豊川流域における水資源の社会経済的影響の評価

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概要

　東三河は、愛知県の東部に位置し、豊川流域および渥美半島で、遠州灘に面する地域である。東三河地域における広域的課題としては、三河湾の環境保全、高規格道路網の整備、市町村合併、山間地での高齢化および過疎化の進行などがあげられるが、水需給問題は長年に及ぶ課題である。東三河地域は豊川用水の通水により産業が飛躍的に発展しており、水は東三河地域の生活・経済活動にとって重要な資源のひとつである。本研究では、愛知県東三河地域の社会経済構造を把握し、水資源が地域社会経済に与えている影響を分析する。外部環境の変化や政策の導入が地域社会経済に与える影響を評価することができる計量経済モデルを構築する。水資源に関わるシナリオを前提としてシミュレーション分析を行い、地域経済への影響を明らかにする。

Evaluating the Social and Economic Impacts of the Water Resources in the Toyogawa Basin

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1. Introduction

Water resource management is an essential feature of our lives and social and economic activities. Water availability is closely related to the spatial characteristics of the regional and urban economy. The rapid growth in the world population will lead to a serious water shortage, and the imbalance in water resources increases the opportunities for trading water between cities, regions and countries.

There has been a water shortage in East Mikawa, Japan. Many firms involved in the automobile industry are concentrated in this area and they use industrial water as an intermediate input. This area also has a large agricultural base. The productivity of agricultural businesses also depends strongly on water from the Toyogawa River. In this paper, we construct a multi-regional econometric model to investigate the relationship between the regional economy and water resources in East Mikawa.

East Mikawa faces the Pacific Ocean and is rich in natural resources. The main cities of East Mikawa are located on the Toyogawa basin and the Toyogawa River flows into Mikawa Bay. This area has a comprehensive transport network, which is formed of the Tomei Expressway, the Tokaido Shinkansen, and Mikawa Port. East Mikawa is the eastern region of Aichi prefecture and it is expected to develop as an area with economic potential in the near future. However, this area must deal with several issues including a shortage of water, an aging population, depopulation and environmental conservation.

Econometric modeling has been extensively employed for analyzing the spatial economy policy in many regions and cities throughout the world (Fukuchi 1964, Klein 1969, Bolton 1985, Fukuchi and Yamaguchi 1997). The standard structure of the simultaneous equations used for regional

econometric modeling includes demographic information, income, employment, retail sales activities, residential real estate, transportation and public utilities (Hunt and Snell 1977, Fukuchi et al. 1996). Although these regional econometric models are used in relation to a wide variety of public policy, these models cannot be extended to encompass water usage. An attempt was made to apply the approach to the water use in El Paso (Thomas M.F 2001), but their model was based on a single-region framework.

In the East Mikawa area, a wide-ranging analysis of urban and regional issues has been undertaken by the Institute of Regional Research of Chubu (1998) and the East Mikawa Development Council (1994). Esaki (1992) and Makino (1997) analyzed the economic impact of the Toyogawa waterway in East Mikawa. Sakatou et al. (1990) investigated the relationship between water demand and land use in the Toyogawa basin. Matsukura et al. (1998) explored environmental issues such as the quality of water in the Toyogawa River and Mikawa Port. Most of those previous studies simply relied on regional statistical data and a questionnaire.

However, there have been few attempts to determine the relationship between water resources and the regional economy using the econometric approach. In our multi-regional specification, we divide East Mikawa into four regions based on the spatial distribution of the waterways of the Toyogawa River. We assess the usefulness of multi-regional econometric modeling with respect to water demand and supply at the waterway level. In this paper, we analyze the impact of water demand and supply on the social and economic structure in East Mikawa using our multi-regional econometric model.

2. Outline of East Mikawa

(1) Location

East Mikawa is located in the east of Aichi Prefecture. It consists of five cities, (Toyohashi, Toyokawa, Gamagori, Tahara, and Shinshiro), two towns and one village. Socio-economic activity is concentrated in Toyohashi City. East Mikawa is 1,812km^2 in area, which accounts for 35% of Aichi prefecture. The land use is as follows: housing 117km^2 (6.5%), agriculture 252km^2(13.9%), and forest 1,190km^2 (65.7%).

(2) Population and Industry

The population of East Mikawa is 770,918 (2009), which is 10.4% of the population of Aichi prefecture. The populations of the five cities, Toyohashi, Toyokawa, Gamagori, Tahara, and Shinshiro, are approximately 375.000, 183,000, 82,000, 66,000, and 50,000, respectively. This area is home to the largest share of Aichi prefecture's primary industry. There is also an advanced agricultural area and it has a high value-added system. The main agricultural land use extends over

the Atsumi area in Toyohashi city. East Mikawa has a superior forestry zone in its northeastern mountains. The main industries are involved in the manufacture of, for example, transport, equipment, electrical machinery, and general machinery.
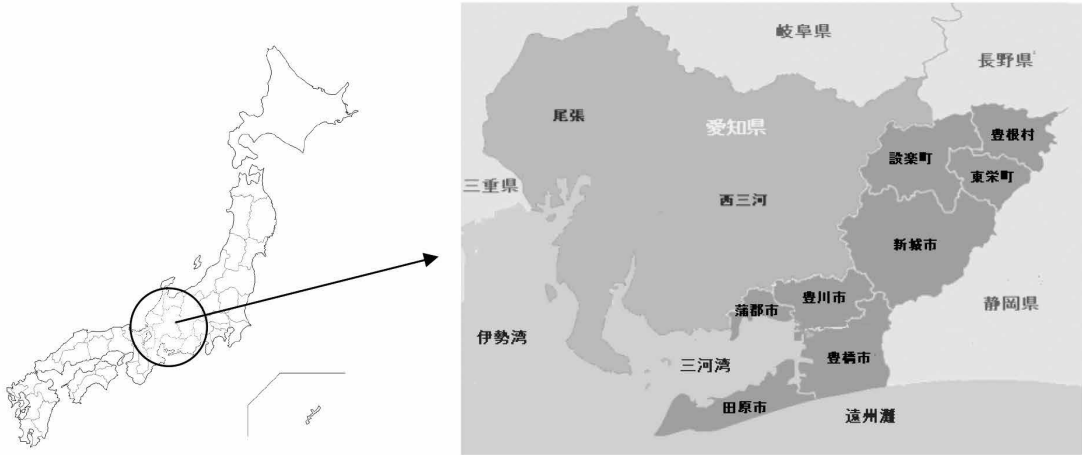

Figure 1. East Mikawa Region

(3) Transportation

Transportation in the region is by road, highway, railway and sea. The area includes two interchanges of the Tomei Expressway (Toyokawa and Gamagori). The national roadway system offers a broad range of transportation services. As regards the railway system, the Tokai Shinkansen, the Tokaido Railway, the Iida Railway, and the Toyohashi Railway all serve Toyohashi Station. Mikawa and Irago ports are part of an international seaway network.

(4) Toyogawa Basin

In this area, the demand for water has increased owing to the progress of urbanization and changes in agricultural forms, and there is a water shortage every year. There is a plan to construct a dam to meet the demand for water in this area. Several actions have been taken by local governments. An irrigation waterway called the Toyogawa Waterway was constructed to supply water to the agricultural and industrial sectors. The waterway is now rather old, and so its rebuilding has become an important issue in this area.
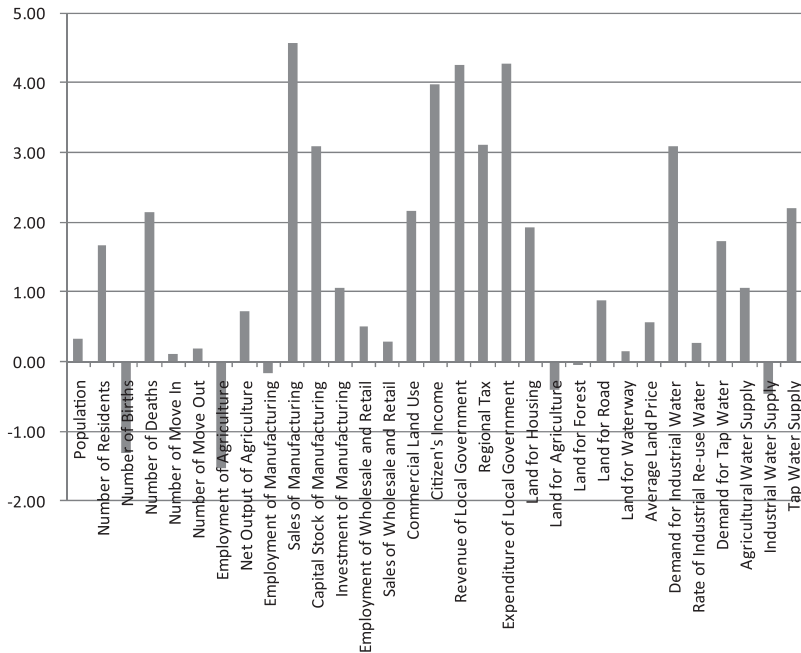
Figure 2 Average Growth Rate from 1985 to 2005 (%/year)

The Toyogawa Waterway has three functions, namely to provide water for agricultural, industrial and domestic use. It supplies water to the southeastern plains of Aichi prefecture, the Atsumi peninsula, and Kosai city in Shizuoka prefecture. The Toyogawa Waterway consists of the eastern, western, and Muro/Matsubara channels. The eastern channel runs through Toyohashi and the Atsumi peninsula. The western channel runs through Toyokawa and Gamagori and it supplies water to an area of 15,900ha. The Muro/Matsubara channel supplies industrial water to Toyohashi and Toyokawa and agricultural water to an agricultural area of about 1,700ha. The water supplied for agricultural, domestic and industrial use amounts to about 197,901, 63,855, and 15,954 thousand m3/year, respectively (2008). The percentages of agricultural, domestic, and industrial water are 70.8%, 23.3%, and 5.9%, respectively. In particular, on the Atsumi peninsula where the main industry is agriculture, the share of agricultural water exceeds 80%.

3. East Mikawa Econometric Model

(1) Division of Regions

The East Mikawa area is divided into four regions as shown in Table 1. Toyohashi city is in the center of East Mikawa and this is defined as Region 1. Toyokawa and Gamagori are grouped in Region 2 because the western and Muro/Matsubara channels pass through both cities. Tahara is

defined as Region 3 and it is located on the Atsumi peninsula where the net agricultural output is the highest in Japan. Region 4 includes Shinshiro and other municipalities. Region 4 has a superior forestry zone in the northeastern area and it is the source of the Toyogawa River and other waterways.

Table 1 Division of Regions

No.	Cities, Towns, and Villages	Toyogawa Waterway
Region 0	Whole East Mikawa	
Region 1	Toyohashi	Eastern and Muro/Matsubara Channels
Region 2	Toyokawa, Gamagoori	Western and Muro/Matsubara Channels
Region 3	Tahara	Eastern Channel
Region 4	Shinshiro, Toei, Shitara, Toyone	Eastern ,Western and Muro/Matubara Channels
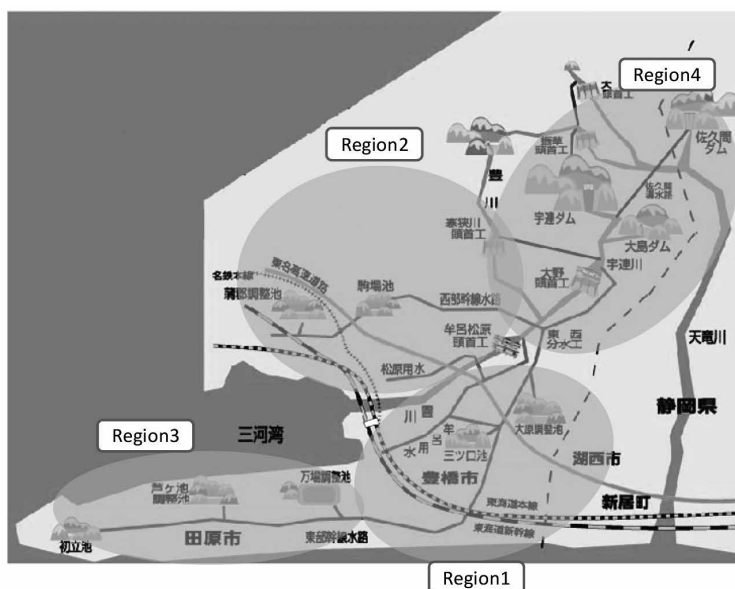
Figure 3 Division of Regions and Toyogawa waterways
Source: Aichi Prefecture Homepage

(2) Structure of Data and Model

All the variables used in this model are shown in Table 2. The variables are classified in terms of demographics, industry, urban life, and water supply and demand. The data are collected from all eight municipalities in East Mikawa and are aggregated to the data of the four regions. Furthermore, for the whole of East Mikawa, these four regional variables are aggregated to one region.

The observation period covers the twenty years from 1985 to 2004. The estimated period is nineteen years because this model has one period lag variable. The estimation employed the Ordinary Least Squares (OLS) method. The monetary variables are deflated with the GNE deflator.

To construct a simultaneous equation system, all the variables are classified as either exogenous or endogenous. In this model, FOR3, FOR4 (the number of alien registration), WMS2, WMS3 (seawater), PW1, PW2, PW3, PW4 (tap water rate), RAIN1, RAIN2, RAIN3, RAIN4 (precipitation), SWA, SWM, SWG (water saving rate), YYT (gross output of the manufacturing sector in Aichi), and T (time trend) are given exogenously. The other variables are determined endogenously through a simultaneous system. There are 122 endogenous variables and 23 exogenous variables excluding the dummy variables. 114 equations are estimated by the OLS and 8 equations are defined. Our multi-regional econometric model is constructed using these 114+8 simultaneous equations.

Table 2. List of Variables

	Series	Definition
Demographics	NB*	Number of births (person)
	ND*	Number of deaths (person)
	NR*	Number of residents (person)
	NI*	Number of those who move in (person)
	NO*	Number of those who move out (person)
	NE*	Number of discrepancy (person)
	FOR*	Number of alien registration (person)
Industry	EA*	Employment of the agricultural sector (person)
	SA*	Net Output of the agricultural sector (million yen)
	EM*	Employment of the manufacturing sector (million yen)
	CSM*	Wage payment of the manufacturing sector (million yen)
	SM*	Sales of the manufacturing sector (million yen)
	KM*	Capital stock of the manufacturing sector (million yen)
	INM*	Investment of the manufacturing sector (million yen)
	ES*	Employment of wholesale and retail (person)
	SS*	Sales of wholesale and retail (million yen)
	AS*	Commercial land use (m^2)
Urban life	Y*	Citizen's income (million yen)
	RE*	Total revenue of the local government (million yen)
	TX*	Total regional tax (million yen)
	GE*	Total expenditure of the local government (million yen)
	LHA*	Housing land use (hectare)
	LHB*	Other housing land use (hectare)
	LA*	Agricultural land use (hectare)
	PL*	Average land price (thousand yen /m^2)

Water Demand	WMH*	Industrial water (thousand m^3)
	WMI*	Other industrial water (thousand m^3)
	WMR*	Re-used water (thousands m^3)
	WMT*	Total water demand of the manufacturing sector (thousand m^3)
	WMS*	Sea water (thousand m^3)
	WGT*	Household water use (thousand m^3)
	PW*	Tap water rate (per ten m^{3}3)
Water Supply	RAIN*	Annual precipitation (mm/year)
Eastern waterway	WWAE	Agricultural water supply (thousand m^3)
	WWME	Industrial water supply (thousand m^3)
	WWGE	Tap water supply (thousand m^3)
Western waterway	WWAW	Agricultural water supply (thousand m^3)
	WWMW	Industrial water supply (thousand m^3)
	WWGW	Tap water supply (thousand m^3)
Muro/Matsubara waterway		
	WWAM	Agricultural water supply (thousand m^3)
	WWMM	Industrial water supply (thousand m^3)
	WWGM	Tap water supply (thousand m^3)
	WWA	Total agricultural water supply (WWA=WWAE+WWAW+WWAM)
	WWM	Total industrial water supply (WWM=WWME+WWMW+WWMM)
	WWG	Total tap water supply (WWG=WWGE+WWGW+WWGM)
	Water	Saving Rate
	SWA	Agricultural Water Saving Rate (%)
	SWM	Industrial Water Saving Rate (%)
	SWG	Tap Water Saving Rate (%)
Aichi Prefecture	YYT	Gross Output of the manufacturing sector in Aichi (million yen)
	PET	GNE Deflator
	T	Time Trend

Note: In this table * indicates the region number. For example, NR1 represents the population of Region 1 (Toyohashi city).

(3) Estimated Equations

114 estimated equations were obtained with OLS. In our discussion we focus particularly on the estimated results for Region 1 since Toyohashi is a central city in East Mikawa. We also examine the water supply and demand functions. We explain 15 equations to assess the relationship between water resources and the regional economy.

The notations of the equations are as follows. The number in < > indicates the *t*-value. A variable with (-1) denotes its value in the previous year. D** indicates a dummy variable in ** year. "const" is a constant term. RR is the coefficient of multiple determinations. RRB is the adjusted RR. SD is the standard error of the estimate. DF is the degree of freedom. DW is the Durbin-Watson d-static.

MAPE is the mean of absolute percentage error (for a partial test).

1) Production

The agricultural labor productivity in Region 1 is shown as Equation (1). The land productivity (LA1/EA1) and the water supply (WWAE, WWAM) are statistically significant. This equation suggests that the water supply is an important factor regarding the productivity of the agricultural sector in Toyohashi.

$$
\begin{aligned}
L(SA1/EA1) \ &= -2.1523846* \ \text{const.} \quad +1.0574303*L(LA1/EA1) \quad +.34781553*L(WWAE+WWAM) \\
&\quad < \ -1.010> \qquad\qquad < \ \ 6.848> \qquad\qquad < \ \ \ 1.997> \\
&\quad +.10213283* \ (D91 \quad) \quad +.10698097* \ (D00 \quad) \\
&\quad < \ \ \ 2.370> \qquad\qquad < \ \ \ 2.619> \\
&\text{RR}=0.8819 \quad \text{RRB}=0.8482 \quad \text{SD}= 3.730D\text{-}02 \quad \text{DW}=2.010 \quad \text{DF}= 14 \quad \text{MAPE}= \ 1.80
\end{aligned}
\tag{1}
$$

Equation (2) shows the sales of the manufacturing sector in Region 1, which is specified as a production function with labor (LM1) and capital (KM1). The water input (WMT1) is statistically significant.

$$
\begin{aligned}
L(SM1 \quad) \ &= -8.7159492* \ \text{const.} \qquad +.48121719*L(EM1 \quad) \quad +.23196345*L(KM1 \quad)_{\text{-}1} \\
&\quad < \ -1.570> \qquad\qquad\quad < \ \ 1.654> \qquad\qquad < \ \ \ 2.382> \\
&\quad +1.1043418*L(WMT1 \quad) \\
&\quad < \ \ \ 3.604> \\
&\text{RR}=0.8320 \quad \text{RRB}=0.7984 \quad \text{SD}= 5.886D\text{-}02 \quad \text{DW}=1.251 \quad \text{DF}= 15 \quad \text{MAPE}= \ 0.31
\end{aligned}
\tag{2}
$$

The capital productivity of the services sector in Region 1 is given by Equation (3). The wholesale and retail sales in neighboring regions (SS2, SS3, SS4), the per capita income in East Mikawa (Y0/NR0), the total sales of manufacturing sector (SM0), and the time trend are all statistically significant. Toyohashi is a central city of the East Mikawa region. The economic and commercial activities are concentrated in this city. This equation shows that the productivity of the services sector is influenced by an agglomeration factor in East Mikawa.

$$
\begin{aligned}
L(SS1/AS1) \ &= \ 33.134666* \ \text{const.} \ +3.2102214*L(ES1/AS1) \ -.70174487*L(SS2+SS3+SS4) \\
&\quad < \ \ \ 1.391> \qquad\qquad < \ \ \ 2.618> \qquad\qquad < \ -1.242> \\
&\quad +.81798662*L(SM0 \quad) \ +1.0586862*L(Y0/NR0) \quad -1.371D\text{-}02* \ (T \qquad) \\
&\quad < \ \ \ 2.868> \qquad\qquad < \ \ \ 2.607> \qquad\qquad < \ -1.058> \\
&\quad -.17175507* \ (D92 \quad) \quad -8.660D\text{-}02* \ (D93 \quad) \\
&\quad < \ -2.388> \qquad\qquad < \ \ -1.411> \\
&\text{where } Y0=Y1+Y2+Y3+Y4, \ \ NR0= NR1+NR2+NR3+NR4, \ \ SM0=SM1+SM2+SM3+SM4 \\
&\text{RR}=0.9061 \quad \text{RRB}=0.8463 \quad \text{SD}= 5.597D\text{-}02 \quad \text{DW}=1.633 \quad \text{DF}= 11 \quad \text{MAPE}= \ 2.44
\end{aligned}
\tag{3}
$$

2) Urban life

The household income in Region 1 is specified as Equation (4), and consists of wage income and

capital income. The aggregated output and sales (SA1+SM1+SS1) from the agriculture, industry, and service sectors is interpreted as the wage income. The capital income is explained using the value of housing capital (PL1*LHA1).

$$
\begin{aligned}
(Y1\quad) &= -905920.87 * const. \;+.33417525 *\quad(Y1\quad)_{-1} +3.2182245 * (NR1\quad) \\
&\quad <\;-5.102> \qquad\qquad <\;3.529> \qquad\qquad\quad <\;5.101> \\
&\quad +1.758D\text{-}02 * (SA1+SM1+SS1) +.27307809 * (PL1*LHA1) +26080.079 * (D92\quad) \\
&\quad <\;1.269> \qquad\qquad\qquad <\;3.622> \qquad\qquad <\;3.815> \\
&\quad -9853.2853 * (D03\quad) \\
&\quad <\;-1.418>
\end{aligned}
$$
(4)

RR=0.9962 RRB=0.9943 SD= 6039.3363 DW=1.843 DF= 12 MAPE= 0.72

3) Water Demand

The industrial water demand in Region 1 is shown as Equation (5). In this specification, the industrial water supply (WWME), the re-used water in Region 1 (WMR1), and the industrial water saving rate (1-SWM) are statically significant.

$$
\begin{aligned}
L(WMH1\quad) &= -70.556660 * const. \qquad +.25642067 * L(WWME\quad) \quad -.59161653 * L(WMR1\quad) \\
&\quad <\;-6.343> \qquad\qquad\qquad <\;1.967> \qquad\qquad\quad <\;-1.569> \\
&\quad +6.689D\text{-}02 * L(1\text{-}SWM\,) \quad +4.258D\text{-}02 * (T\qquad) \quad +.12231676 * (D91\text{-}95) \\
&\quad <\;1.344> \qquad\qquad\qquad <\;5.767> \qquad\qquad\quad <\;2.858>
\end{aligned}
$$
(5)

RR=0.9372 RRB=0.9131 SD= 4.989D-02 DW=1.462 DF= 13 MAPE= 0.35

Equation (6) shows the demand for industrial water that is reused in Region 1. We assume that it depends on the sales of the manufacturing sector (SM1), the industrial water saving rate (1-SWM), and the time trend (T). The time trend may reflect the technological progress that has been made in water recycling.

$$
\begin{aligned}
L(WMR1\quad) &= -13.935269 * const. \qquad +.28108112 * L(SM1\quad) \quad -4.098D\text{-}02 * L(1\text{-}SWM\,) \\
&\quad <\;-3.606> \qquad\qquad\qquad <\;2.690> \qquad\qquad\quad <\;-1.146> \\
&\quad +1.167D\text{-}02 * (T\qquad) \quad +4.981D\text{-}02 * (D93\quad) \quad -7.059D\text{-}02 * (D96\quad) \\
&\quad <\;4.833> \qquad\qquad\qquad <\;1.238> \qquad\qquad\quad <\;-1.712>
\end{aligned}
$$
(6)

RR=0.8952 RRB=0.8549 SD= .03787944 DW=1.264 DF= 13 MAPE= 0.20

The demand for domestic tap water is specified as Equation (7). Following a standard method, we estimated the total water demand using the population (NR1+FOR1) and the tap water rate (PW1) in Region 1. In Equation (7), the tap water supply (WWGE+WWGM) is also statistically significant. This term is interpreted as the tap water supply capacity.

$$
\begin{aligned}
L(WGT1\quad) &= \; 1.3077787 * const. \quad +.45626714 * L(WWGE+WWGM) \quad +.48041084 * L(NR1+FOR1) \\
&\quad <\;0.497> \qquad\qquad <\;3.716> \qquad\qquad\qquad\quad <\;1.347> \\
&\quad -.24907168 * L(PW1\quad) \\
&\quad <\;-1.519>
\end{aligned}
$$
(7)

RR=0.9663 RRB=0.9596 SD= 1.598D-02 DW=0.793 DF= 15 MAPE= 0.12

4) Water Supply

(a) Agriculture

Agriculture water supply functions are shown as Equations (8)-(10). A key explanation variable is the agricultural land use productivity. The productivity is defined by the waterway supply area. For example, with the eastern waterway, the agricultural land use productivity is defined as (SA1+SA3+SA4)/(LA1+LA3+LA4). This means that the area supplied by the eastern waterway includes three regions, namely Regions 1, 3, and 4. This term reflects the area supplied by the waterway. The agricultural water saving rate is also statistically significant for each waterway. The water supply in the previous year is also an explanation variable in those specifications. The term is interpreted as the supply capacity. In the specifications of the western and Muro/Matsubara waterways, the annual precipitation in the region is statistically significant as shown by Equations (9) and (10).

$$
\begin{aligned}
L(WWAE\ ) \ = \ & 4.5262087^* \text{const.} \quad +.55703405^*L(WWAE\ )_{-1} +9.146D\text{-}02^*L(1\text{-}SWA\ ) \\
& <\ \ 3.298> \qquad\qquad <\ \ 4.682> \qquad\qquad <\ \ 3.639> \\
& +.09731786^*L((SA1+SA3+SA4)/(LA1+LA3+LA4)) \quad -.11076462^* (D93\quad) \\
& <\ \ 1.356> \qquad\qquad\qquad\qquad\qquad\qquad\qquad <\ \ -3.857> \\
& -.12580557^* (D96\quad) \\
& <\ \ -4.284> \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (8)
\end{aligned}
$$

RR=0.8675 RRB=0.8165 SD= 2.672D-02 DW=1.953 DF= 13 MAPE= 0.15

$$
\begin{aligned}
L(WWAW\ ) \ = \ & \text{-}4.7421173^* \text{const.} \quad +.38243705^*L(WWAW\ )_{-1} +.24486450^*L(1\text{-}SWA\ ) \\
& <\ \ -0.468> \qquad\qquad\ <\ \ 1.901> \qquad\qquad\ <\ \ 2.859> \\
& +1.1648714^*L(LA2+LA4) \quad +.88520011^*L((SA2+SA4)/(EA2+EA4)) \\
& <\ \ 1.006> \qquad\qquad\quad <\ \ 2.124> \\
& -.19386229^*L(RAIN2\ ) \quad -.21632442^* (D96\quad) \quad -8.151D\text{-}02^* (D01\quad) \\
& <\ \ -1.588> \qquad\qquad <\ \ -2.532> \qquad\qquad <\ \ -1.032> \qquad (9)
\end{aligned}
$$

RR=0.8887 RRB=0.8178 SD= 6.232D-02 DW=2.190 DF= 11 MAPE= 0.39

$$
\begin{aligned}
L(WWAM\ ) \ = \ & 33.775260^* \text{const.} \quad +.36206375^*L(WWAM\ )_{-1} +.17437163^*L(1\text{-}SWA\ ) \\
& <\ \ 3.690> \qquad\qquad\ <\ \ 2.688> \qquad\qquad\qquad <\ \ 1.892> \\
& +1.0512758^*L((SA1+SA2)/(LA1+LA2)) \quad -.17437216^*L((RAIN1+RAIN2)/2) \\
& <\ \ 4.110> \qquad\qquad\qquad\qquad\qquad\qquad <\ \ -1.326> \\
& -1.438D\text{-}02^* (T\qquad)-.37621136^* (D88\quad) \quad +.10893937^* (D02\quad) \\
& <\ \ -3.004> \qquad\qquad <\ \ -4.598> \qquad\qquad <\ \ 1.612> \qquad (10)
\end{aligned}
$$

RR=0.9140 RRB=0.8593 SD= 5.637D-02 DW=2.454 DF= 11 MAPE= 0.29

(b) Industry

The eastern and western industrial water supply functions are specified as Equations (11) and (12). The key explanation variable is the industrial water demand. We can understand that the eastern waterway provides industrial water to firms and factories in Regions 1 and 3. In each equation, the industrial water saving ratio is statistically significant. The explanation variable of the water supply in the previous year is interpreted as the supply capacity.

L(WWME) = 44.027741* const. +.33164087*L(WWME)$_{-1}$ +8.478D-02*L(1-SWM)
        < 3.773>   < 1.636>   < 1.488>
        +.76228167*L(WMH1+WMH3) -2.297D-02* (T   ) +9.646D-02* (D96   )
        < 2.512>   < -3.621>   < 1.513>
        -.15234375* (D99   )
        < -2.304>   (11)

RR=0.9050   RRB=0.8576   SD= 5.887D-02   DW=1.784   DF= 12   MAPE= 0.36

L(WWMW) = 3.1465796* const. +.47216841*L(WWMW)$_{-1}$ +4.911D-02*L(1-SWM)
        < 2.180>   < 3.216>   < 1.283>
        +.10347447*L(WMH2   ) -5.835D-02* (D98   ) +.26734021* (D99   )
        < 1.101>   < -1.453>   < 6.428>
        +5.928D-02* (D00   )
        < 1.112>   (12)

RR=0.8685   RRB=0.8028   SD= 3.752D-02   DW=1.812   DF= 12   MAPE= 0.25

(c) Tap water supply

The tap water supply functions are specified as Equations (13)-(15). The key explanation variable is domestic water use. In each equation, the tap water saving ratio is statistically significant. The explanation variable of the watery supply in the previous year is interpreted as the supply capacity. In the Muro/Matsubara waterway, the precipitation is statistically significant.

L(WWGE) = -4.5232756* const. +.60135912*L(WWGE)$_{-1}$ +.18190628*L(1-SWG)
        < -1.766>   < 3.673>   < 1.772>
        +.69391307*L(WGT1+WGT3+WGT4)
        < 1.972>   (13)

RR=0.9101   RRB=0.8921   SD= 5.608D-02   DW=2.258   DF= 15   MAPE= 0.38

L(WWGW) = .17919873* const. +.36245247*L(WWGW)$_{-1}$ +.20385868*L(1-SWG)
        < 0.126>   < 1.838>   < 2.638>
        +.50826749*L(WGT2   )
        < 2.310>   (14)

RR=0.7685   RRB=0.7222   SD= .04196324   DW=1.838   DF= 15   MAPE= 0.32

L(WWGM) = 10.784398* const. +.53932467*L(WWGM)$_{-1}$ +.10231611*L(1-SWG)
        < 2.137>   < 2.242>   < 1.043>
        +1.2042658*L(WGT1+WGT2+WGT4) -9.878D-02*L((RAIN1+RAIN2+RAIN4)/3)
        < 2.192>   < -1.108>
        -9.658D-03* (T   ) -7.052D-02* (D93   ) -8.463D-02* (D97   )
        < -2.354>   < -1.762>   < -2.035>   (15)

RR=0.9514   RRB=0.9204   SD= 3.270D-02   DW=1.761   DF= 11   MAPE= 0.21

For all the estimated equations, the RRB value exceeds 0.7. The absolute value of the *t*-value is greater than 1 and statistically significant. The estimated signs of the variables are as we expected. Figure 4 shows the causal relationship in Region 1 (Toyohashi).
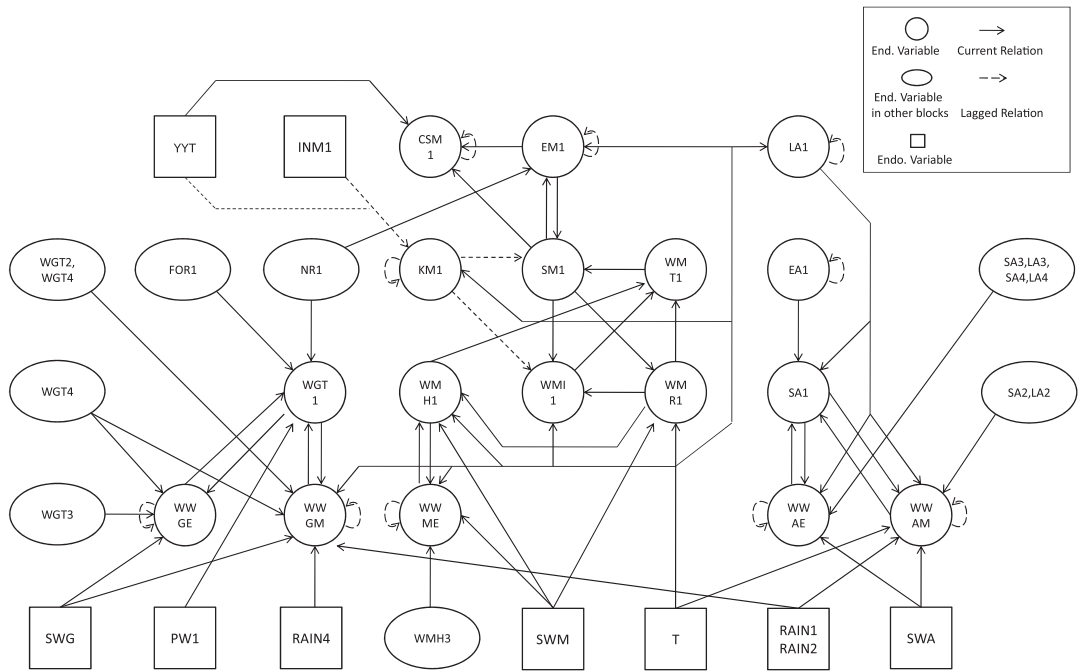
Figure 4 Causal Relationship in Region 1

4. Final Test and Intra-Simulation

(1) Result of Final Test

To confirm the validity of the entire econometric model, a final test was conducted over the estimated periods from 1986 to 2004. Table 3 shows the results of the final test. The table shows that the coefficients of the correlations of all the endogenous variables are less than 0.7 and the mean absolute percentage errors (MAPE) are less than 10%.

Table 3. Results of Final Test

R ＼ MAPE	1%以下	1〜3%	3〜5%	5〜10%	over 10%	total
0.95〜1.00	16	30	17	2	0	65
0.9〜0.95	0	15	11	4	0	30
0.8〜0.9	0	8	7	4	0	19
0.7〜0.8	0	4	3	1	0	8
less 0.7	0	0	0	0	0	0
total	16	57	38	11	0	122

(2) Intra-Simulation

In this study, we tried to assess the impacts of changes in social and economic conditions. In this simulation, the base values are given by the results of the final test. Table 4 shows simulations. These conditional simulation tests were conducted during the estimated periods.

Table 4. Simulations

	Scenario	Change of variables
Case 1	Population is more concentrated in Region 1.	The population value in the initial period in Region 1 increases by 5% (initial value test).
Case 2	The economy of Aichi prefecture shifts to a high level.	The GRP of Aichi prefecture increases by 5% over all periods.
Case 3	The economy of Aichi prefecture shifts to a low level.	The GRP of Aichi prefecture decreases by 5% over all periods.
Case 4	A long-term water shortage occurs.	The saving rates of agricultural, industrial and tap water increase by 5% over all periods.
Case 5	The water shortage problem is improved for a certain period.	The saving rates of agricultural, industrial and tap water are set at 0 % from 1996 to 2002 (shock test).
Case 6	The technology for water recycling is improved.	The re-used industrial sector water increases by 5% over all periods.

Table 6 is a summary of the simulation results. The third column in Table 5 represents the simulated values in the final year, which were obtained from the final test, and they reflect the base values The 4th-9th columns represent a change at the final year in each case.

We can observe that, in Cases 1, 2, and 3, the population of Toyohashi city and the GRP of Aichi prefecture have a significant economic impact on Region 1 and the entire East Mikawa region. This shows that Toyohashi is a central city and that Mikawa is an economic center . The output of the manufacturing sector of Aichi prefecture is the highest in Japan. The economy of the East Mikawa area is affected by that of Aichi prefecture.

In Cases 4 and 5, the production activities in East Mikawa are affected by the water supply conditions. If the water shortage becomes more serious in East Mikawa as shown in Case 4, the industrial sector will try to increase the use of recycled water. We can see that changes in the water saving rates have a significant effect on the supply and demand for tap water. If the water shortage is improved as shown in Case 5, the demand for tap water and industrial water increases. In Case 6, the sales of the manufacturing sector increase because of the improved recycling of industrial water.

Table 5 Summary of Simulation Results

Variable	Region	Base Case (Value at Final Test)	Change (%)					
			case1	case2	case3	case4	case5	case6
Population	Whole	750,920	1.76	0.25	−0.25	−0.01	0.00	−0.16
	Region 1	359,884	5.23	0.02	−0.02	−0.02	−0.01	−0.39
Employment (All Sectors)	Whole	191,165	2.12	2.19	−2.24	−0.02	0.03	0.03
	Region 1	77,256	6.15	0.55	−0.55	−0.02	−0.15	0.03
Output (All Sectors)	Whole	6,737,789	−0.88	3.80	−3.87	−0.06	0.21	1.90
	Region 1	2,330,402	−1.37	1.98	−2.21	−0.08	0.27	0.64
Income	Whole	1,145,815	7.23	7.01	−7.04	−0.06	−0.02	−0.73
	Region 1	565,686	17.53	1.10	−1.10	−0.06	−0.29	−1.04
Industrial Water Use	Whole	1,962,585	0.86	0.39	−0.25	−0.04	0.27	6.68
	Region 1	578,154	3.14	1.08	−1.17	0.14	0.16	6.30
Rate of Industrial Water Re−Use	Whole	0.93296	0.11	−0.08	0.07	0.11	−0.23	0.53
	Region 1	0.89632	0.30	0.16	−0.18	0.10	−0.13	0.82
Tap Water Use	Whole	84,532	3.31	4.33	−4.20	−3.51	5.81	−0.59
	Region 1	40,634	7.19	4.53	−4.38	−4.71	7.89	−0.94
Agricultural Water Supply	−	200,828	0.00	1.38	−1.45	−1.70	3.02	0.01
Industrial Water Supply	−	15,664	−5.24	2.03	−1.70	−7.11	16.52	−5.11
Tap Water Supply	−	70,667	10.88	8.18	−7.54	−8.61	15.17	−1.28

Note: The values of the cells in each case represent the percentage change from the base value.

5. Concluding Remarks

In this paper, we constructed a multi-regional economic model of East Mikawa. We then examined the relationship between the regional social and economic activities and the water resources using the econometric model. We also observed that Toyohashi has an important role regarding the economic activity in this area. We showed that the Toyogawa waterway contributes strongly to the regional economic growth in this area, especially that of the agricultural sector. Our study suggests that the infrastructure of the water resources in this area must be properly managed if we are to maintain regional sustainability.

There are several topics that have yet to be considered. First, we should perform a forecast simulation analysis. Second, we should include the water market structure in our model based on more detailed water data. Finally, we should incorporate a variable representing the distance between regions into our model.

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