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Water Shortages, Water Allocation and Economic Growth: The Case of China

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Abstract

Current projections indicate that by 2025, water scarcity will affect over one quarter of the world's population. This suggests that the need to manage water more efficiently will become more pressing during the next few years as the demand for water increases along with the expansion of economies and their populations. This paper investigates the economic impacts of efficient intra-regional and/or inter-regional water reallocation, and examines their corresponding economic gains. A Ramsey-type growth model of a small, open, competitive economy is fitted to year 2000 Chinese data andthe empirical model is used to perform policy experiments. Within region water reallocation increases per-capita Chinese GDP by about 1.5% per year over the period 2000-2060. The aggregate potential welfare gain due to this reallocation is 1002.51 billion RMB. Transferring water from southern to northern China via the South-North Water Transfer Project, on average, has a smaller impact on per-capita GDP over the period 2000-2060, with an aggregate welfare gain of 557.23 billion RMB. Combining intra-regional and inter-regional water reallocations, on average, increases per-capita GDP by 0.38% per year over the period and the aggregate welfare gain from this combination is 1148.06 billion RMB.

1 Introduction

Seckler et al. (1999) examined the demands and sources of fresh water for 118 countries and projected that by 2025 one-quarter of the worlds population, and over one-third of people living in developing countries will experience severe water scarcity. The reason underlying increased water scarcity in most countries is projected to come from increases in residential/urban consumption and increases in water demand from manufacturing and service sectors [Seckler et al (1999), Barbier (2004)]. Barbier (2004) aptly observes a natural question for economists to ask is what impact, if any, does water scarcity have on economic growth. Barbier then uses cross country regressions on over 120 countries to search for evidence that current fresh water use rates were constraining growth, and found little evidence of such effects.

In this paper we investigate the link between water scarcity and growth from a slightly different perspective than Barbier, and instead, examine the impact of intersectoral and interregional water allocations on growth. This study uses China as a backdrop to examine the potential impact of allocating water to its most productive uses. We focus on China because it has characteristics similar to many other countries, both developed and developing. First, China's existing water supplies face increased pressure from growing urban residential and manufacturing demand. Next, governmental agencies allocate water to major productive sectors – agriculture, manufacturing, services, and urban residential consumption. These agencies also influence regional water allocations. Finally, China has implemented large scale interregional/interbasin water transfer projects: a strategy Seckler et al. suggests will be considered by many of the soon to be water scarce countries.

Future water scarcity is almost surely linked to increased population and economic growth, and with increased presures for reallocation of limited supplies arising from increased residential/urban demands and from manufacturing and services. To capiture this likely evolution over time, we develop a multisector, general equilibrium growth model with endogenous savings and examine the impact of optimally allocating water across sectors over time. We also examine the economic impacts of a large scale interbasin water transfer project: the South-North Water Transfer Project (South-North WTP). The economy has two regions (North and South), each having five sectors: agriculture, manufacturing, services, residental water, and composite capital. The North consists of the following 14 provinces or municipalities: Beijing, Tianjin, Hebei, Shandong, Shanxi, Henan, Ningxia, Shaanxi, Qinghai, Gansu, Inner Mongolia, Liaoning, Jilin and Heilongjiang. The South consists of the following 17 provinces or municipalities: Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Sichuan, Guizhou, Fujian, Guangdong, Guangxi, Yunnan, Xinjiang and Tibet. We fit the model to China national accounts and water availability data and find that, indeed, efficient water allocation can potentially yield a 1.5% increase in annual per capita income between 2000 and 2060.

We feel the line of research presented here is important, as most countries – both developed and developing – typically do not have water policies that consider the economywide influence of water allocation decisions. Instead, historical and political influences tend to guide current water use. However, with increased water demand coming from various sources, political considerations aside, it is important to understand the potential gains and costs of water allocation decisions, and we should understand the implications from both a short-run and long-run perspective. As Seckler et al (1999) note, long-run analysis is important when planning large scale water infrastructure projects, as such projects have ten to twenty year implementation horizons. The analysis that follows can serve as a template for developing a powerful planning tool that one can fit to national or regional data and use to examine a variety of policy relevant questions. We reserve discussion of potential uses for the conclusion.

The paper is organized as follows. The next section gives a brief overview of water policy and scarcity issues in China. Section 3 presents a framework for studying intersectoral and interregional water shortage issues. This section describes the environment of the model and characterizes an equilibrium under a "status quo" water allocation. Next, we describe the procedures for solving the long-run and transition equilibrium. Finally we very briefly discuss the equilibria with a "market-based" water allocation and (or) the South-North WTP. Section 4 fits the theoretical model to the year 2000 Chinese economy, and uses the empirical analogue to conduct an economic analysis of four policy scenarios: (i) the base scenario in which we take the country's current water assignments as given and leave the water assignments unchanged over time; (ii) an intra-regional water reallocation scenario (allocate water optimally across sector within each region); (iii) an inter-regional water reallocation scenario (move water from the South to the North); and (iv) an inter-intra-regional water reallocation scenario which is a combination of the intra-regional water reallocation and the inter-regional water reallocation. Section 5 provides a summary of results and discusses possible applications of the model.

2 A Brief Overview of China Water Scarcity

China started opening its borders to the West and initiated several social and economic reforms. Since that time China's national economy has grown rapidly, with per capita gross domestic product increasing from 460 RMB in 1980 to 7,078 RMB in 2000 (National Bureau of Statistics, 2001) – an 8 percent annual rate of growth over the period. One consequence of this growth is Chinese living standards, notably food consumption, have improved substantially. Accompanying this achievement, however, is a significant increase in the country's total volume of water consumption. Between 1980 and 2000, total water use increased from 443.7 billion m^3 (United Nations, 1997) to 553.1 billion m^3 (Ministry of Water Resources, 2002), with the increased water demand coming mostly from municipal and industrial sources. This increased volume of water consumption has led to significant water scarcity problems in China. This paper examines the economics of intersectoral and interregional water transfers to manage water scarcity problems in China.

By one estimate, in 2001 water shortages cost China more than RMB 120 billion (US$14.5 billion) in lost agricultural and industrial production. This is equivalent to 1.3% of that year's national gross domestic product (Hu, 2001). Water shortages have occurred in many parts of China, especially in the Northern regions.[1] An increasingly dry climate, combined with rapid economic growth, population growth, and increasing water pollution, have greatly exacerbated water shortages in the North (Chen, Zhang and Zhang, 2002). Water shortages are particularly severe in the Hai, Huang (Yellow), and Huai River Basins (World Bank, 2001). For example, in Shangdong, the country's top grain-producing province, available water supplies met only 73% of its needs (Thomson, 2003), and in a number of northern cities, water supply barely met 70% of demand during the dry season (Ministry of Water Resources, 1998). In addition to regional water shortages in the North, localized water shortages have also been reported in both northern and southern cities.

Currently, China allocates water across the major use groups – agricultural, industrial and residential – via government decree. During the early 2000s, agriculture received about 69% of available water, industry received 21%, and residential and service received 7% and 3% respectively. Increasing water shortages and increased water demand, especially from sectors outside agriculture, have placed great pressure on water authorities to rethink current intersectoral water allocations:

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[1] Traditionally, the North and South of China are divided by the Chang (Yangtze) River. Southern China includes the provinces which are located in areas south of and including the Yangtze River Basins. Northern China consists provinces located in the north of the Yangtze River Basins.

this is especially true in the northern region, where irrigation dependent grain production is facing unprecedented competition for water (Yang and Zehnder, 2001).

To alleviate the severe water shortages in the North, several projects have been launched or are about to start. Of these projects, construction of the South-North Water Transfer Project (*Nan Shui Bei Diao*) is the most ambitious and controversial. This project is expected to have a significant influence on the macroscopic allocation of water resources and economic development in China. Analysts believe more reliable water supplies would benefit economic development and create much-needed employment in northern China – currently lagging behind the prosperous southern coastal regions.[2]

Several studies have examined water scarcity issues in China. Hou (1991) and Liu (1996) focus on the economics of increasing water supply or enhancing water conservation and efficiency improvement, e.g., desalination, recycling water, developing water-saving technologies, and improving conservation management. Liu (1996) concludes water conservation efforts could save 100 billion m^3 of water or above each year, far more than any proposed water transfers. Other studies examine the effect of trade on water scarcity, see Brown and Halweil (1998), Conrad et al, (1998), and Yang and Zehnder (2001). The trade based studies set a grain output goal for a region, or the country, and assess whether there is enough water to produce the desired level of output. If not, imports are needed. Yang and Zehnder (2001) projected water demand and deficits over the next two decades for the North China Plain, and then calculated the amount of wheat the region should import in order for the country to meet expected water demands. Almost all relevant research indicates water shortages will continue in the coming years and a huge amount of grain will be imported from international sources.

One limitation of the above studies is they are partial equilibrium studies, and focus only on the agricultural sector. As noted earlier, China's recent increase in water consumption has mainly come from industrial and domestic/municipal uses, suggesting the need to examine the water allocation problem from a more integrated, general equilibrium, approach. One general equilibrium analysis of water management is found in Diao, Roe and Doukkali (2002), who analyze the potential economic

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[2] Numerous environmental and ecological problems may arise with this project. Examples include secondary salinization of the soil due to a rise in aquifer levels, adverse effects on fish and other aquatic life, and the possibility of polluted sewage water entering conveyance canals and salt water intrusion due to the declined flow to the estuary of the Yangtze River (Liu, 1998).

gains from allocating surface irrigation water to its most productive use in Morocco, and evaluate a decentralized mechanism for achieving this result in a spatially heterogeneous environment. Although their analysis is based on a general equilibrium model, discussion centers only on the agriculture sector.

3 A multisector Ramsey model with water allocation

3.1 Environment

The modeled economy is small, open, and perfectly competitive with two regions, North and South. Index regions by $i \in I = \{1, 2\}$, with $i = 1$ representing the North region. Each region produces four final goods indexed by $j \in J = \{a, m, s, \omega\}$, where a, m, s, and ω represent agriculture, manufacturing, services, and residential water. These final goods are shown as boxes in the center panel of Figure 1. Each final good j produced in region i is traded at price p_{ji}. The goods produced in the North are assumed to not be a perfect substitute for the corresponding good produced in the South. For example, in the case of agriculture, the North might produce wheat while the South produces rice.

Denote the time t production of residential water and the agricultural, manufacturing, and service good respectively by $Y_{\omega i}$ and Y_{ai}, Y_{mi}, Y_{si}. Note that for most variables, we suppress the time t notation: i.e., we represent the time t production of North agriculture by Y_{ai} instead of $Y_{ai}(t)$. For each region, residential water and the service good are pure consumption goods that are only consumed within the region, thus making the shadow value of water and the service good price endogenous to each region. The two agricultural goods are also pure consumption goods, but they are traded in domestic and international markets at given prices. The manufacturing good produced in each region is used either as: (i) a consumption good traded in domestic and international markets, or (ii) an intermediate capital good used to produce composite capital, where composite capital Y_k is a least cost combination of the two regional manufactured goods, Y_{m1} and Y_{m2}. Traded good markets are shown by the circles and ROW (rest of world) boxes in the upper panel of Figure 1. The accumulation of composite capital, net of depreciation, yields capital stock, the services of which are employed in producing the agricultural, manufacturing, and service goods. The value of water, composite capital, and land are assets held by households.

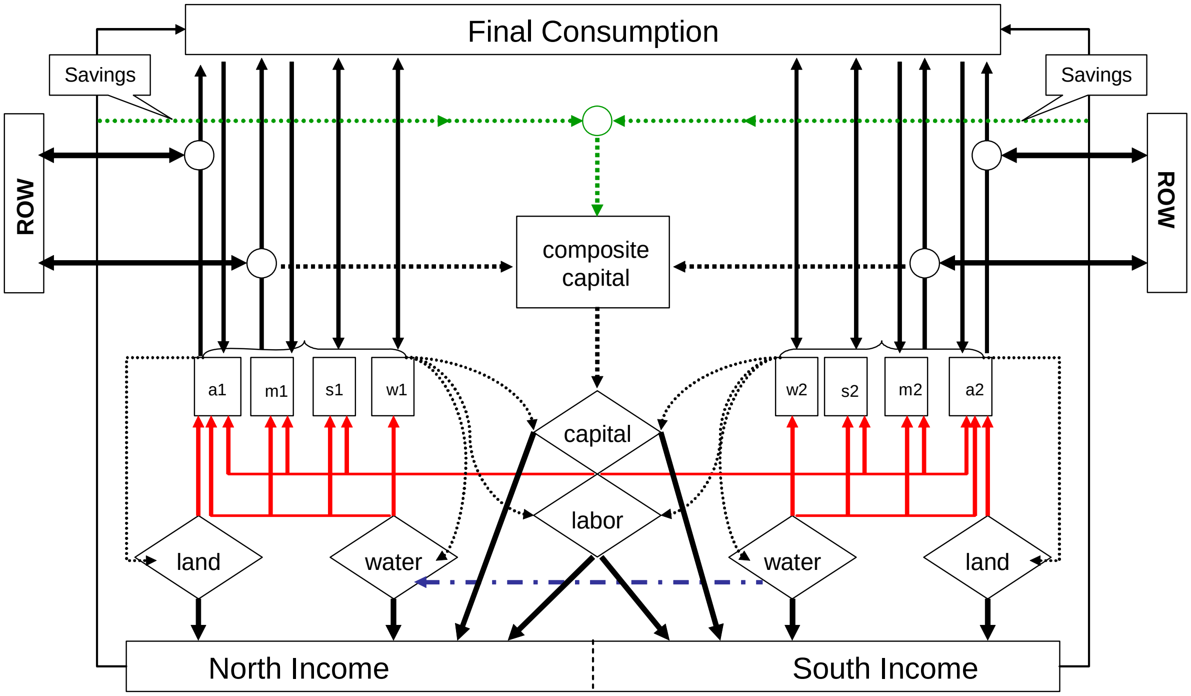

Figure 1. Circular flow diagram of economy.

The diamond boxes in the lower panel of Figure 1 depict the region specific resources, water $\bar{E}_i$ and land $\bar{T}_i$. Without construction of a large-scale water projects like the South-North WTP, water cannot move from one region to the other region. Both the stock of land and available water remain constant over time. Labor and composite capital are mobile across regions and sectors. For each region, the services of labor L, capital K, and the region's water endowment are employed to produce the agricultural, manufacturing and service goods. Each region's land endowment, denoted T_i, is a factor specific to agriculture in that region. Residential water production in region i only requires water as in input.

At each instant in time, households earn income from the following sources: (i) providing labor services L in exchange for wage w, (ii) earning interest income at rate r on capital assets K, (iii) receiving rent τ_i from land T_i, and (iv) capturing rent from water resources $\bar{E}_i$. The representative agent uses income to invest in composite capital and purchase final consumption goods Q_{ji}. Here, Q_{ji} is the consumption of good j produced by region i, e.g. Q_{a1} is region 1 agriculture. The initial capital stock K_0, is given, and the initial endowment of labor is normalized to unity, as are the prices of internationally traded goods, p_{m1}, p_{m2}, p_{a1}, and p_{a2}. Labor grows at the exogenous rate $n > 0$. Thus, labor supply is given by $L(t) = L_0 e^{nt} = e^{nt}$.

3.2 Production

Agricultural production in region i is represented by the constant returns to scale (CRS) technology:

$$Y_{ai} = F^{ai}(A\,(t)\,L_{ai}, K_{ai}, \Lambda\,(t)\,E_{ai}, B\,(t)\,T_i), i = 1, 2,$$

while region i manufacturing and service good production are represented by the CRS technologies:

$$Y_{ji} = F^{ji}(A\,(t)\,L_{ji}, K_{ji}, \Lambda\,(t)\,E_{ji}),\ j = m, s; i = 1, 2.$$

Here L_{ji} denotes the time t level of labor used in producing good $ji \in J \times I$: i.e., sector $j \in J$ output in region $i \in I$. Likewise, K_{ji} and E_{ji} denote the time t levels of capital stock, and water employed in producing good $ji \in J \times I$. The functions $A\,(t)$, $\Lambda\,(t)$ and $B\,(t)$ represent the exogenous level of growth in labor, water, and land productivity, respectively. Thus, in addition to labor augmenting technological change, technological change in the employment of water and land in each region may also occur. The technologies $F^{ji}(\cdot)$ are increasing and strictly concave in each argument, and satisfy the standard Inada conditions.

Production of composite capital, Y_k, is governed by the CRS Cobb-Douglas technology:

$$Y_k = \Upsilon_{m1}^{\zeta}\ \Upsilon_{m2}^{1-\zeta},\ 0 < \zeta < 1.$$

Here Υ_{mi} denotes the time t amount of region i's manufacturing output used in producing composite capital. Then the composite capital good's corresponding cost function is given by:

$$c^k(p_{m1}, p_{m2})Y_k = \zeta^{-\zeta}(1-\zeta)^{-(1-\zeta)} p_{m1}^{\zeta} p_{m2}^{1-\zeta} Y_k = p_k Y_k,$$

with the unit cost of composite capital given by

$$p_k = \zeta^{-\zeta}(1-\zeta)^{-(1-\zeta)} p_{m1}^{\zeta} p_{m2}^{1-\zeta}. \tag{1}$$

Since the northern and southern manufacturing goods are internationally traded, their prices p_{m1} and p_{m2} are exogenous. Hence, by equation (1), composite capital's equilibrium price, p_k, is constant over time. The factor demand function for the manufacturing good Υ_{mi} is obtained using Shepard's lemma. Note, that if Y_k units of composite capital are produced, the stock of capital increases by Y_k. Hence, in equilbrium, the instantaneous change in the stock of capital, denoted $\dot{K}$, is given by $\dot{K} = Y_k$.

For residential water, instead of assuming the household directly consumes water, we assume there is a factory in each region which simply employs water to produce residential water. No other factor is involved in the production of residential water. The time t production of residential water in region i is

$$Y_{\omega i} = \Lambda\left(t\right) E_{\omega i},$$

where $E_{\omega i}$ is the time t amount of water used to produce residential water in region i.

3.3 Households

Define the representative household's time t consumption vector per household member as

$$q\left(t\right) \equiv \left(q_{a1}\left(t\right), q_{m1}\left(t\right), q_{s1}\left(t\right), q_{\omega 1}\left(t\right), q_{a2}\left(t\right), q_{m2}\left(t\right), q_{s2}\left(t\right), q_{\omega 2}\left(t\right)\right),$$

where $q_{ji}(t) = Q_{ji}(t)/L(t)$. The present value of intertemporal utility is a weighted sum of all future utility flows

$$U = \int_0^\infty \frac{u(q(t))^{1-\mu} - 1}{1-\mu} e^{(n-\rho)t} dt, \tag{2}$$

where $\rho > n$ is the discount rate of future consumption and $\mu > 0$ is the inverse of the elasticity of intertemporal substitution. We assume the felicity function $u(\cdot)$ is homothetic, continuous, increasing and strictly concave in each argument, and satisfies the standard Inada conditions. The number of household members is assumed to be proportional to the number of workers, and to grow at the exogenously given rate $n > 0$.

Given prices $p\left(t\right) \equiv \left(p_{a1}, p_{m1}, p_{s1}\left(t\right), p_{\omega 1}\left(t\right), p_{a2}, p_{m2}, p_{s2}\left(t\right), p_{\omega 2}\left(t\right)\right)$, the minimum expenditure capable of yielding welfare level $\bar{u}$ per household member is given by

$$M\left(p, \bar{u}\right) = \varkappa(p)\ \bar{u} \equiv \min_{\{q_{ji}\}} \left\{ \left(\sum_{i \in I} \sum_{j \in J} p_{ji} q_{ji} \right) \mid \bar{u} \leq u(q) \right\}. \tag{3}$$

The properties of $u\left(\cdot\right)$ imply that the expenditure function is increasing and concave in p, increasing in $\bar{u}$, and satisfies Shepard's lemma.

The flow budget constraint expresses time t savings, denoted $\dot{A}(t)$, as the difference between income and expenditures. Let τ_i denote rent per effective unit of land $B\left(t\right)T_i$ in region i, and let v_{ji} denote the rents/shadow value per effective unit of water $\Lambda\left(t\right)\bar{E}_{ji}$ in sector j of region i. Here $\bar{E}_{ji}$ denotes the amount of water allocated (initially, by government decree) to good j production in region i. Income is derived from labor income, wL, returns to the capital asset, rK, returns to land assets in each region $\tau_1 B\left(t\right)T_1 + \tau_2 B\left(t\right)T_2$, and returns to water as measured by the shadow value of water in the two regions $\sum\limits_{i\in I}\sum\limits_{j\in J} v_{ji}\Lambda\left(t\right)\bar{E}_{ji}$. Thus, as modeled, the rents to the government's decreed allocation of water accrue to households.

The representative household's flow budget constraint in per worker terms is expressed as

$$\dot{k} = \left[w + p_k k(r-n) + \sum_{i\in I}\tau_i\tilde{B}\left(t\right)T_i + \sum_{i\in I}\sum_{j\in J} v_{ji}\tilde{\Lambda}\left(t\right)\bar{E}_{ji} - M\right]\frac{1}{p_k}. \tag{4}$$

Here $k = K/L\left(t\right)$, $\tilde{B}\left(t\right) = B\left(t\right)/L\left(t\right)$ and $\tilde{\Lambda}\left(t\right) = \Lambda\left(t\right)/L\left(t\right)$. The representative household chooses the sequence of consumption bundles $\{q(t)\}_{t\in[0,\infty)}$ to maximize intertemporal utility(2) subject to the flow budget constraint (4).

For the case where $\mu \to 1$, the utility maximization obtained from the present value Hamiltonian corresponding to (2) and (4) yields the following Euler equation

$$\frac{\dot{M}}{M} = r - \rho. \tag{5}$$

Since the initial labor stock is normalized to one, the initial capital stock is

$$k(0) = K_0, \tag{6}$$

and the transversality condition is given by

$$\lim_{t\to\infty}\left[\lambda(t)\ k(t)\right] = 0. \tag{7}$$

Here the costate variable $\lambda(t)$ is the present value shadow price of income. The Euler equation (5) and the equation of motion (4), together with the initial condition (6) and the transversality condition (7), characterize the representative household's optimization problem.

In the next section, the production side of the economy is normalized in terms of *effective* labor units, $A\left(t\right)$ (should be $A(t)L(t)$). We presume that

$$e^{xt} = A\left(t\right),$$

where x is the Harrod neutral rate of technical change. The budget constraint (4) and the Euler equation are used to characterize equilibrium and to derive the model's differential equations. Hence, the budget constraint and the Euler equation need to be specified in units of effective labor. Specifyng expenditure M per worker in effective units, we have

$$\hat{M} = Me^{-xt}$$

so that

$$\frac{\dot{\hat{M}}}{\hat{M}} = \frac{\dot{M}}{M} - x.$$

Thus, (5) becomes

$$\frac{\dot{\hat{M}}}{\hat{M}} = r - \rho - x. \tag{8}$$

Similarly, normalizing the budget constraint (4) by e^{-xt} yields

$$\dot{\hat{k}} = \left[\hat{w} + p_k\hat{k}(r-n-x) + \sum_{i\in I}\tau_i\hat{B}\left(t\right)T_i + \sum_{i\in I}\sum_{j\in J}v_{ji}\hat{\Lambda}\left(t\right)\bar{E}_{ji} - \hat{M}\right]\frac{1}{p_k}. \tag{9}$$

where $\hat{w} = we^{-xt}, \hat{k} = ke^{-xt}, \hat{B} = \tilde{B}e^{-xt}$, and $\hat{\Lambda}\left(t\right) = \tilde{\Lambda}e^{-xt}$.

If factor productivity specific to agriculture $B\left(t\right)$, and specific to water $\Lambda\left(t\right)$ grow at the rate of $x+n$, then

$$\hat{B}\left(t\right) = \hat{\Lambda}\left(t\right) = 1 \tag{10}$$

and the system of differential equations derived below are autonomous. In what follows, we assume (10) prevails.

3.4 A competitive equilibrium with centrally planned water allocations

We now examine characteristics of the economy's baseline equilibrium: the case where the central government allocates a fixed amount of water to each productive sector that remains invariant over time – i.e., the baseline model assumes there is no water allocation reform. In this case, water is a fixed factor in producing each final good. The following technologies are all expressed in per labor-efficiency-unit (LEU) terms.

Define for each sector-ji, the following variables in intensive form: $l_{ji} = \frac{L_{ji}}{L}, \hat{k}_{ji} = \frac{K_{ji}}{AL_{ji}}$, and $\bar{E}_{ji} = \frac{\hat{\Lambda}\bar{E}_{ji}}{AL}$. For each region, agricultural firms maximize the total returns to their land and water endowments T_i and $\bar{E}_{ai}$:

$$\pi^{ai}\left(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i\right) \equiv \max_{\{l_{ai}, \hat{k}_{ai}\}} \{l_{ai}[p_{ai} f^{ai}(\hat{k}_{ai}, \bar{E}_{ai}, T_i) - \hat{w} - r\hat{k}_{ai}]\},$$

Given the properties of f^{ai}, π^{ai} is concave in $\hat{w}, r$, and p_{ai}, and satisfies Hotelling's Lemma. The shadow prices of effective land and water endowments can be calculated as follows:

$$\tau_i = \frac{\partial \pi^{ai}(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i)}{\partial T_i}; \qquad v_{ai} = \frac{\partial \pi^{ai}(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i)}{\partial \bar{E}_{ai}}.$$

If land rental markets are complete, τ_i is the rental rate per effective unit of land among all farmers in region i. Together with the shadow price of water, gross returns equal factor payments, i.e.,

$$p_a \hat{y}_{ai} - \hat{w} l_{ai} - r\hat{k}_{ai} - \tau_i T_i - v_{ai}\bar{E}_{ai} = 0$$

where $\hat{y}_{ai} = Y_{ai} e^{-(x+n)t}$.

Maximum returns to water in the manufacturing and service sector are given by

$$\pi^{ji}(\hat{w}, r, p_{ji}, \bar{E}_{ji}) = \hat{\nu}_{ji}(\hat{w}, r)\bar{E}_{ji} \equiv \max_{\{l_{ji}, \hat{k}_{ji}\}} \{l_{ji}[p_{ji} f^{ji}(\hat{k}_{ji}, \bar{E}_{ji}) - \hat{w} - r\hat{k}_{ji}]\}$$

The function π^{ji} is concave in $\hat{w}, r$, and p_{ai}, and satisfies Hotelling's Lemma. The shadow value of water allocated to production of good j in region i is given by

$$v_{ji} = \frac{\partial \pi^{ji}(\hat{w}, r, p_{ji}, \bar{E}_{ji})}{\partial \bar{E}_{ji}}.$$

The corresponding maximum return to water used in region-i residential water production is

$$\pi_{\omega i} = v_{\omega i}(p_{\omega i})\bar{E}_{\omega i} \equiv p_{\omega i}\bar{E}_{\omega i},$$

where, in units of effective labor, we have

$$\begin{aligned} v_{\omega i}(p_{\omega i}) &= p_{\omega i} \\ \hat{y}_{\omega i} &= \bar{E}_{\omega i}. \end{aligned}$$

Now the flow budget constraint (9) can be rewritten as

$$\dot{\hat{k}} = \left[\hat{w} + p_k \hat{k}(r - x - n) + \sum_{i \in I} \pi(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i) + \sum_{i \in I} \sum_{j=m,s} \pi(\hat{w}, r, p_{ji}, \bar{E}_{ji}) - \hat{M}\right] \frac{1}{p_k}. \qquad (11)$$

3.4.1 Characterization

Given water assignments $\{\bar{E}_{a1}, \bar{E}_{m1}, \bar{E}_{s1}, \bar{E}_{\omega 1}, \bar{E}_{a2}, \bar{E}_{m2}, \bar{E}_{s2}, \bar{E}_{\omega 2}\}$ and the endogenous sequence of values $\{\hat{k}, \hat{M}\}_{t\in[0,\infty)}$, the six-tuple sequence of positive values $\{\hat{w}, r, p_{s1}, p_{s2}, p_{\omega 1}, p_{\omega 2}\}_{t\in[0,\infty)}$ must satisfy the following six intra-temporal conditions at each t:

1. Labor market clearing

$$-\sum_{i\in I}\sum_{j=m,s}\frac{\partial\pi^{ji}(\hat{w}, r, p_{ji}, \bar{E}_{ji})}{\partial\hat{w}} - \sum_{i\in I}\frac{\partial\pi^{ai}(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i)}{\partial\hat{w}} = 1 \tag{12}$$

2. Capital market clearing

$$-\sum_{i\in I}\sum_{j=m,s}\frac{\partial\pi^{ji}(\hat{w}, r, p_{ji}, \bar{E}_{ji})}{\partial r} - \sum_{i\in I}\frac{\partial\pi^{ai}(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i)}{\partial r} = \hat{k} \tag{13}$$

3. The service good market clears in each region

$$\frac{\partial\hat{M}}{\partial p_{si}} = \frac{\partial\pi^{si}(\hat{w}, r, p_{si}, \bar{E}_{si})}{\partial p_{si}}, \qquad i = 1, 2, \tag{14}$$

   and

4. The residential water market clears in each region

$$\frac{\partial\hat{M}}{\partial p_{\omega i}} = \bar{E}_{\omega i}, \qquad i = 1, 2. \tag{15}$$

The system (12) – (15) yields a solution for which each endogenous variable is a function of the exogenous variables $\{p_{mi}, p_{ai}, T_i, \bar{E}_{ji}\}$ and the remaining endogenous variables $\{\hat{k}, \hat{M}\}$. However, in practice, solving the system is facilitated by representing $\{p_{s1}, p_{s2}, p_{\omega 1}, p_{\omega 2}, \hat{M}\}$ as a function of $\{\hat{w}, r, \hat{k}\}$. Hence, the solution can be identified with three equations of motion. The next two subsections derive the steady-state solution and the three equations of motion.

3.4.2 The long-run (steady state) equilibrium

Using the factor market clearing conditions (12) and (13), express p_{s1} and p_{s2} as a function of $\{\hat{w}, r, \hat{k}\}$

$$p_{s1} = P^{s1}(\hat{w}, r, \hat{k}) \tag{16}$$

$$p_{s2} = P^{s2}(\hat{w}, r, \hat{k}), \tag{17}$$

where we suppress the exogenous variables $\{p_{mi}, p_{ai}, \bar{E}_{ai}, T_i\}$. Substitute (16) and (17) into the service good market clearing condition (14) to obtain

$$\hat{M} = \frac{\partial \pi^{s1}(\hat{w}, r, P^{s1}\left(\hat{w}, r, \hat{k}\right), \bar{E}_{s1})}{\partial p_{s1}} \frac{P^{s1}\left(\hat{w}, r, \hat{k}\right)}{\eta_{_{s1}}\left(\hat{w}, r, \hat{k}\right)} = S^1\left(\hat{w}, r, \hat{k}\right) \tag{18}$$

$$\hat{M} = \frac{\partial \pi^{s2}(\hat{w}, r, P^{s2}\left(\hat{w}, r, \hat{k}\right), \bar{E}_{s2})}{\partial p_{s2}} \frac{P^{s2}\left(\hat{w}, r, \hat{k}\right)}{\eta_{_{s2}}\left(\hat{w}, r, \hat{k}\right)} = S^2\left(\hat{w}, r, \hat{k}\right), \tag{19}$$

where

$$\eta_{_{si}}\left(\hat{w}, r, \hat{k}\right) = \left.\frac{\partial \hat{M}}{\partial p_{si}} \frac{p_{si}}{\hat{M}}\right|_{p_{si} = P^{si}(\hat{w}, r, \hat{k}), i=1,2}$$

is the share of income spent on services in region i. Substituting (18) into the residential water market clearing condition (15) yields $p_{\omega 1}$ and $p_{\omega 2}$ as a function of $\{\hat{w}, r, \hat{k}\}$

$$p_{\omega 1} = P^{\omega 1}(\hat{w}, r, \hat{k}) \tag{20}$$

$$p_{\omega 2} = P^{\omega 2}(\hat{w}, r, \hat{k}). \tag{21}$$

Dividing (18) by (19), we get

$$\frac{S^1(\hat{w}, r, \hat{k})}{S^2(\hat{w}, r, \hat{k})} = 1. \tag{22}$$

If a steady state exists, given $\mu \to 1$, the Euler equation (8) implies

$$r_{ss} = \rho + x. \tag{23}$$

Substitute (16) - (18), (20), and (21) into the budget constraint (11), and then replace r buy the steady state result (23). This yields the a flow budget constraint in arguments $\dot{\hat{k}}$, $\hat{w}$, and $\hat{k}$.

$$\begin{aligned} \dot{\hat{k}} = & \left\{ \hat{w} + p_k \hat{k}(r_{ss} - x - n) + \sum_{i \in I} \pi(\hat{w}, r_{ss}, p_{ai}, \bar{E}_{ai}, T_i) \right. \\ & \left. + \sum_{i \in I} P^{\omega i}(\hat{w}, r_{ss}, \hat{k}) \bar{E}_{\omega i} - S^1(\hat{w}, r_{ss}, \hat{k}) + \sum_{i \in I} \sum_{j=m,s} \pi(\hat{w}, r_{ss}, P^{ji}(\hat{w}, r_{ss}, \hat{k}), \bar{E}_{ji}) \right\} \frac{1}{p_k}. \end{aligned} \tag{24}$$

Finally, if a steady state exists, $\dot{\hat{k}} = 0$, and the root $\{\hat{w}_{ss}, \hat{k}_{ss}\}$ satisfying (22) and (24) for r_{ss} should be real and positive. Knowing these steady state values permits calculation of the remaining steady state endogenous variables.

3.4.3 Transition path equilibrium

Substituting (16) - (18), (20), and (21) into the budget constraint (11) yields a differential equation in three unknowns, $\hat{w}$, r and $\hat{k}$:

$$\begin{aligned}\dot{\hat{k}} &= \Bigg\{ \hat{w} + p_k \hat{k}(r - x - n) + \sum_{i \in I} \pi(\hat{w}, r, p_{ai}, \bar{E}_{ai}, T_i) \\ &\quad + \sum_{i \in I} \sum_{j = m,s} \pi(\hat{w}, r, P^{ji}(\hat{w}, r, \hat{k}), \bar{E}_{ji}) + \sum_{i \in I} P^{\omega i}(\hat{w}, r, \hat{k}) \bar{E}_{\omega i} - S^1(\hat{w}, r, \hat{k}) \Bigg\} \frac{1}{p_k} \\ &= G^1(\hat{w}, r, \hat{k}). \end{aligned} \tag{25}$$

To find the differential equations for $\hat{w}$ and r, totally differentiate (18) and (19) with respect to t to obtain

$$\dot{\hat{M}} = \frac{\partial S^1(\hat{w}, r, \hat{k})}{\partial \hat{w}} \dot{\hat{w}} + \frac{\partial S^1(\hat{w}, r, \hat{k})}{\partial r} \dot{r} + \frac{\partial S^1(\hat{w}, r, \hat{k})}{\partial \hat{k}} \dot{\hat{k}} \tag{26}$$

$$\dot{\hat{M}} = \frac{\partial S^2(\hat{w}, r, \hat{k})}{\partial \hat{w}} \dot{\hat{w}} + \frac{\partial S^2(\hat{w}, r, \hat{k})}{\partial r} \dot{r} + \frac{\partial S^2(\hat{w}, r, \hat{k})}{\partial \hat{k}} \dot{\hat{k}}. \tag{27}$$

Next, solve the above two equations for $\dot{\hat{w}}$ and $\dot{r}$ to obtain

$$\dot{\hat{w}} = \frac{\frac{\partial S^1(\hat{w},r,\hat{k})}{\partial r}\left(\dot{\hat{M}} - \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial \hat{k}} \dot{\hat{k}}\right) + \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial r}\left(\frac{\partial S^1(\hat{w},r,\hat{k})}{\partial \hat{k}} \dot{\hat{k}} - \dot{\hat{M}}\right)}{\frac{\partial S^1(\hat{w},r,\hat{k})}{\partial r} \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial \hat{w}} - \frac{\partial S^1(\hat{w},r,\hat{k})}{\partial \hat{w}} \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial r}} \tag{28}$$

$$\dot{r} = \frac{\frac{\partial S^1(\hat{w},r,\hat{k})}{\partial \hat{w}}\left(\dot{\hat{M}} - \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial \hat{k}} \dot{\hat{k}}\right) + \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial \hat{w}}\left(\frac{\partial S^1(\hat{w},r,\hat{k})}{\partial \hat{k}} \dot{\hat{k}} - \dot{\hat{M}}\right)}{\frac{\partial S^1(\hat{w},r,\hat{k})}{\partial \hat{w}} \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial r} - \frac{\partial S^1(\hat{w},r,\hat{k})}{\partial r} \frac{\partial S^2(\hat{w},r,\hat{k})}{\partial \hat{w}}}. \tag{29}$$

Substitute (18) into the Euler equation (8) to express $\dot{\hat{M}}$ as a function of $\{\hat{w}, r, \hat{k}\}$ and express the result as

$$\dot{\hat{M}} = M(\hat{w}, r, \hat{k}). \tag{30}$$

Finally, substitute (25) and (30) into (28) and (29) to yield the other two differential equations

$$\dot{\hat{w}} = G^2(\hat{w}, r, \hat{k}) \tag{31}$$

$$\dot{r} = G^3(\hat{w}, r, \hat{k}) \tag{32}$$

Pending stability conditions, the three equations of motion (25), (31) and (32), together with the initial condition (6) and transversality condition (7) describe the transition path equilibria

$$\{\hat{w}(t), r(t), \hat{k}(t)\}_{t\in[0,\infty)}. \tag{33}$$

Empirically, the system of differential equations given by (25), (31) and (32) is solved using the Time-Elimination Method discussed in Mulligan and Sala-i-Martin (1991) for the case where condition (10) holds.[3]

Substituting (33) into (18) allows the calculation of $\{\hat{M}\}_{t\in[0,\infty)}$. Together with the intra-temporal system, the remaining sequence of factor payments, firm and household allocations are readily recovered.

3.5 Altering the water allocation policy

In principle, several mechanisms can potentially implement an efficient water allocation – i.e., allocations that equate the marginal value product of water across all uses. By changing the water allocation mechanism to account for the "market-based-efficient" allocation of water, the above characterization of equilibrium must also change. Likewise, the corresponding system of differential equations differ slightly from the system (25), (31) and (32). To conserve on space, we simply note there are differences and offer the interested reader to contact us for further details.

To introduce the South-North WTP into the model, we ignore the project's construction cost.[4] With the water diversion project, the behavior of households and firms, the definition and characterization of equilibria, and the procedure for solving the dynamic equilibria under the centrally planned or market-based water allocation are exactly the same as those without the diversion project. This result occurs because the South-North WTP simply changes the water endowments of each region. The projected changes in water endowments are taken from the Ministry of Water Resources, 1998. When water is allocated by the central government, the water assignment without the project is given by $\{\bar{E}_{a1}, \bar{E}_{m1}, \bar{E}_{s1}, \bar{E}_{\omega1}, \bar{E}_{a2}, \bar{E}_{m2}, \bar{E}_{s2}, \bar{E}_{\omega2}\}$. We represent the allocation with the project by

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[3] If (10) does not hold, then one or more of the three differential equations are non-autonomous in which case one might appeal to the numerical method discussed by Brunner and Strulick (2002).

[4] The official cost estimate of this project is RMB 532 billion (US$ 64 billion), and is projected to take about 50 years to complete. Hence, assuming the project cost is spread over 50 years, the annual cost of the project is less than 0.1% of each year's GDP. The zero cost assumption will make the results slightly different from those of including the cost in the model, however, the transition pattern will be almost the same for both cases.

the vector $\{\widetilde{\bar{\bar{E}}}_{a1}, \widetilde{\bar{\bar{E}}}_{m1}, \widetilde{\bar{\bar{E}}}_{s1}, \widetilde{\bar{\bar{E}}}_{\omega 1}, \widetilde{\bar{\bar{E}}}_{a2}, \widetilde{\bar{\bar{E}}}_{m2}, \widetilde{\bar{\bar{E}}}_{s2}, \widetilde{\bar{\bar{E}}}_{\omega 2}\}$,where

$$\begin{aligned}
\widetilde{\bar{\bar{E}}}_{a1} &= \bar{E}_{a1} + 17.20, \quad \widetilde{\bar{\bar{E}}}_{a2} = \bar{E}_{a1} - 43 \\
\widetilde{\bar{\bar{E}}}_{m1} &= \bar{E}_{m1} + 18.06, \quad \widetilde{\bar{\bar{E}}}_{m2} = \bar{E}_{m2} \\
\widetilde{\bar{\bar{E}}}_{s1} &= \bar{E}_{s2} + 2.15, \quad \widetilde{\bar{\bar{E}}}_{s2} = \bar{E}_{s2} \\
\widetilde{\bar{\bar{E}}}_{\omega 1} &= \bar{E}_{\omega 1} + 5.59, \quad \widetilde{\bar{\bar{E}}}_{\omega 2} = \bar{E}_{\omega 2}.
\end{aligned} \tag{34}$$

The projected changes in the water endowments shown in (34) are in billions of m^3 per year, and are taken from the Ministry of Water Resources, 1998. Each year, the Ministry of Water Resources plans to take 43 billion m^3 of water from Southern agriculture and distribute 17.2 billion m^3 to Northern agriculture, 18 m^3 to Northern manufacturing and the rest of the water to Northern services and residential demand.

For an economy with a "market-based" water allocation mechanism, the South-North WTP simply changes the water endowments in both regions by adding 43 billion m^3 of water to the North and subtacting the same amount from the South

$$\begin{aligned}
\widetilde{\bar{\bar{E}}}_{1} &= \bar{E}_{1} + 43 \\
\widetilde{\bar{\bar{E}}}_{2} &= \bar{E}_{2} - 43,
\end{aligned}$$

where $\widetilde{\bar{\bar{E}}}_{1}$ and $\widetilde{\bar{\bar{E}}}_{2}$ are the respective new water endowments in the North and South for the economy with both market-based water allocation and the South-North WTP.

4 Model estimation

This section describes how we fit the model to the Chinese economy so as to reproduce the country's year 2000 data. We then use the empirical model to analyze the economics of four policy scenarios: (i) the base scenario in which the country's current water assignments are given and unchanged over time; (ii) an intra-regional water reallocation scenario (Intra-WRS) in which water is allocated across sectors within each region to equate the marginal value product of water across sectors in that region ; (iii) an inter-regional water reallocation scenario (Inter-WRS) in which water is transported from the South to the North via the South-North WTP, but keeping a fixed, unchanged water assignment over time; and (iv) an inter-intra-regional water reallocation scenario (Inter-Intra-WRS), which is a combination of the intra-regional water reallocation and the inter-regional water reallocation scenarios.

4.1 Fitting the model to data

Data for our empirical specification are derived from three sources: the China Statistical Yearbook (CSY), the Shangnong Survey Data (www.sangnong.gov.cn), and Water Resources Bulletin (The Ministry of Water Resources). The CSY provides data on provincial aggregate GDP, sectoral GDP, and payments to labor for each sector. The Shangnong Survey Data provides data on payments to capital and land. The Water Resources Bulletin provides data on annual water availability, water supplies, and water allocation among users for each province in China. Time series data are used to estimate total factor productivity, and to help calibrate the equations of motion.

We parameterize the model to year 2000 data by deriving the cost share and scale parameters for the technologies introduced above, and calculating the expenditure share parameters for the Cobb-Douglas household felicity function. Considering the low degree of substitution between water and other factors in agriculture, the agricultural production functions are constant elasticity of substitution (CES) functions. The remaining final good technologies are Cobb-Douglas. Table 1 presents the production cost shares used in the empirical analysis.

Table 1. Production cost shares

	Agriculture		Manufacturing		Services		Composite
	North	South	North	South	North	South	capital good
Labor	0.545	0.550	0.499	0.432	0.407	0.440	-
Capital	0.226	0.187	0.484	0.548	0.585	0.552	-
Water	0.102	0.087	0.017	0.020	0.008	0.008	-
Land	0.127	0.176	-	-	-	-	-
North manufacturing	-	-	-	-	-	-	0.439
South manufacturing	-	-	-	-	-	-	0.561

Consumption shares are given in Table 2.

Table 2. Consumption shares

Agriculture		Manufacturing		Services		Residential water	
North	South	North	South	North	South	North	South
0.1291	0.1593	0.0562	0.0902	0.2193	0.3418	0.0016	0.0024

We also must specify values for the time discount factor ρ, the population growth rate n, the rate of growth in labor productivity x, water productivity ε, land productivity ν, and the CES production technology's substitution parameter θ. Between 1978 and 1998, on average, the working population in China grew 1.4 percent per year, and, hence, we set $n = 0.014$. Between the same period, labor productivity growth averaged 3.6 percent per year (Young, 2003). Young, however observes that after accounting for the aging and improved educational attainment of the workforce, the growth rate of labor productivity should be adjusted down to about 2.6 percent. It is reasonable to view 3.6 percent as the upper bound of x, and 2.6 percent as its lower bound. In the empirical model we choose the average of the two extremes and set $x = 0.031$. Yeung and Roe (1978) use data on Japanese agricultural production from 1915 to 1940 and estimate the elasticity of factor substitution, which ranged between 0.2373 and 0.2263. We select 0.23 as the elasticity of factor substitution for agricultural production, which results in $\theta = 3.3$. To guarantee the existence of the steady state, we assume water productivity and land productivity grow at the same rate as the rate of growth in labor efficiency, see condition (10). With this assumption, $\varepsilon = \upsilon = n + x = 0.044$. Given the above values, we choose the time discount factor ρ so the savings rate associated with the parameterized economy is close to the actual savings rate in the base year. This value is $\rho = 0.039$. These values are summarized in Table 3

Table 3. Other economy-wide parameters

Variable	Symbol	Value	Variable	Symbol	Value
Substitution parameter	θ	3.3	Growth rate in labor productivity	x	0.031
Time discount factor	ρ	0.039	Growth rate in water productivity	ε	0.045
Population growth rate	n	0.014	Growth rate in land productivity	ν	0.045
Capital Stock, RMB per worker	$p_k K_0$	65122.4			

4.2 The Base Scenario and Corresponding Model Dynamics

Table 4 summarizes the difference in selected macroeconomic indicators for the base scenario (i) above, and the Intra-WRS senario (ii) above. We represent the steady state variables in labor effective units (LEU) since un-normalized level variables in per worker terms grow at the rate x forever and are thus not constant. Dividing the steady state values of simulation (ii) by base solution (i), as in the last column of Table 4, is more meaningful because their common normalization term cancels. Table 4 reveals that capital deepening occurs over time, and as a result, wages increase – reflecting the increased marginal productivity of labor over time. Steady state consumption, in

LEU, is higher than in the initial period simply because capital deepening allows for greater output and, in the steady state, less income is foregone The more interesting results are reported in the last column of Table 4. In the long run, real GDP per worker remains 2.67% higher than the base when intra-regional water allocation equates water's marginal value product of water across all regional uses. This increase in efficiency induces more capital per worker (4.7%), higher wages (5.8%) and an even higher level of aggregate consumption of 8.4% (i.e., the $\bar{u}$ in equation (3)). Moreover, these results are obtained with a smaller percentage of income being allocated to savings.

Table 4. Comparison of macroeconomic variables, base solution to intra-WRS

	Initial period Yr 2000	(i) Base Steady State*/	(ii) Intra-WRS Steady State*/	(ii) Intra-WRS÷(i) Base % change
Real GDP in RMB/LEU.	9746.79	10232.53	10505.71	2.67
Capital in RMB/LEU	65122.39	71830.72	75201.52	4.69
Wages in RMB/LEU	4479.50	4688.64	4739.21	1.08
Consumption in RMB/LEU	6529.06	6981.77	7077.42	1.62
Saving rate	0.33015	0.31646	0.32348	2.22

*/Real GDP in RMB per labor effective unit in the steady state.

To understand the impact of capital deepening on final good production sectors, turn to Table 5, which reveals the final goods sectors respond to the increase in a Rybczynski-type fashion. By Table 1, North manufacturing and both agricultural sectors are labor intensive sectors, while South manufacturing and both service sectors are capital intensive. One implication of the Rybczynski theorem is if a factor endowment increases, all else constant, the output of the sector using that factor most intensively increases, while the other sector's output falls. In a dynamic setting all else is not constant since home good prices are changing, and with more than two sectors and sector specific resources, the Rybczynski results do not apply. Nevertheless, similar forces remain in play since supply is homogenous of degree one in their factor levels. Here, both labor and the stock of capital increase over time, but the capital stock grows at a faster rate than labor – capital deepening. In this dynamic setting, *the share of aggregate GDP* provided by each of the capital intensive sectors increases (at a decreasing rate) over time, while *the share of aggregate GDP* in each labor intensive sector falls (at a decreasing rate) over time. The result is, relative to the initial period, the steady state share of output produced by the capital (labor) intensive sectors increase (decrease).

Table 5. Sectoral shares of GDP per capita: Base model

	Agriculture/GDP		Manufacturing/GDP		Services/GDP		Residential/GDP	
	North	South	North	South	North	South	North	South
Initial period	0.05915	0.09315	0.19252	0.27666	0.14692	0.22895	0.00108	0.00158
Steady state	0.05551	0.08746	0.15969	0.31108	0.14992	0.23362	0.00111	0.00161
% change	-6.150	-6.104	-17.052	12.445	2.042	2.038	2.044	.2044

The final, and probably, most important observation for our story are the differentials among water shadow values. Table 6 reveals that in the base model, water is not allocated efficiently and the shadow value of water varies across sectors. With each sector in the North having higher shadow values than its counterpart in the South, one can also conclude that water is a more scarce resource in the North. In the initial period, agriculture has the lowest shadow value of water in both regions, while the service sector has the highest shadow value. The gap in shadow values increases over time, indicating that doing nothing, i.e., ignoring water reform, allows the problem to worsen over time, increasing the level of inefficiency in water use. Inefficient water allocations also have indirect effects. Specifically, having relatively cheaper water, agriculture locks up more capital and labor resources than it should, and the economy forgoes potential efficiency gains both from releasing water from less productive uses, and in turn, freeing up more labor and capital to the more productive manufacturing and service sectors. As an aside, since the production technology for residential water uses only water for production, with a fixed endowment of water and increasing demand, it is no surprise the shadow value of residential water increases over time.

Table 6. Water shadow values in the base model[♯]

	Agriculture		Manufacturing		Services		Residential Water	
	North	South	North	South	North	South	North	South
Initial period	0.56000	0.32000	0.98894	0.66917	1.81268	1.32200	0.90132	0.60088
Steady state	0.52129	0.29851	0.85962	0.78851	1.93833	1.41359	0.96381	0.64254
% change	-6.913	-6.717	-13.077	17.833	6.932	6.928	6.934	6.934

[♯] The transition path for each shadow value is monotonic.

4.3 Model results for the Intra-WRS

We now investigate more closely, the economic impact of efficiently allocating water across users within each region. In the Intra-WRS, water is allocated so the marginal value product of water is equal across sectors.

Table 4 suggests that allocating water efficiently across sectors within each region yields good payoffs. For instance, compared to base case steady state levels, the Intra-WRS allocation increases the steady state level of real GDP per capita by 2.67%, while consumption and savings increase 1.62% and 2.22% respectively. GDP increases because some of the water tied up in relatively lower valued agricultural uses is released to manufacturing and service sector uses, both of which have higher water marginal value products. Accordingly, as water moves from less to more efficient uses, capital and labor becomes more productive in the receiving sectors and the economy gets a boost in output. Consumption levels increases because the increased efficiency in water allocation yields higher levels of final good production. Savings increase because as water moves to higher valued uses, the productivity of capital and labor also increase, as evidenced by the 4.69% increase in the capital-to-labor ratio and the 1.08% increase in wage levels.

Where does the water released from agriculture go? Figure 2 shows the percent change in water allocation across production activities between the Intra-regional and base scenarios, i.e., $\frac{E_{ji}(t)-\bar{E}_{ji}(t)}{\bar{E}_{ji}(t)}$. The water shadow values in Table 6 suggest both agricultural sectors would release water in an Intra-WRS. Agriculture in both regions, does in fact, release water to the other sectors, but we do not include in Figure 2, the percent changes for agriculture. In the Intra-WRS regime, initially all non-agricultural sectors receive increased water allocations. Rybcinzski-like effects, however enter the picture again as the capital intensive South and North Services, and North Manufacturing receive the biggest jump in water allocations in the initial period. Being a labor intensive sector, however, over time the share of GDP generated by Northern manufacturing falls, and accordingly, slowly releases water to its service sector and residential water demands. On the other hand, capital deepening in Southern Manufacturing allows it to continue receiving increased water allocations water until reaching the steady state. In the North's long run equilibrium, relative to their current water assignments, the amount of water employed by the agricultural and manufacturing sectors decreases by 12.25% and 11.26%, while the amount of water employed by service and residential water sectors increases by 210.72% and 54.43%; In the South, the amount of water employed by the agricultural sector declines by 28.20% relative to its current water assignment, whereas that employed by the manufacturing, service and residential water sectors increases by 63.22%, 129.04% and 4.12% respectively.

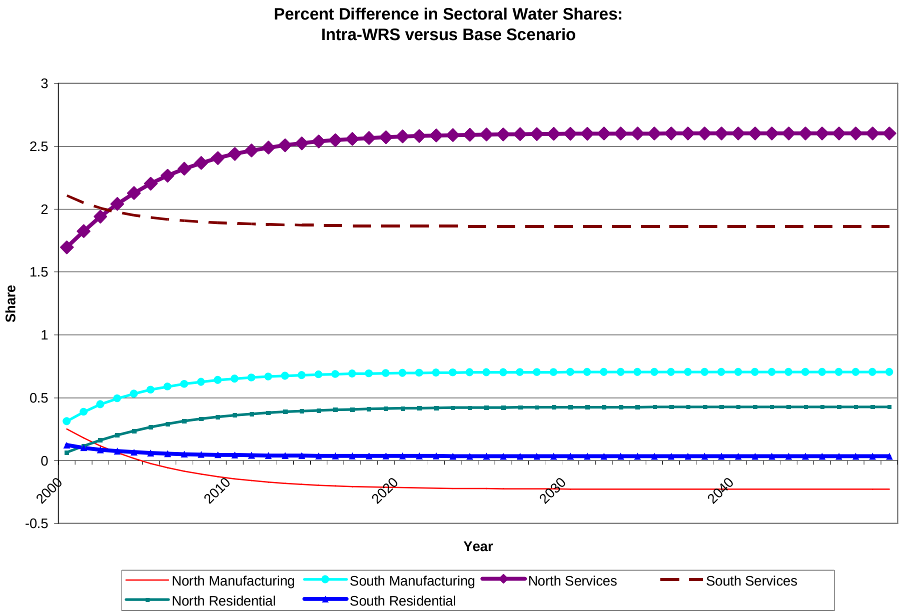

Figure 2

Not surprisingly, in terms of social welfare, the economy under the Intra-WRS is more efficient than the base economy. The present value of lifetime utility is 290.342 for the base scenario, while this number is 290.481 for the Intra scenario. In terms of a discounted equivalent value measure, the aggregate welfare gain from implimenting an "optimal" Intra-regional water allocation in each region, is 1002.51 billion RMB: about 10.3% of China's Year 2000 GDP.

4.4 Model results for the Inter-WRS

In the prior section, we examined the economic impact of reallocating water across the respective users to equate the marginal value product of water within each region. In this subsection, we investigate the economic impact of reallocating water across regions, i.e., transferring water from the South to the North. In this scenario, each year about 43 billion m^3 of water is diverted to the North from agricultural use in the South via the South-North WTP. Here, 43 billion m^3

represents about 11.3% of Southern agriculture's water endowment. The transferred water is then distributed by the central government to sectors in the North according to the rules listed in (34). Table 7 presents a summary of some differences between the base scenario and the intra-regional water reallocation scenario. Moving water from the South to the North leaves long run GDP levels virtually unchanged. Wages and consumption increase slighty, while savings and capital accumulation decrease slightly.

Table 7. Comparison of macroeconomic variables, base solution to intra-WRS

	Initial period Yr 2000	(i) Base Steady State[*/]	(ii) Intra-WRS Steady State[*/]	(ii) Intra-WRS÷(i) Base % change
Real GDP in RMB/LEU.	9746.79	10232.53	10231.96	negligible
Capital in RMB/LEU	65122.39	71830.72	71651.15	-0.25
Wages in RMB/LEU	4479.50	4688.64	4719.76	0.66
Consumption in RMB/LEU	6529.06	6981.77	7003.51	0.13
Saving rate	0.33015	0.31646	0.31554	-0.29
[*/] Real GDP in RMB per labor effective unit in the steady state.				

In terms of improving long run per capita GDP, the South-North WTP is of no apparent value. It does, however, improve GDP levels in the short and intermediate run, and improves on the productivity of water. This is reflected in the increased water shadow values in the North and decreased shadow values in the South (see Table 8).

Table 8. Water shadow values in the base model[♯]

	Agriculture		Manufacturing		Services		Residential Water	
	North	South	North	South	North	South	North	South
Intra-WRS Steady State	0.52129	0.29851	0.85962	0.78851	1.93833	1.41359	0.96381	0.64254
Inter-WRS Steady State	0.39290	0.47814	0.71160	0.68369	1.44877	1.41605	0.65399	0.64366
% change	-24.629	60.178	-17.218	-13.293	-25.257	0.174	-32.146	0.174

[♯] The transition path for each shadow value is monotonic.

When water is taken from Southern agriculture, its shadow value increases, hence increasing the productivity of water compared to the Base scenario. The steady state shadow value of water in the Northern sectors falls, decreasing the differentials in Northern and Southern shadow values: i.e., moving water from the South to the North increases the productive efficiency of the economy.

With the Northern sectors having lower shadow values (more water), their ability to compete for capital and labor improves and they pull resources from the Southern region. Although we don't graph the transition values here, the evoloution of GDP shares produced by each sector follows a Rybcinzski-type pattern, with the share of capital (labor) intensive sectors increasing (decreasing) at a decreasing rate over time.

Figure 3 shows that moving water from the South to the North has a small advantage during the earlier years in terms of improved per capita GDP levels. Calculations reveal the present value of lifetime utility is 290.424 for the Inter scenario, compared to 290.342 for the base scenario. In terms of discounted equivalent values, however, the lifetime welfare gain of the Inter-WRS relative to that of the base is 557.23 billion RMB: about 5.7% of China's Year 2000 GDP. Recall that the official cost estimate of the South-North WTP is 532 billion RMB. Then, ignoring potential environmental externalities, the South-North WTP by itself is economically feasible since its direct economic benefits appear to justify the direct costs. However, the welfare gain of inter-regional water reallocation is only about half of that of intra-regional water reallocation. In other words, as far as social welfare is concerned, the intra-regional water reallocation is more preferred to the inter-regional water reallocation.

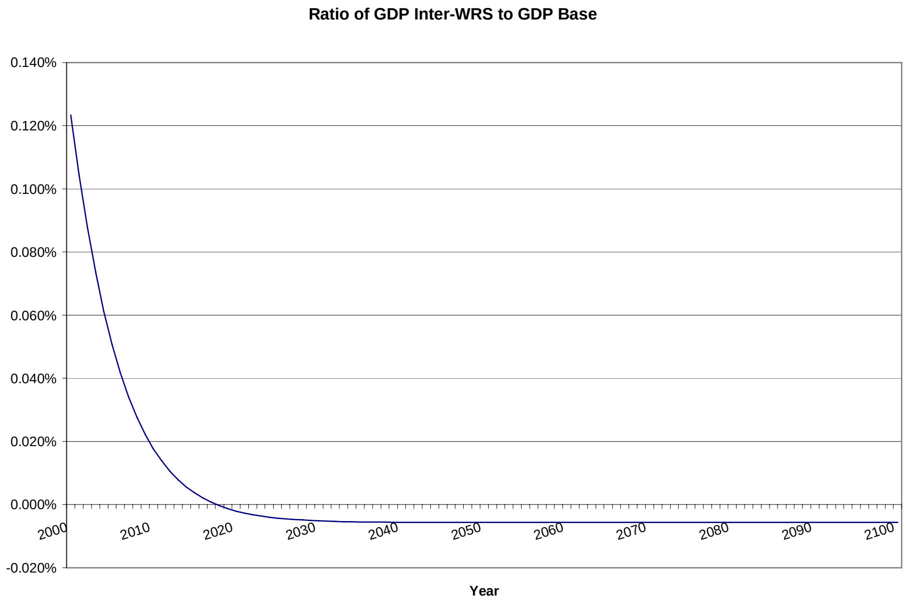

Figure 3

4.5 Model results for the Inter-Intra-WRS

This section reports the results of transfering water from the South to the North and then optimally reallocating the new regional water endowments across uses within each region. Table 9 presents a summary of some differences between the base scenario and the combined water transfer scenario. In terms of per capita GDP enhancement, combining both policies proves to be less effective than simply reallocating water efficiently across sectors, but improves on the performance of an interregional water allocation scheme. Higher long run wages, however, suggest that combining the two water policies leads to a better allocation of resources, as the higher wages imply labor is more productive.

Table 9. Comparison of macroeconomic variables, base solution to intra-WRS

	Initial period Yr 2000	(i) Base Steady State$^{*/}$	(ii) Intra-WRS Steady State$^{*/}$	(ii) Intra-WRS÷(i) Base % change
Real GDP in RMB/LEU.	9746.79	10232.53	10304.03	0.70
Capital in RMB/LEU	65122.39	71830.72	72331.85	0.70
Wages in RMB/LEU	4479.50	4688.64	4745.12	1.25
Consumption in RMB/LEU	6529.06	6981.77	7035.68	0.59
Saving rate	0.33015	0.31646	0.31721	0.24
$^{*/}$Real GDP in RMB per labor effective unit in the steady state.				

The economics of the combined policy is quite similar to that of the Intra-WRS. As in the Inter-WRS, moving water from Southern agriculture to the Northern sectors gives an initial productivity boost to each of the Northern sectors and decreases initial period production by Southern agriculture and manufacturing. Following the initial period boost, sectoral output behaves as we now expect: the share of GDP produced by capital (labor) intensive sectors increases (decreases) over time at a decreasing rate. See Figure 4.

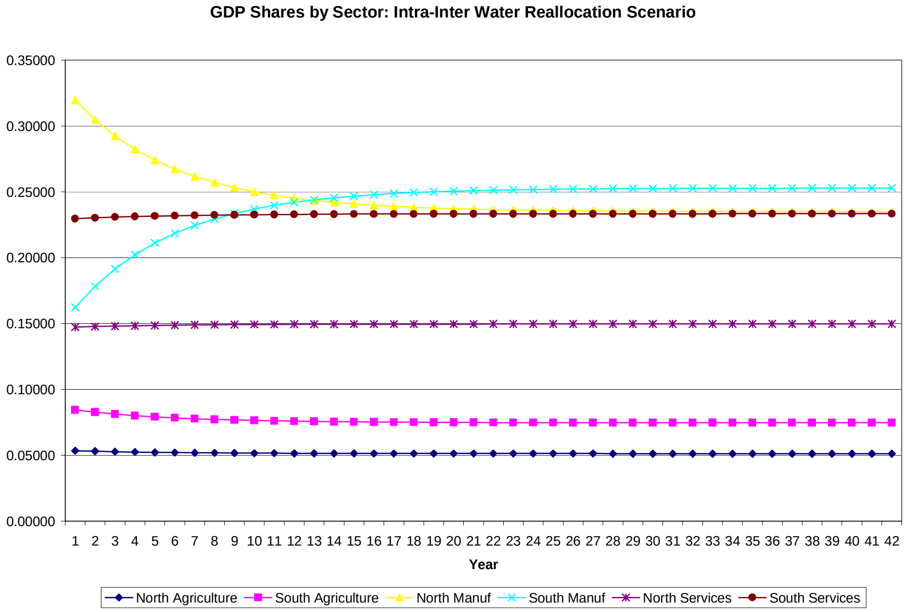

Figure 4

The resource allocations associated with a combined water transfer scheme yield a welfare gain equal to 1148.06 billion RMB (in discounted equivalent value terms), which is about 11.8% of China's Year 2000 GDP. This is the largest welfare gain of the four scenarios considered. Although this generates the largest welfare gain, it is only slightly larger than 1046 billion RMB gain associated with the intra-regional water transfer, but more than twice the welfare gain generated by the inter-regional transfer.

5 Conclusions

Water scarcity is a problem faced by countries throughout the world, and is a problem that is expected to worsen over time. Economic growth, rural to urban migration, along with increasing populations are one of the main causes of increased water scarcity. In China, as in many other countries, growing water shortages have placed great pressure on governments to develop policies and strategies to better manage water resources. Among a variety of suggestions for managing water shortages, Chinese policymakers have been particularly interested in the following two measures: (i) reallocating water across productive users within each region (intra-regional water transfers) and (ii) transporting water from the South to the North via the South-North WWTP (inter-regional water transfer). This paper examines the likely impacts of changing water policies on aggregate GDP, total consumption, income distribution across producers, labor and capital allocations, and input and output prices.

To achieve these objectives, we develop a Ramsey-type growth model of a small, open, competitive economy with five sectors (agriculture, manufacturing, services, composite capital and residential water) and two regions (Northern and Southern China). We then fit the model to the Chinese economy for the year 2000, and use the empirical model to conduct an economic analyses of four policy scenarios: (i) the base scenario in which we take the country's current water assignments as given and leave these water assignments unchanged over time; (ii) an intra-regional water transfer scenario; (iii) an inter-regional water transfer scenario; and (iv) a combined inter-regional and intra-regional water transfer scenario.

We report two major findings. First, model results suggest leaving unchanged the current water quotas assigned by the Chinese central government would exacerbate the disparity in water productivity (the marginal value product of water) across producers over time. A dynamic, intra-regional reallocation of water can eliminate the current disparity in water productivity across sectors within each region. And although a disparity in water productivity across regions remains in the short run, in the long run capital and labor movements eventually lead to an equalization of water productivity across regions.

Second, construction of the South-North Water Transfer Project greatly reduces the disparity in water productivity within each sector across regions, and therefore reduces the regional difference in average water productivity. The project, however, only contributes slightly to alleviating the disparity in water productivity across sectors. This inter-regional water reallocation increases the overall productivity of water over the period 2000-2060. The combination of intra-regional water reallocation and inter-regional water reallocation dramatically reduces the disparity in water productivity both across sectors and across regions. However, the average improvement of overall water productivity following the introduction of an inter-intra water reallocation is not greater than that caused by the intra-regional water allocation alone over the period 2000-2060, but instead slightly less.

In the presence of intra-regional water transfers, aggregate GDP is about 1% larger than the base aggregate GDP over the period 2000-2030, and over the period 2031-2060 it is about 2% larger.

In the steady-state, aggregate GDP is projected to about 2.7% larger. When reallocating water both across and within regions, aggregate GDP is about 0.32% larger than base aggregate GDP during 2000-2030, and during 2031-2060 about 0.45% larger. In the steady state, it is projected to be about 0.7% larger. In terms of GDP, the inter-regional water reallocation almost has no effect on improving the aggregate GDP. Efficient water allocations also lead to an increase in household consumption and welfare. The discounted equivalent value measure associated with inter-regional water transfers is 557.23 billion in year 2000 RMB. The discounted equivalent value measure associated with the intra-regional water transfer is 1002.51 billion RMB, and with both an inter-regional and intra-regional transfer is 1148.06 billion RMB. One policy implication here is, given the Chinese government has started to construct the South-North Water Transfer Project, there is still potential for significant welfare improvements by reallocating water across sectors within each region.

We feel the spirit of these results will likely hold for most countries, i.e., that the efficient management of scarce water resources can yield dividends in terms of increased aggregate GDP and increased welfare. Since optimal water allocations evolve over time, another implication of the study is that water authorities should not lock themselves into fixed long run allocation patterns, as doing so will eventually yield diverging water shadow values across the major productive sectors, and the differential in shadow values will tend to worsen over time.

Although there are several possible extensions to this study, one of the most policy relevant applications is that of valuing the regional and aggregate economic costs and benefits to upstream (e.g., North) and downstream (e.g., South) regions and/or economies. A baseline exercise would begin with the status quo allocation and use the analytical/empirical framework outlined here to identify the value to upstream and downstream regions, and estimate the values accruing to their respective subsectors. The next exercise would view the entire water endowment as an asset that gets allocated optimally across all sectors and both regions. This gives an idea of the maximum income that can be generated for the entire river basin. Of course, these two exercises can provide a starting point for regional or even transnational negotiations on water use.

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