operation cost than typical Nonsurvey method, it is necessary to have at least a Partial-Survey on key sectors in a regional research, especially when most available input-output tables in China statistics yearbook were incomplete and overdue.

3.4. Non-Parameter Methodology for Missing Data Interpolation

According to the 2007 statistics yearbook of Gansu Province, we got records of Value-added input of the Tertiary Industry in Shandan County as a benchmark because we assumed the later data is better to indicate economic structure. However, there are still amount of missing data through 1992–2007 statistics yearbook at provincial level and even worse at county level. Therefore, non-parameter methodology has to be considered as a supplemental approach to interpolate missing data.

There is lack of reliable studies on incomplete dataset interpolation. Deng *et al.* did a non-parametric method for filling in the missing value of a cross-sectional dataset in 2012. Their model is valid when the kernel function is defined as the density function of continuous variable following a normal distribution from a spatial perspective [26]. Some others did the likelihood-based or the Bayesian stochastic process to simulate a transformation of an original point in a missing-value dataset for statistical network research, which is known as Agent-based simulation process with incomplete data [34]. In this study, we tried to follow Deng's non-parametric method with evaluated by Kohn's ARIMA model because the autoregressive conditional heteroscedasticity may attribute the interpolation data to a non-normal distribution or a mixed distribution with lack of available time series data, such as just across 15 years in this study.

4. Study Area

Shandan County is located between 100.6°–101.7° E, 38°–39° N in Hehei Basin. It is in the central part of Gansu Corridor, with the height between 1550 m and 4441 m. It is surrounded by mountains at three sides, and is located at soil and water conservation district of Heihe Basin under the influence of the Continental Plateau Climate. Animal husbandry is the pillar industry in this county, which is also the traditional animal husbandry base and horse breeding base in China. Gross domestic product in Shandan County is 2.01 billion in 2007, with the annual growth rate of 12.7%. The value added in agriculture sector was 0.47 billion in 2007, in which food crops, cash crops, and forage grass were the main products of the crop farming. Industrialization started relatively late in this county, so far it has formed six major pillar industries, including building material, chemical, casting, mining, and light industry and processing, with a total added value of 0.61 billion, but still being in poverty with the per capita average income of 5984 CNY in 2007.

5. Data Collection

The principles of data collection are as follows. Firstly, data collection is based on the published provincial accounting statistics and census of business accounting statistics in China; all of which come from the Statistics Yearbook of Gansu Province published by National Bureau of Statistics of China during 1992–2007 [35]. Secondly, sectoral data in the regional input-output table of Shandan County are arranged in a uniform format, which is parallel to the format at the provincial level. Thirdly, adjusted sectoral inputs and outputs are computed according to Partial-Survey data in the study area. Fourthly, hydrological data of water consumption are offered by Water Department of Shandan County and Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.

There are 12 sectors representing the economic structure at county level, which are aggregated from 144 sectors in provincial statistics. In this paper, the 12 aggregated sectors are named as agriculture (AGR), forestry (FRT), animal husbandry (HCD including Hay, Cattle, and Dairy), fisheries (FISH), and all of their service (ADS) in the Primary Industry; ferrous metal smelting and rolling industry (FSR), other non-metallic mineral mining industry (ONM), chemical raw materials and chemical products manufacturing (CPM), and other secondary industry (OSI) in the Secondary Industry; transportation and warehousing postal industry (TWP), wholesale and retail trade (WRT) , and other tertiary industries (OTI) in the Tertiary Industry (Appendix Tables A1 and A2); with prefix of "X" as their relative input respectively; in addition, total value-added (TVA), total inputs (TI), total imports and exports (XIM), total final demand (XFD), total outputs (GO), and the error them (ERR) also presented in the Appendix.

6. Empirical Comparison Results

By introducing water resource consumption into regional input-output table, the obvious difference between two models in Primary Industry is shown in the empirical comparison Table 1. Appendix Table A1 included a more complete description of a RAS-IO table of Shandan County, which is obtained with hybrid methodology through the General Algebraic Modeling System (GAMS) with the codes used for correcting RAS-IO table of Shandan County in Appendix B. In the Primary Industry of Shandan County, the regional output in agriculture sector is overestimated in weighted provincial IO table. The regional output in Agriculture sector is 17.1% lower than the weighted provincial average because cultivated land in Shandan County depends upon natural water irrigation, which contributes to the total water demand in regional economic structure. Thus, the actual output of agriculture sector is lower than its weighted provincial average proportion when taking the economic value of natural water resource into accounts. It illustrates that regional economic structure can be different from provincial economic structure when considering natural resource consumption. From the policy-making perspective, the Tertiary Industry makes more contribution to the output of Primary Industry at weighted provincial level than at county level, which is shown by the difference-percentage of input of Others in Tertiary industries for output of Primary Industry in Table 1. It is notable that the outputs of Primary Industry are aggregated outputs of those sectors in Primary Industry including agriculture (AGR), forestry (FRT), animal husbandry (HCD including Hay, Cattle, and Dairy), fisheries (FISH), and all of their services (ADS). Intuitively, transportation is addressed to rural economy development. It is very interesting that the percentage of Transportation and Warehousing Postal at the county level is much lower than the provincial average for total outputs of Primary Industry. Note here transportation is over addressed when natural resource consumption is not considered by conventional economic research on relationships between marketable consumption behaviors and transportation based on central place theory [36]. Additionally, Wholesale and Retail trade have still been debated about efficiency on rural outputs. In this study, its contribution to total output of Primary Industry at county level is lower than it is at weighted provincial level.

Table 1. Primary Industry Output in Comparison Table of County *vs.* Weighted Province in 2007.

Primary Industry Total Output	Weighted Provincial-level	Difference from county-level	Diff percentage
	(Thousand CNY)		(%)
Agriculture	36,955.8	−6317.9	−17.1
Forestry	1628.7	204.2	12.5
Animal Husbandry	455.1	−14.5	−3.2
Fisheries	0.3	0.0	-
Others in Primary Industry	0.1	0.0	-
Ferrous Metal Smelting & Rolling	0.0	0.0	-
Other Non-metallic Mineral Mining	0.4	−0.4	-
Chemical Raw Materials & Products Manufacturing	64,042.5	−43741.2	−68.3
Others in Secondary industry	69,635.0	−724.1	−1.0
Transportation and Warehousing Postal	1975.7	−1822.0	−92.2
Wholesale and Retail trade	559.1	−500.2	−89.5
Others in Tertiary industries	3464.1	−2658.4	−76.7

In the Secondary Industry of Shandan County, the regional output is underestimated in the weighted provincial IO table when taking natural water resource into accounts. The regional input in Other Secondary Industry for total output of Secondary Industry is 160% higher than that at weighted provincial average. This indicates that the contribution of Other Secondary Industry to local economic structure is much more underestimated as Table 2 shows. Sequentially, it illustrates potential industrialization would further contribute to economic structural changes. Moreover, sectoral input of the Other Tertiary Industry that contributes to total output in Secondary Industry is overestimated by approximately 82% at county level when comparing to that at the weighted provincial level. Additionally, sectoral input of the Secondary Industry and Tertiary Industry that contribute to total output in Tertiary Industry is overestimated at weighted provincial level. It demonstrates that the actual regional total output of Tertiary Industry is overestimated when taking natural resource consumption into account. Furthermore, according to the Partial-Survey reports, although Shandan County is located at far rural area, ongoing industrialization with economic diversity is costing natural resources and continually increasing imports from other regions, and therefore the natural resource consumption for regional industrialization is underestimated.

Table 2. Difference Percentage of Economic Structure in Shandan County on Gansu Province.

Sectoral Input for Total Output in Other Industries	Secondary Industry (%)	Tertiary Industry (%)
Agriculture	−92	−91
Forestry	-	-
Animal Husbandry	-	-
Fisheries	-	−99
Others in Primary Industry	-	-
Ferrous Metal Smelting & Rolling	56	-
Other Non-metallic Mineral Mining	−93	-
Chemical Raw Materials & Products Manufacturing	−34	−93
Others in Secondary industry	160	−16
Transportation and Warehousing Postal	−93	−69
Wholesale and Retail trade	-	−99
Others in Tertiary industries	−82	−5

From the Partial-Survey, we also found that in a short run the proportion of Household Income (HI) and Government Purchase (GP) would increase in stocks, and Export (EXP) is relatively stable when assuming the proportion of total output in 2007 Statistical Yearbook as a control volume remains unchanged. Thus, the empirical evidence shows the economic structure of Shandan County is relatively consistent during 1992–2007. Hence, these evidences further illustrate that the industrialization and increasing household consumption drive high-speed resource consumption through the Secondary and Tertiary Industries.

On the other hand, when considering the counterfactual empirical results, if the water resource becomes scarce, the cost of water consumption would be a limiting factor of the local economic structure. Hence, water should be plugged into economic structure. According to the empirical comparison results, if water scarcity happens in the future, the regional economic structure would be modified by lack of water supply. For instance, lack of water will lead to less irrigated land; then, and subsequently lack of crops production will lead to more dependence on imports, even bringing about emigration of Shandan County according to the available estimated population statistics, which indicates the growth rate of population is showing a decreasing trend but the number of population is still increasing [32]. Thus, if the water usage per person is taken into account, the domestic water resource consumption would confront severe scarcity, and future water consumption would drive economic structural changes through all sectors in this area.

7. Conclusion and Discussion

This study aimed to depict a more accurate economic structure for water resource consumption and regional economic-resource analysis at the county level. We addressed water consumption for cultivation of the Primary Industry and water usage of other industries at Shandan County in Gansu Province, China. By taking both natural water resource and original water production sector into account, the empirical analysis results and their counterfactual deduction also show the evidence that our adjusted IO table at county level can more efficiently describe the economic structure than simply weighted provincial IO table does. First, outputs of Primary Industry and Tertiary Industry are overestimated with a simple weighted provincial IO table when plugging water resource consumption, while the output of Secondary Industry are underestimated with the weighted provincial IO table; second, regional economic structure would be very different from the weighted average because of its unique geographical and economic characteristics; finally, water resource consumption would be an limiting factor for rural development. This study proved high cost of water resource for ongoing industrialization with economic diversity in arid area. In addition, by comparing the economic structure with water consumption at county level with weighted average provincial level, it is found that far rural economic development is more dependent on natural resource of regional geographical characteristics. Therefore, more regional extended IO research should be carried out for further natural resource utilization of economic consumption at county level, particularly when polycentric population density is expending from urban to rural in China.

By combining Non-Survey-based RAS-technique for possible iterated results and Partial-Survey-based current situation for actual ongoing resource-consumption, our modified hybrid model gives more accurate regional input-output table than simple weighted coefficient model based on provincial IO table after validly interpolating those missing data. By introducing water resource consumption into the local IO table, empirical results shows hybrid method makes some improvement in presenting the regional economic structure [37]. Moreover, regional ongoing industrialization is depending on utilization of natural resource and relies on unique geographical location, especially in a far rural area. Therefore, water resource is vital importance to sustainable development in regions such as Shandan County, and water scarcity would be a constraint of regional agglomeration.

Through reviewing the methodological approach, the evaluation of RAS-algorithm with Partial-Survey would be considered as the next research direction. As different quotients make difference of substitution effects and fabrication effects in other methodologies, such as Purchases-only Location Quotients, Cross-Industry Quotients, Semilogarithmic Quotients, Regional Purchase Coefficients, all of them have their own representative case studies in different regions. Moreover, evaluation of the validation of missing data interpolation would also be an interesting research topic because regional study is usually confronted with incomplete dataset, which somehow may lead to uncertainties in the research results.

Acknowledgments

This research was financially supported by the major research plan of the National Natural Science Foundation of China (Grant No. 91325302), the National Natural Science Funds of China for Distinguished Young Scholar (Grant No. 71225005), and National Key Program for Developing Basic Science in China (Grant No. 2010CB950900). The authors would like to thank Feng Wu and Juan Huang from Beijing Normal University, Qian Xu and Yujian Ma from China University of Geosciences (Wuhan) and Yanfei Li from Hubei University for their contributions on household survey and participating the compilation of the Input Output Tables used in the paper.

Author Contributions

Xiangzheng Deng designed research and went through all sectional works. Fan Zhang analyzed the data; Zhan Wang performed research, analyzed the data, and wrote paper with results checking; Xing Li collected original data; Tao Zhang compiled reference list and collected background materials. All authors read and approved the final manuscript.

Appendix

Appendix A

Table A1. The Shandan County Level RAS-IO table (Thousand CNY in 2007).

	XWAT	XAGR	XFRT	XHCD	XFISH	XADS	XFSR	XONM	XCPM	XOSI	XTWP	XWRT	XOTI	XFD	GO	XIM
WATER	133	548	174	1	0	0	1	1	1	99	3	1	85	6399	6142	−1304
AGR	0	28,284	0	1090	0	1263	0	0	0	4955	1572	0	266	209,207	337,947	91,309
FRT	0	0	1833	0	0	0	0	0	0	136	0	0	1	10,327	13,807	1509
HCD	0	0	0	440	0	1	0	0	0	73	0	0	2	78,037	113,299	34,747
FISH	0	0	0	0	0	0	0	0	0	0	0	0	30	4602	906	−3726
ADS	0	0	0	0	0	0	0	0	0	4	0	0	0	36,571	12,261	−24,314
FSR	0	0	0	0	0	0	577,990	0	306	16131	1	0	1	43,237	624,907	−12,759
ONM	0	0	0	0	0	0	1	1271	13	897	4	0	2	10,475	20,266	7603
CPM	14	19,327	496	0	0	478	1459	22	63,219	6614	11	0	846	166,629	121,714	−137,402
OSI	2534	29,375	5756	30506	2405	869	71,843	13,560	61,995	3,924,667	67,531	2069	148,177	1,460,661	2,514,478	−3,307,470
TWP	13	44	32	5	3	69	440	82	119	3362	12,326	1811	1285	199,692	254,790	35,506
WRT	0	0	0	0	0	59	0	0	0	0	3	0	11	124,571	171,759	47,115
OTI	442	161	195	120	87	242	4380	453	697	17,789	4305	6368	155,123	1,043,561	896,549	−337,374
TVA	6842	204,937	7345	92,221	5380	4692	201,792	9910	34,104	689,681	135,970	124,487	561,822	0	0	0
TI	9979	282,677	15,831	124,383	7875	7675	857,905	25,299	160,455	4,664,409	221,726	134,736	867,650	3,393,969	5,088,825	

Table A2. The Shandan IO table at Weighted Provincial Level (Thousand CNY in 2007).

	XWAT	XAGR	XFRT	XHCD	XFISH	XADS	XFSR	XONM	XCPM	XOSI	XTWP	XWRT	XOTI	XFD	GO	XIM	ERR
WATER	129	12,402	1401	81	0	4	223	39	110	7090	308	130	6367	6399	6142	−2264	−26,276
AGR	0	25,343	0	8492	0	3120	0	0	0	59,236	15,132	0	6152	207,357	337,947	−8151	21,266
FRT	0	0	1607	0	0	22	89	0	13	10,837	4	0	323	10,235	13,807	−4686	−4636
HCD	0	0	0	434	0	21	0	0	0	6857	0	0	309	77,347	113,299	−1203	29,534
FISH	0	0	0	0	0	0	0	0	0	172	0	0	4712	4561	906	−3893	−4647
ADS	0	0	0	0	0	0	0	0	0	1803	0	0	0	36,248	12,261	−32,200	6411
FSR	0	0	0	0	0	0	294,502	0	1776	84,927	17	0	10	338,223	624,907	−138,662	44,115
ONM	0	0	0	0	0	0	53	1176	541	27,608	287	0	166	10,383	20,266	−1334	−18,613
CPM	82	59,662	1648	0	0	2733	13,775	208	40,308	53,905	170	0	12,523	165,156	121,714	−131,423	−97,033
OSI	1129	38,640	2974	27,127	212	682	82,531	7828	40,035	1,436,127	70,307	5703	183,543	1,414,133	2,514,478	−736,680	−59,813
TWP	67	1173	218	107	3	475	7938	667	1624	47,876	11,414	15,682	22,049	197,926	254,790	−63,809	11,381
WRT	0	0	0	0	0	559	8	0	4	42	349	0	1451	123,469	171,759	0	45,877
OTI	599	1521	410	913	22	597	26227	1301	3572	100,547	22,686	26,774	124,480	1,034,332	896,549	−499,866	52,434
TVA	4135	199,206	5549	76,144	668	4048	199,561	9048	33,733	677,453	134,117	123,469	534,466	0	0	0	0
TI	6142	337,947	13,807	113,299	906	12,261	624,907	20,266	121,714	2,514,478	254,790	171,759	896,549	3,393,969	5,088,825	0	0

Appendix B. GAMS codes used for correcting RAS-IO table of Shandan County.

```
$SETGLOBAL PROGPATH E:\IGSSNR\Shandan\code
*$SETGLOBAL DATAPATH E:\IGSSNR\Shandan\code\data\
*$SETGLOBAL DATANAM Shandan

SETS
i SECTORS/
WAT Water
AGR Agriculture
FRT Forestry
HCD Animal Husbandry
FISH Fisheries
ADS Others in Primary Industry
FSR Ferrous Metal Smelting & Rolling
ONM Other Non-metallic Mineral Mining
CPM Chemical Raw Materials & Chemical Products Manufacturing
OSI Others in Secondary industry
TWP Transportation and Warehousing Postal
WRT Wholesale and Retail trade
OTI Others in Tertiary industries
TVA Value-added
/,
HH columns/
XWAT water
XAGR Agriculture
XFRT Forestry
XHCD Animal Husbandry
XFISH Fisheries
XADS Others in Primary Industry
XFSR Ferrous Metal Smelting & Rolling
XONM Other Non-metallic Mineral Mining
XCPM Chemical Raw Materials & Chemical Products Manufacturing
XOSI Others in Secondary industry
XTWP Transportation and Warehousing Postal
XWRT Wholesale and Retail trade
XOTI Others in Tertiary industries
* XIMP Imports
XFD Final Demand
/;
* Program requires three different data inputs:
* CONFLOW: the matrix of original flows
```

```
* C0: column containing row sum controls
* CON: column containing column sum controls
TABLE CONFLOW(i,hh) INITIAL PRIVATE CONSUMPTION FLOWS

* weighted privincial level IO table should be followed;

PARAMETER c0(i) Control vector;
c0("WAT") = 6141.94302;
c0("AGR") = 337947.33512;
c0("FRT") =13806.9385;
c0("HCD") = 113299.11636;
c0("FISH") = 905.8044;
c0("ADS") = 12261.47662;
c0("FSR") = 624906.5642;
c0("ONM") = 20266.28528;
c0("CPM") = 121714.10924;
c0("OSI") = 2514477.82296;
c0("TWP") = 254789.58278;
c0("WRT") = 171758.5029;
c0("OTI") = 896549.4087;
c0("TVA") = 0.0;
PARAMETER CON(hh) AGGREGATE INPUT CONSUMPTION LEVELS;
CON("XWAT") = 6141.94302;
CON("XAGR") = 337947.33512;
CON("XFRT") = 13806.9385;
CON("XHCD") = 113299.11636;
CON("XFISH") = 905.8044;
CON("XADS") = 12261.47662;
CON("XFSR") = 624906.5642;
CON("XONM") = 20266.28528;
CON("XCPM") = 121714.10924;
CON("XOSI") = 2514477.82296;
CON("XTWP") = 254789.58278;
CON("XWRT") = 171758.5029;
CON("XOTI") = 896549.4087;
CON("XFD") = 0.0;
ALIAS(I,RR);
ALIAS(HH,CC);
PARAMETER a0(rr,cc) Initial coefficients matrix to RAS
a1(rr,cc) Final coefficients matrix after RAS
rasmat0(rr,cc) Initial flows matrix to RAS
ct(cc) RAS column control totals
```

```
rt(rr) RAS row control totals
ratio Adjustment parameter on control totals
checkcol Check sum of column control totals
checkrow Check sum of row control totals
sumccc Original column sums of RAS matrix
sumrrr Original row sums of RAS matrix;
VARIABLES
DEV Deviations
RASMAT(rr,cc) RASed matrix
R1(rr) Rho of RAS matrix
S1(cc) Sigma of RAS matrix
LOSS Objective (loss) function value;
* Parameter initialization
sumccc(cc) = SUM(rr, conflow(rr,cc));
sumrrr(rr) = SUM(cc, conflow(rr,cc));
a0(rr,cc) = conflow(rr,cc) / sumccc(cc);
rasmat0(rr,cc) = a0(rr,cc) * CON(cc);
ct(cc) = CON(cc);
rt(rr) = c0(rr);
ratio = SUM(rr, rt(rr))/SUM(cc, ct(cc));
ct(cc) = ct(cc) * ratio;
checkcol = SUM(cc, ct(cc));
checkrow = SUM(rr, rt(rr));
display ratio, checkcol, checkrow;
display conflow, a0;
display con, ct;
display c0, rt;
* Variable initialization

DEV.L = 0.0;
R1.L(rr) = 1;
S1.L(cc) = 1;
RASMAT.L(rr,cc) = a0(rr,cc) * ct(cc);
CON(cc) = ct(cc);
EQUATIONS
BIPROP(rr,cc) Bi-proportionality for RAS matrix
DEVSQ Definition of squared deviations
OBJ Objective function
RCONST(rr) Row constraint
CCONST(cc) Column constraint;
BIPROP(rr,cc).. RASMAT(rr,cc) =E= R1(rr)*S1(cc)*rasmat0(rr,cc);
CCONST(cc).. ct(cc) = E = SUM(rr, RASMAT(rr,cc));
```

```
RCONST(rr).. rt(rr) = E = SUM(cc, RASMAT(rr,cc));
DEVSQ.. DEV = E = SUM( (rr,cc)$rasmat0(rr,cc),
SQR( (RASMAT(rr,cc) − rasmat0(rr,cc))/rasmat0(rr,cc)));
OBJ.. LOSS = E = SUM(rr, R1(rr)**2 + (1/R1(rr))**2 )
 + SUM(cc, S1(cc)**2 + (1/S1(cc))**2);
* Variable bounds
RASMAT.LO(rr,cc) = 0.0;
R1.LO(rr) = 0.01;
S1.LO(cc) = 0.01;
MODEL CONSUMERAS/BIPROP
CCONST
RCONST
* DEVSQ
OBJ/;
*DEVSQ is commented out

OPTIONS ITERLIM = 10000,LIMROW = 0,LIMCOL = 0,SOLPRINT=OFF;
SOLVE CONSUMERAS USING NLP MINIMIZING LOSS;
display rasmat.l, r1.l, s1.l;
a1(rr,cc) = rasmat.l(rr,cc)/ct(cc);
display a0, a1;
```

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Duarte, R.; Sánchez-Chóliz, J.; Bielsa, J. Water use in the Spanish economy: An input-output approach. *Ecol. Econ.* **2002**, *43*, 71–85.
2. Ciscar, J.C.; Iglesias, A.; Feyen, L.; Szabó, L.; van Regemorter, D.; Amelung, B.; Soria, A. Physical and economic consequences of climate change in Europe. *Proc. Nat. Acad. Sci. USA* **2011**, *108*, 2678–2683.
3. Xie, W.; Li, N.; Ji, Z.; Wu, J. Spatial and economic impacts analysis of an emergency event. In Proceedings of the Information Science and Service Science and Data Mining (ISSDM), 2012 6th International Conference on New Trends in, Taipei, Taiwan, 23–25 October 2012.
4. Huang, J.; Liu, Y.; Martin, W.; Rozelle, S. Changes in trade and domestic distortions affecting China's agriculture. *Food Policy* **2009**, *34*, 407–416.
5. You, F.; Tao, L.; Graziano, D.J.; Snyder, S.W. Optimal design of sustainable cellulosic biofuel supply chains: Multiobjective optimization coupled with life cycle assessment and input-output analysis. *AIChE J.* **2012**, *58*, 1157–1180.

6. Daniels, P.L.; Lenzen, M.; Kenway, S.J. The ins and outs of water use—A review of multi-region input-output analysis and water footprints for regional sustainability analysis and policy. *Econ. Syst. Res.* **2011**, *23*, 353–370.
7. Leontief, W.W. Quantitative input and output relations in the economic systems of the United States. *Rev. Econ. Stat.* **1936**, *18*, 105–125.
8. McMillan, H.K.; Krueger, T.; Freer, J.E.; Westerberg, I. Benchmarking observational uncertainties for hydrology. In Proceedings of the AGU Fall Meeting Abstracts, San Francisco, CA, USA, 9–13 December 2013.
9. Wu, F.; Zhan, J.; Shi, C.; Zhao, C. An extended input-output table for environmental and resources accounting. *Chin. J. Popul. Resour. Environ.* **2014**, *12*, 33–41.
10. Calzadilla, A.; Rehdanz, K.; Tol, R.S. *The GTAP-W Model: Accounting for Water Use in Agriculture (No. 1745)*; Kiel Working Papers: Kiel, Germany, 2011.
11. Titze, M.; Brachert, M.; Kubis, A. The identification of regional industrial clusters using qualitative input-output analysis (QIOA). *Reg. Stud.* **2011**, *45*, 89–102.
12. Zhang, Z.; Shi, M.; Yang, H.; Chapagain, A. An input-output analysis of trends in virtual water trade and the impact on water resources and uses in China. *Econ. Syst. Res.* **2011**, *23*, 431–446.
13. Leontief, W.W. *Studies in the Structure of American Economy, 1919–1929*; Harvard University Press: Cambridge, MA, USA, 1941.
14. Leontief, W. Environmental repercussions and the economic structure: An input-output approach. *Rev. Econ. Stat.* **1970**, *52*, 262–271.
15. Lofting, E.M.; McGauhey, P.H. *Economic Valuation of Water: An Input-Output Analysis of California Water Requirements*; Water Resources Center, University of California: Oakland, CA, USA, 1968.
16. Duchin, F. Input-output analysis and industrial ecology. *The Greening of Industrial Ecosystems*; National Academy press: Washington, DC, USA, 1994; pp. 61–68.
17. Baumol, W.J. Leontief's great leap forward: Beyond Quesnay, Marx and von Bortkiewicz. *Econ. Syst. Res.* **2000**, *12*, 141–152.
18. Lange, G.M. Applying an integrated natural resource accounts and input-output model to development planning in Indonesia. *Econ. Syst. Res.* **1998**, *10*, 113–134.
19. Kim, H.B.; Jin, S.Y.; Yun, K.S. Impact Analysis of a Water Quality Enhancing Policy: A Simple Input-Output Approach. *Reg. Stud.* **2001**, *35*, 103–111.
20. Velazquez, E. An input-output model of water consumption: Analysing intersectoral water relationships in Andalusia. *Ecol. Econ.* **2006**, *56*, 226–240.
21. Wang, Y.; Xiao, H.L.; Lu, M.F. Analysis of water consumption using a regional input-output model: Model development and application to Zhangye City, Northwestern China. *J. Arid Environ.* **2009**, *73*, 894–900.
22. Stone, R. *Input-Output and National Accounts*; Organisation for European Economic Co-operation: Paris, France, 1961.
23. Oosterhaven, J.; Piek, G.; Stelder, D. Theory and practice of updating regional *versus* interregional interindustry tables. *Pap. Reg. Sci.* **1986**, *59*, 57–72.
24. Ghahramani, Z.; Jordan, M.I. Learning from Incomplete Data. Available online: http://hdl.handle.net/1721.1/7202 (accessed on 24 January 1995).

25. Kohn, R.; Ansley, C.F. Estimation, prediction, and interpolation for ARIMA models with missing data. *J. Am. Stat. Assoc.* **1986**, *81*, 751–761.
26. Deng, X.; Fang, Y.; Lin, Y.; Yuan, Y. Non-parametric method for filling in the missing value for cross-sectional dataset: A validation on the per capita GDP data at county level in China. *J. Food Agric. Environ.* **2012**, *10*, 1350–1354.
27. West, G.R. Regional trade estimation: A hybrid approach. *Int. Reg. Sci. Rev.* **1990**, *13*, 103–118.
28. Van der Mensbrugghe, D.; Roson, R. *Climate, Trade and Development*; Centre for Trade and Economic Integration (CTEI): Geneva, Switzerland, 2010.
29. Toh, M.H. The RAS approach in updating input-output matrices: An instrumental variable interpretation and analysis of structural change. *Econ. Syst. Res.* **1998**, *10*, 63–78.
30. Lahr, M.L. A review of the literature supporting the hybrid approach to constructing regional input-output models. *Econ. Syst. Res.* **1993**, *5*, 277–293.
31. Lahr, M.L. *A Strategy for Producing Hybrid Regional Input-Output Tables*; Center for Urban Policy Research, Rutgers, The State University: New Brunswick, NJ, USA, 1998.
32. Miller, R.E.; Blair, P.D. *Input-Output Analysis: Foundations and Extensions*; Cambridge University Press: Cambridge, UK, 2009.
33. Kurz, H.D.; Dietzenbacher, E.; Lager, C. *Input-Output Analysis, Volume 1*; Edward Elgar Publishing: Cheltenham, UK, 1998.
34. Rodriguez, A.; Dunson, D.B. Nonparametric Bayesian models through probit stick-breaking processes. *Bayesian Anal.* **2011**, *6*, 145–177.
35. National Bureau of Statistics of China. *Statistics Yearbook of Gansu Province*; National Bureau of Statistics of China: Beijing, China, 1992–2007.
36. Smith, J.W.; Floyd, M.F. The urban growth machine, central place theory and access to open space. *City Cult. Soc.* **2013**, *4*, 87–98.
37. Van der Linden, J.A.; Dietzenbacher, E. The determinants of structural change in the European Union: A new application of RAS. *Environ. Plan. A.* **2000**, *32*, 2205–2230.