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A Multi-Country Multi-Sectoral Analysis on the Virtual Water Balance within the Asia-Pacific Region

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A Multi-Country Multi-Sectoral Analysis on the Virtual Water Balance within the Asia-Pacific Region*

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Abstract

This paper aims at analyzing the virtual water balance within the Asia-Pacific region. For this purpose, we construct a multi-country multi-sectoral model which is based on international input-output tables in constant prices and local currencies. The results on the virtual water balance within the region show that Indonesia, the Philippines, Thailand, China, and the United States are exporters whilst Malaysia, Singapore, Taiwan, South Korea, and Japan are importers. Employing the model, we also quantify the effects of population aging in China on the virtual water balance within the region. The virtual water balance decreases in China whereas it increases in most sectors of the other economies. One of the exceptions is the agricultural sector in the United States. In this sector, water use embedded in exports greatly decreases due to the deterioration of the U.S. price competitiveness. Water embedded in domestic demand also decreases because of the fall in China's demand. Since population is definitely aging in the Asia-Pacific region other than the United States and aging itself is negatively correlated to the agricultural consumption, the results imply that population aging has potential to substantially change the level and composition of the U.S. virtual water balance.

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1. Introduction

Water is an important element in our lives. Moreover, water is widely used in industries: e.g., water is inevitable in order to grow agricultural products and to cool down or wash manufacturing goods in the process of production. Without water, people and the current economic system would not survive. However, water is a limited resource. Since water supply largely depends on climate which is an uncontrollable factor to us, analysis or management on water use becomes crucial.

The amount of water use has a positive relation to our economic activities. Since water use is often categorized into agricultural, industrial, and domestic uses, a multi-sector economic model is more suitable to analyze issues on water use. Duarte et al. (2002) and Kondo (2005) employ a national input-output model of Spain and Japan, respectively. Velázquez (2006) and Okadera et al. (2006) respectively analyze water use by applying a regional input-output model of Andalusia, Spain and Chongqing, China. By contrast, Guan and Hubacek (2007) construct an inter-regional input-output model and analyze the virtual water trade within China. Since water is one of the production factors, water is embodied in products. In order to analyze the water use of a nation, we must subtract water embedded in exports from the total water use of an economy and add water embedded in imports to the total water use: i.e., an application of the virtual water trade.[1] This approach inevitably requires international trade to be included in an economic model. In this sense, a multi-country multi-sectoral model is the most appropriate tool for analysis of the virtual water use. In fact, Berrittella et al. (2005, 2007a, 2007b) examine the virtual water trade along this line. Specifically, they employ a variant of the Global Trade Analysis Project (GTAP) model which consists of sixteen regions and seventeen industrial sectors.[2]

In addition to economic activities, population is also an effective factor for water use (see, e.g., Bouwer 2000 and Hoekstra 2003). Vörösmarty et al. (2000) and Fujino et al. (2002) contain population in their models to analyze environmental issues including water problems.[3] Although population increase is an important demographic issue, population aging is also substantial in both developed and developing economies (particularly in Asia). Preferences of the people are expected to vary as they age. Therefore, population aging generates changes in consumption pattern and industrial structure.[4] Since embedded water differs product by product, these factors inevitably affect water use. Despite its potential effects on water use, population aging has rarely been focused on in previous studies regarding water use. Hence, we analyze the effects of population aging on water use by constructing a multi-country multi-sectoral model for the Asia-Pacific region. It is worth noting that the model is built on international input-output tables; however, the tables are in constant prices and in local currencies. Economic agents determine their behavior by observing economic performance in their local currencies. Hence, it is not

[1] The virtual water trade is intensively analyzed by Hoekstra (2003).
[2] Details on the GTAP model are provided in Hertel (1997).
[3] Fujino et al. (2002) employ the AIM/Trend model. Its structure is also presented in AIM Project Team (2002).
[4] Although population aging is not dealt with, Hoekstra and Chapagain (2007) reveal the effects of consumption pattern on water footprints.

appropriate to construct a multi-country multi-sectoral model by using data denominated in a specific currency. Since data of interest are not provided publicly, it is imperative to construct data in order to build the model. In addition to the model structure, construction of necessary data is also briefly explained in this paper.

The rest of the paper consists of five sections. In section 2, we explain the construction of international input-output tables in constant prices and local currencies. Section 3 presents the theoretical structure of the model. Section 4 deals with the empirical properties of the model. Selected estimation and final test results are shown. Section 5 illustrates simulation analysis. Finally, section 6 provides conclusions.

2. International Input-Output Tables in Constant Prices and Local Currencies

International input-output tables are normally evaluated in current prices and denominated in a specific currency. Thus, we need to deflate international input-output tables and convert the specific currency unit to local currencies. By following a method shown in Yano and Kosaka (2008), we construct data of interest. The deflation procedure is based on the double-deflation method. Typically, it is difficult to obtain sectoral prices. Therefore, viewing the sectoral GDP deflator taken from national accounts data as the corresponding sector's value-added deflator in an international input-output framework, we obtain sectoral price by backtracking the double-deflation method. Subsequently, applying the sectoral price, we deflate the international input-output tables by the double-deflation method. Since the double-deflation method is used, intermediate transactions, final demand components, exports to the rest of the world, statistical discrepancy, and sectoral output are converted in the currency of the source country. In contrast, value added components are denominated in the currency of the country which employs the components. A layout of international input-output tables in constant prices and local currencies is illustrated in Tables 1A and 1B.

In international input-output tables, income of employees is provided as wages whereas that of farmers and owners of private enterprises is included in operating surplus. For each country, we compute household income by using estimated coefficients of a consumption function whose explanatory variables are real wages and real operating surplus.

Further details on data construction are provided in Yano and Kosaka (2008).

3. The Model Structure

The model is built on the international input-output tables which are explained in Section 2. It consists of the three blocks as sectoral output, sectoral price, and sectoral water use blocks. Sectoral output and its components are explained in the sectoral output block whereas sectoral price and cost factors are determined in the sectoral price block. These blocks are built on international input-output tables. Meanwhile, the sectoral water use block accounts for water use at the sector level by employing the sectoral water use coefficient. In the explanation of the model structure, we consider that international input-output tables contain r countries and n sectors for each country.

3.1. Sectoral Output Block

Following the identity with respect to demand in the international input-output tables, sectoral output in the ith sector of the hth country (in constant prices and in the currency of the hth country), $XXR_i^h(t)$, is determined by the following equation:

$$
\begin{aligned}
XXR_i^h(t) = &\sum_{j=1}^{n}\sum_{k=1}^{r} XHR_{ij}^{hk}(t) + \sum_{k=1}^{r} CPHR_i^{hk}(t) + \sum_{k=1}^{r} CGHR_i^{hk}(t) \\
&+ \sum_{k=1}^{r} IHR_i^{hk}(t) + \sum_{k=1}^{r} IVHR_i^{hk}(t) + EHR_i^h(t) + QHR_i^h(t) \\
&i = 1, 2, \ldots, n;\ h = 1, 2, \ldots, r
\end{aligned}
\tag{1}
$$

where $XHR_{ij}^{hk}(t)$ is intermediate goods delivered from the ith sector of the hth country to the jth sector of the kth country (in constant prices and in the currency of the hth country), $CPHR_i^{hk}(t)$ is private consumption of the kth country delivered from the ith sector of the hth country (in constant prices and in the currency of the hth country), $CGHR_i^{hk}(t)$ is government consumption of the kth country delivered from the ith sector of the hth country (in constant prices and in the currency of the hth country), $IHR_i^{hk}(t)$ is investment of the kth country delivered from the ith sector of the hth country (in constant prices and in the currency of the hth country), $IVHR_i^{hk}(t)$ is inventories of the kth country delivered from the ith sector of the hth country (in constant prices and in the currency of the hth country), $EHR_i^h(t)$ is exports to the rest of the world (ROW) in the ith sector of the hth country (in constant prices and in the currency of the hth country), $QHR_i^h(t)$ is statistical discrepancy in the ith sector of the hth country (in constant prices and in the currency of the hth country), and t denotes time.

Intermediate demand for the ith goods in the jth sector of the kth country (in constant prices and in the currency of the hth country) is determined by using input coefficient, $a(X)_{ij}^{k}(t)$, as:

$$\sum_{h=1}^{r} XHR_{ij}^{hk}(t)\left[\frac{e^k(t^*)}{e^h(t^*)}\right] = a(X)_{ij}^k(t) XXR_j^k(t) \qquad i,j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r \tag{2}$$

where $a(X)_{ij}^k(t) = \dfrac{\sum_{h=1}^{r} XHR_{ij}^{hk}(t)\left[\frac{e^k(t^*)}{e^h(t^*)}\right]}{XXR_j^k(t)}$, $e^k(t)$ is the exchange rate of the kth country, and t^* is the base year. Note that the source countries are not distinguished in intermediate demand explained by equation (2). The allocation of intermediate demand for the ith goods in the jth sector of the kth country into the source economies is determined by the Armington's (1969) approach as:

$$\frac{XHR_{ij}^{hk}(t)\left[\frac{e^k(t^*)}{e^h(t^*)}\right]}{\sum_{q=1}^{r} XHR_{ij}^{qk}(t)\left[\frac{e^k(t^*)}{e^q(t^*)}\right]} = \kappa(X)_{ij}^{hk}\left[\frac{\{1+t_i^{hk}(t)\}P_i^h(t)\left\{\frac{e^k(t)/e^h(t)}{e^k(t^*)/e^h(t^*)}\right\}}{PXK_{ij}^k(t)}\right]^{\eta(X)_{ij}^k} \tag{3}$$

$$i,j = 1, 2, \ldots, n;\ h, k = 1, 2, \ldots, r$$

where $t_i^{hk}(t)$ is the tariff rate in the kth country levied on the ith goods of the hth country (computed by using the required variables in the currency of the kth country), $P_i^h(t)$ is price in the ith sector of the hth country (in the currency of the hth country), and $PXK_{ij}^k(t)$ is the average price of the ith goods in the jth sector of the kth country which is expressed as:

$$PXK_{ij}^k(t) = \sum_{h=1}^{r}\left[\{1+t_i^{hk}(t)\}P_i^h(t)\frac{\left\{\frac{e^k(t)}{e^h(t)}\right\}}{\left\{\frac{e^k(t^*)}{e^h(t^*)}\right\}}\right]\left[\frac{XHR_{ij}^{hk}(t)\left\{\frac{e^k(t^*)}{e^h(t^*)}\right\}}{\sum_{q=1}^{r} XHR_{ij}^{qk}\left\{\frac{e^k(t^*)}{e^q(t^*)}\right\}}\right] \tag{4}$$

$$i,j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r$$

Final demand is further divided into the following components: private consumption, government consumption, investment, and inventories. Among these four components, private consumption and investment are explained endogenously. The rest of final demand components, exports to the rest of the world, and statistical discrepancy are exogenous in this model.

In order to include the effects of demographic change, we explain the total private consumption and income at the per person level. The per capita private consumption of the kth country is a function of the per capita income of the corresponding country as:

$$CPKR1^k(t) = CPKR1^k \left[\frac{YIK1^k(t)}{PCPK^k(t)} \right] \qquad k = 1, 2, \ldots, r \tag{5}$$

where $CPKR1^k(t)$ is the per capita private consumption of the kth country (in constant prices and in the currency of the kth country), $YIK1^k(t)$ is the per capita income of the kth country (in current prices and in the currency of the kth country), and $PCPK^k(t)$ is the deflator for the total private consumption of the kth country (in the currency of the kth country). Multiplying the per capita consumption of the kth country by the total population of the kth country, we obtain the total consumption of the kth country (in constant prices and in the currency of the kth country) as:

$$\sum_{i=1}^{n} \sum_{h=1}^{r} CPHR_i^{hk}(t) \left[\frac{e^k(t^*)}{e^h(t^*)} \right] = CPKR1^k(t) \times POP^k(t) \qquad k = 1, 2, \ldots, r \tag{6}$$

where $POP^k(t)$ is the total population of the kth country. The ith sector's share in the total private consumption of the kth country, $SCP_i^k(t)$, is explained by the ratio of people aged over 65 of the kth country to the total population (hereafter the ratio of aged people) of the corresponding country as:

$$SCP_i^k(t) = SCP_i^k \left[\frac{POP65^k(t)}{POP^k(t)} \right] \qquad i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r \tag{7}$$

where $SCP_i^k(t) = \dfrac{\sum_{h=1}^{r} CPHR_i^{hk}(t) \left[\dfrac{e^k(t^*)}{e^h(t^*)} \right]}{CPKR1^k(t) \times POP^k(t)}$ and $POP65^k(t)$ is population aged over 65 in the kth country. Using the sectoral share explained by equation (7), private consumption in the ith sector of the kth country (in constant prices and in the currency of the kth country) is determined as:

$$\sum_{h=1}^{r} CPHR_i^{hk}(t)\left[\frac{e^k(t^*)}{e^h(t^*)}\right] = SCP_i^k(t) \times CPKR1^k(t) \times POP^k(t) \qquad i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r \quad (8)$$

Applying the Armington's (1969) formulation, private consumption delivered from the ith sector of the hth country to the kth country (in constant prices and in the currency of the kth country) is explained as:

$$\frac{CPHR_i^{hk}(t)\left[\frac{e^k(t^*)}{e^h(t^*)}\right]}{\sum_{q=1}^{r} CPHR_i^{qk}(t)\left[\frac{e^k(t^*)}{e^q(t^*)}\right]} = \kappa(C)_i^{hk}\left[\frac{P_i^h(t)\left\{\frac{e^k(t)/e^h(t)}{e^k(t^*)/e^h(t^*)}\right\}}{PCPK_i^k(t)}\right]^{\eta(C)_i^k} \qquad (9)$$

$$i = 1, 2, \ldots, n;\ h,\ k = 1, 2, \ldots, r$$

where $PCPK_i^k(t)$ is the deflator for the ith private consumption of the kth country (in the currency of the kth country).

Since the main source of household income is wages, the per capita income of the kth country (in current prices and in the currency of the kth country) is explained by the wage rate of the kth country as:

$$YIK1^k(t) = YIK1^k\left[\frac{\sum_{j=1}^{n} WK_j^k(t)}{\sum_{j=1}^{n} L_j^k(t)}\right] \qquad k = 1, 2, \ldots, r \qquad (10)$$

where $WK_j^k(t)$ is wages in the jth sector of the kth country (in current prices and in the currency of the kth country) and $L_j^k(t)$ is employment in the jth sector of the kth country. Deflators regarding private consumption (in the currency of the kth country), $PCPK_i^k(t)$ and $PCPK^k(t)$, are determined as:

$$PCPK_i^k(t) = \sum_{h=1}^{r}\left[P_i^h(t)\frac{\left\{\frac{e^k(t)}{e^h(t)}\right\}}{\left\{\frac{e^k(t^*)}{e^h(t^*)}\right\}}\right]\left[\frac{CPHR_i^{hk}(t)\left\{\frac{e^k(t^*)}{e^h(t^*)}\right\}}{\sum_{q=1}^{r} CPHR_i^{qk}(t)\left\{\frac{e^k(t^*)}{e^q(t^*)}\right\}}\right] \qquad i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r \ (11)$$

and

$$PCPK^k(t) = \sum_{i=1}^{n} PCPK_i^k(t) \left[\frac{\sum_{h=1}^{r} CPHR_i^{hk}(t) \left\{ \frac{e^k(t^*)}{e^h(t^*)} \right\}}{CPKR1^k(t) \times POP^k(t)} \right] \qquad k = 1, 2, \ldots, r \tag{12}$$

Regarding investment, we first explain the total investment of the kth country (in constant prices and in the currency of the kth country) as:

$$\sum_{i=1}^{n} \sum_{h=1}^{r} IHR_i^{hk}(t) \left[\frac{e^k(t^*)}{e^h(t^*)} \right] = IKR^k \left[\sum_{j=1}^{n} XXR_j^k(t) \right] \qquad k = 1, 2, \ldots, r \tag{13}$$

where $IHR_i^{hk}(t)$ is investment of the kth country delivered from the ith sector of the hth country (in constant prices and in the currency of the hth country). Investment in the ith sector of the kth country (in constant prices and in the currency of the kth country) is a function of the total investment of the corresponding country:

$$\sum_{h=1}^{r} IHR_i^{hk}(t) \left[\frac{e^k(t^*)}{e^h(t^*)} \right] = IKR_i^k \left[\sum_{i=1}^{n} \sum_{h=1}^{r} IHR_i^{hk}(t) \left\{ \frac{e^k(t^*)}{e^h(t^*)} \right\} \right] \qquad i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r \tag{14}$$

Employing the Armington's (1969) approach, we explain investment of the kth country delivered from the ith sector of the hth country (in constant prices and in the currency of the kth country) as:

$$\frac{IHR_i^{hk}(t) \left[\frac{e^k(t^*)}{e^h(t^*)} \right]}{\sum_{q=1}^{r} IHR_i^{qk}(t) \left[\frac{e^k(t^*)}{e^q(t^*)} \right]} = \kappa(I)_i^{hk} \left[\frac{P_i^h(t) \left\{ \frac{e^k(t)/e^h(t)}{e^k(t^*)/e^h(t^*)} \right\}}{PIK_i^k(t)} \right]^{\eta(I)_i^k} \tag{15}$$

$$i = 1, 2, \ldots, n;\ h, k = 1, 2, \ldots, r$$

where $PIK_i^k(t)$ is the deflator for the ith investment of the kth country (in the currency of the kth country). This is formulated as:

$$PIK_i^k(t)=\sum_{h=1}^{r}\left[P_i^h(t)\frac{\left\{\frac{e^k(t)}{e^h(t)}\right\}}{\left\{\frac{e^k(t^*)}{e^h(t^*)}\right\}}\right]\left[\frac{IHR_i^{hk}(t)\left\{\frac{e^k(t^*)}{e^h(t^*)}\right\}}{\sum_{q=1}^{r}IHR_i^{qk}\left\{\frac{e^k(t^*)}{e^q(t^*)}\right\}}\right] \quad i=1,2,\ldots,n;\ k=1,2,\ldots,r \tag{16}$$

3.2. Sectoral Price Block

The determination of sectoral price is based on the identity with respect to input in the international input-output framework. Among the cost components, material and labor costs are explicitly employed as the explanatory variables for sectoral price. Price in the jth sector of the kth country (in the currency of the kth country), $P_j^k(t)$, is explained as:

$$P_j^k(t)=P_j^k\left[\frac{\sum_{i=1}^{n}\sum_{h=1}^{r}P_i^h(t)XHR_{ij}^{hk}(t)\left\{\frac{e^k(t)}{e^h(t)}\right\}}{XXR_j^k(t)},\frac{WK_j^k(t)}{XXR_j^k(t)}\right] \quad j=1,2,\ldots,n;\ k=1,2,\ldots,r \tag{17}$$

The wage rate in the jth sector of the kth country (in current prices and in the currency of the kth country), $w_j^k(t)$, is determined by the following expression:

$$w_j^k(t)=w_j^k\left[PCPK^k(t),\frac{XXR_j^k(t)}{L_j^k(t)}\right] \quad j=1,2,\ldots,n;\ k=1,2,\ldots,r \tag{18}$$

In order to account for economies of scale, we explain sectoral employment by employing Ozaki's (1979) formulation as:

$$L_j^k(t)=\alpha_j^k\left[XXR_j^k(t)\right]^{\beta_j^k} \quad j=1,2,\ldots,n;\ k=1,2,\ldots,r \tag{19}$$

Using the sectoral wage rate and employment, we obtain sectoral wages (in current prices and in the currency of the kth country) as:

$$WK_j^k(t)=w_j^k(t)\times L_j^k(t) \quad j=1,2,\ldots,n;\ k=1,2,\ldots,r \tag{20}$$

3.3. Sectoral Water Use Block

Sectoral water use is determined by applying the corresponding sector's water use coefficient. It is worth noting that the sector classification of water use differs from that of the international input-output block. Water use is divided into the following three categories: agricultural, industrial, and domestic uses. Letting the symbols A, M, and D denote the agricultural, industrial, and domestic sectors of water use, we formulate the water use coefficient in these sectors of the hth country, $WC_l^h(t^*)$ $(l = A, M, D)$, as:

$$WC_A^h(t^*) = \frac{WTR_A^h(t^*)}{\sum_{i \in A} XXR_i^h(t^*)} \qquad h = 1, 2, \dots, r \tag{21}$$

$$WC_M^h(t^*) = \frac{WTR_M^h(t^*)}{\sum_{i \in M} XXR_i^h(t^*)} \qquad h = 1, 2, \dots, r \tag{22}$$

and

$$WC_D^h(t^*) = \frac{WTR_D^h(t^*)}{\sum_{i \in D} XXR_i^h(t^*)} \qquad h = 1, 2, \dots, r \tag{23}$$

where $WTR_A^h(t)$, $WTR_M^h(t)$, and $WTR_D^h(t)$ are the agricultural, industrial, and domestic water use of the hth country, respectively. Using these coefficients, sectoral water use of the hth country are determined as:

$$WTR_A^h(t) = WC_A^h(t^*) \times \sum_{i \in A} XXR_i^h(t) \qquad h = 1, 2, \dots, r \tag{24}$$

$$WTR_M^h(t) = WC_M^h(t^*) \times \sum_{i \in M} XXR_i^h(t) \qquad h = 1, 2, \dots, r \tag{25}$$

and

$$WTR_D^h(t) = WC_D^h(t^*) \times \sum_{i \in D} XXR_i^h(t) \qquad h = 1, 2, \dots, r \tag{26}$$

Employing the same sectoral water use coefficients, we explain water embedded in each component of sectoral output with respect to demand. Water embedded in intermediate goods is expressed as:

$$WTRX_{lm}^{hk}(t) = WC_l^h(t^*) \times \sum_{i \in l} \sum_{j \in m} XHR_{ij}^{hk}(t) \qquad l, m = A, M, D;\ h, k = 1, 2, \ldots, r \tag{27}$$

where $WTRX_{lm}^{hk}(t)$ is water embedded in intermediate goods delivered from the lth sector of the hth country to the mth sector of the kth country. Water embedded in final demand components are written as:

$$WTRC(t)_l^{hk} = WC_l^h(t^*) \times \sum_{i \in l} CPHR_i^{hk}(t) \qquad l = A, M, D;\ h, k = 1, 2, \ldots, r \tag{28}$$

$$WTRG(t)_l^{hk} = WC_l^h(t^*) \times \sum_{i \in l} CGHR_i^{hk}(t) \qquad l = A, M, D;\ h, k = 1, 2, \ldots, r \tag{29}$$

$$WTRI(t)_l^{hk} = WC_l^h(t^*) \times \sum_{i \in l} IHR_i^{hk}(t) \qquad l = A, M, D;\ h, k = 1, 2, \ldots, r \tag{30}$$

$$WTRV(t)_l^{hk} = WC_l^h(t^*) \times \sum_{i \in l} IVHR_i^{hk}(t) \qquad l = A, M, D;\ h, k = 1, 2, \ldots, r \tag{31}$$

$$WTRE(t)_l^{h} = WC_l^h(t^*) \times \sum_{i \in l} EHR_i^{h}(t) \qquad l = A, M, D;\ h = 1, 2, \ldots, r \tag{32}$$

and

$$WTRQ(t)_l^{h} = WC_l^h(t^*) \times \sum_{i \in l} QHR_i^{h}(t) \qquad l = A, M, D;\ h = 1, 2, \ldots, r \tag{33}$$

where $WTRC(t)_l^{hk}$, $WTRG(t)_l^{hk}$, $WTRI(t)_l^{hk}$, and $WTRV(t)_l^{hk}$ are respectively water embedded in private consumption, government consumption, investment, and inventories of the kth country delivered from the lth sector of the hth country and $WTRE(t)_l^{h}$ and $WTRQ(t)_l^{h}$ are respectively water embedded in exports to the rest of the world and statistical discrepancy in the lth sector of the hth country. Water embedded in exports is water use of foreign countries whereas water embedded in imports is water use of the own country. Therefore, the virtual water balance of the

hth country within the region which is covered by international input-output tables, $BWTR(t)^h$, can be written as:

$$\begin{aligned} BWTR(t)^h = & \sum_{l=A,M,D} WTRQ(t)_l^h + \sum_{l=A,M,D} \sum_{m=A,M,D} WTRX(t)_{lm}^{hh} - \sum_{k \neq h}^{r} \sum_{l=A,M,D} \sum_{m=A,M,D} WTRX(t)_{lm}^{hk} \\ & + \sum_{k \neq h}^{r} \sum_{l=A,M,D} \sum_{m=A,M,D} WTRX(t)_{lm}^{kh} + \sum_{l=A,M,D} WTRF(t)_l^{hh} - \sum_{k \neq h}^{r} \sum_{l=A,M,D} WTRF(t)_l^{hk} \\ & + \sum_{k \neq h}^{r} \sum_{l=A,M,D} WTRF(t)_l^{kh} \\ & h = 1, 2, \ldots, r \end{aligned} \tag{34}$$

where $WTRF(t)_l^{hk} = WTRC(t)_l^{hk} + WTRG(t)_l^{hk} + WTRI(t)_l^{hk} + WTRV(t)_l^{hk}$.

4. Empirical Properties of the Model

4.1. Data

In this paper, we construct a six-sector version of 1985-1990-1995-2000 Asian International Input-Output Tables in local currencies by using the Institute of Developing Economies' twenty-four-sector version of the Asian International Input Output Tables for the years 1985, 1990, 1995, and 2000 in current prices and U.S. dollars (Institute of Developing Economies 1993, 1998, 2001; Institute of Developing Economies-Japan External Trade Organization 2006a, 2006b). Our data cover the following ten economies: Indonesia, Malaysia, the Philippines, Singapore, Thailand, China, Taiwan , South Korea, Japan, and the United States. To obtain the sectoral GDP deflators, we use a seven-sector version of GDP in both current and constant prices as well as local currencies (excluding Taiwan) released from the United Nations' National Accounts and a seventeen-sector version of the corresponding data for Taiwan taken from the Directorate General of Budget, Accounting and Statistics, Executive Yuan, the Republic of China. In order to reduce dissimilarities of the sector classifications between the Asian International Input-Output Tables and the sectoral GDP data, we rearrange their classifications into the following six sectors: 1) agriculture, 2) mining and utilities, 3) manufacturing, 4) construction, 5) trade and transportation, and 6) services.[5,6] The base year of our international input-output tables is the year 1990.

As for water use, data are taken from the Food and Agriculture Organization's AQUASTAT and

[5] Even for the six-sector classification, we still have a discrepancy between the Asian International Input-Output Tables and the United Nations' National Accounts in the trade and transportation as well as services sectors. However, we disregard this discrepancy in the construction of our data. Regarding Taiwan, we do not have any discrepancies.

[6] The classification of employment data is also re-organized in accordance with the six-sector classification.

the Water Resource Agency of Taiwan.[7] The data are disaggregated into the following three categories: agricultural, industrial, and domestic uses. The agricultural, industry, and domestic categories correspond to the agricultural, mining and utilities plus manufacturing, construction plus trade and transportation plus services sectors of the international input-output tables, respectively. The sectoral water use coefficient is computed by using the data for the year 2000 since we have all of the necessary data only for the year 2000.[8] The sectoral water use coefficients in 2000 are presented in Table 2. The unit is m^3 per local currency: i.e., m^3 per Rupiah in the case of Indonesia. As this table shows, the agricultural category is the most water-intensive among the three categories.

4.2. Estimation Results of Selected Variables

All stochastic equations are estimated by using panel data methods. Since individual constants represent country-specific or sector-specific effects, the fix-effect model is employed for the estimation. In order to estimate stochastic equations, we apply generalized least squares rather than an estimator for a simultaneous equation model since Mariano (1982) shows that the two-stage least squares is not necessarily favorable under the case of small samples and severe specification errors. Since structural change often occurs in the current world economy, it is easy to have misspecifications in the model. Thus, we consider that generalized least squares is sufficient for the estimation of our model. Note that the White's heteroscedasticity-consistent standard error is applied to all estimations.

4.2.1. Intermediate Demand: Equation (3)

The allocation of the ith intermediate goods in the jth sector of the kth country into the source economies is explained by equation (3). Taking the logarithms, we express the estimated equation as:

$$\ln\left[\frac{XHR_{ij}^{hk}(t)\left\{\dfrac{e^k(t^*)}{e^h(t^*)}\right\}}{\sum_{q=1}^{r} XHR_{ij}^{qk}(t)\left\{\dfrac{e^k(t^*)}{e^q(t^*)}\right\}}\right] = c(1)_{ij}^{hk} + c(2)_{ij}^{k}\ln\left[\frac{\{1+t_i^{hk}(t)\}P_i^h(t)\left\{\dfrac{e^k(t)/e^h(t)}{e^k(t^*)/e^h(t^*)}\right\}}{PXK_{ij}^{k}(t)}\right] \tag{3'}$$

$$i, j = 1, 2, \ldots, n;\ h, k = 1, 2, \ldots, r$$

Note that the parameter $c(2)_{ij}^{k}$ is common among the source economies of the ith goods. Pooling data for intermediate demand with respect to the ith goods, this equation is estimated for each of the jth sector of the kth country ($j = 1, 2, \ldots, n$; $k = 1, 2, \ldots, r$). Table 3 demonstrates estimation

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[7] Water use data for Taiwan include the use in the Fuchien Province of the Republic of China.

[8] Since data of Singapore are available only for 1975, we computed the data of the year 2000. The procedure of estimation is explained in Appendix A2.

results of the parameter $c(2)_{ij}^{k}$ in the manufacturing sector of Indonesia (i.e., $i = 1, 2, \ldots, 6; j = 3$; k = Indonesia). Due to a shortage in the number of observations, we could not estimate intermediate demand delivered from the construction and services sectors. Although the parameter $c(2)_{13}^{IDN}$ has the appropriate sign, it is not statistically significant. In exception to this point, the overall estimation results are acceptable.

4.2.2. Sectoral Share of Private Consumption: Equation (7)

In order to capture the effects of population aging on consumption pattern, we specify the sectoral share of private consumption as follows:

$$\ln SCP_i^k(t) = c(3)_i^k + c(4)_i^k \ln\left[\frac{POP65^k(t)}{POP^k(t)}\right] \qquad i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r \qquad (7')$$

Pooling data with respect to economy (i.e., the index k), we estimate this equation sector by sector. Estimation results of the parameter $c(4)_i^k$ are provided in Table 4. Due to the limited number of non-zero observations, we could not estimate the parameters of interest for the construction sector. Although the sign of the parameter $c(4)_i^k$ basically differs with respect to sector and economy, the sign in the agricultural sector is negative for all economies. This indicates that the shares of the agricultural products in the total private consumption decline as the ratio of aged people rises.

4.2.3. Sectoral Price: Equation (17)

Pooling data with respect to sector (i.e., the index j), the sectoral price equation is estimated economy by economy. The estimated equation of sectoral price is expressed as:

$$\ln P_j^k(t) = c(5)_j^k + c(6)^k \ln\left[\frac{\sum_{i=1}^{n}\sum_{h=1}^{r} P_i^h(t) XHR_{ij}^{hk}(t)\left\{\frac{e^k(t)}{e^h(t)}\right\}}{XXR_j^k(t)}\right] + c(7)^k \ln\left[\frac{WK_j^k(t)}{XXR_j^k(t)}\right] \qquad (17')$$

$$j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, r$$

Table 5 presents the estimation results of the parameters $c(6)^k$ and $c(7)^k$ for South Korea (i.e., k = South Korea). As this table illustrates, the results are sufficient.

4.3. Final Test

In total, the model contains 8,307 equations (6,410 identities and 1,897 stochastic equations) and 3 exogenous variables. Detailed number of equations by types is provided in Table 6. It is worth noting that the estimation results for all stochastic equations are employed to construct the whole model as long as the results possess the correct sign. By contrast, the actual shares or values are employed if the estimated coefficient has the wrong sign or estimation is not possible due to the shortage of non-zero data.

The final test of the model is carried out from 1990 to 2000. Because of their explosive behavior, the sectoral prices in the mining and utilities plus trade and transportation sectors of Taiwan and that in the services sector of Japan are exogenous in the model. Figures 1 and 2 respectively present the results of the final test for the weighted average of sectoral prices and output in total for all ten economies.[9] The results for several items (e.g., the average price for the Philippines and the United States and the total output for Indonesia) are not necessarily satisfactory. However, most parameters of the model are estimated by pooled data of economies with a variety of scales and development stages. Taking this feature into consideration, we can conclude that the overall performance of the model is basically acceptable.

5. Simulation Analysis

5.1. The Baseline

Table 7 illustrates the baseline solutions for the virtual water balance and its components within the Asia-Pacific region. In the region, 1,293 billion m^3 of water is consumed. China is the largest consumer of water and uses approximately 520 billion m^3 (40% of the total water use in the region). The United States uses the second largest amount of water in the region (436 billion m^3). Roughly 74% of the regional total is used by these two economies. Furthermore, approximately 95% of water use in the region is made up of those by China, the United States, Japan, Thailand, and Indonesia.

As for the virtual water trade, Malaysia, Singapore, Taiwan, South Korea, and Japan are importers of water since their virtual water imports are greater than their water exports. By contrast, Indonesia, the Philippines, Thailand, China, and the United States are exporters of water. Among these economies, China and the United States are the largest exporters of water (6.2 billion m^3 and 6.6 billion m^3, respectively). Japan particularly imports the virtual water of 11.5 billion m^3, which nearly corresponds to the summation of the virtual water exports of China and the United States. For most economies, water embedded in domestically produced goods consists of the largest portion in the virtual water balance. However, Singapore's water use embedded in imports is twice greater than water embedded in domestically produced goods, which shows that Singapore's water use structure is quite different.

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9 The unit of output in total is 1,000 local currency.

5.2. Effects of Population Aging on the Virtual Water Balance

In addition to population increase, population aging is also one of the important aspects of demographic issues particularly in Asian economies. It is expected that consumption patterns vary as people age. In this experiment, we add one point to China's percentage of people aged over 65 in 2000 and quantify its effects on the virtual water balance within the Asia-Pacific region.

5.2.1. Sectoral Prices and Outputs

Table 8 illustrates the percent deviations of sectoral prices and outputs for the ten economies.[10] Sectoral price declines around 1.3% in China. For the agricultural and services sectors, the rate of decrease for wages is greater than that for output. Particularly, the wage rate decreases due to the decline of labor productivity.[11] As for the rest of the sectors, the reverse occurs: i.e., the rate of increase for wages is smaller than that for output. The increase of the wage rate is limited as a consequence of the price decline in the agricultural and services sectors. These result in the decrease of the unit labor cost and the fall of price for all six sectors. In addition, the unit material cost also declines because price falls in the six sectors.

Regarding the rest of the nine economies, sectoral price goes down in exception to the agricultural sector of Singapore and the United States. There are two causes for the fall of price. One is the decline of the unit material cost as a consequence of the price fall in China and the increase in output. The other is the decline of the unit labor cost through the limited increase of the wage rate owing to the fall of the deflator for private consumption. On the contrary, price rises in the agricultural sector of Singapore and the United States. When output in a sector decreases, employment in the corresponding sector also decreases. However, the decrease of employment is limited due to the presence of economies of scale. As a consequence, in the agricultural sector of Singapore and the United States, the decrease of output is greater than that of wages, which yields the upsurge of the unit labor cost. The rise of the unit labor cost results in the rise of price.

Sectoral output increases in exception to the agricultural sector of the Philippines, Singapore, China, and the United States plus the services sector of China. The decline of output in the agricultural and services sectors of China is originated in the decrease of private consumption in the corresponding sectors due to population aging. As Table 4 shows, population aging negatively affects the shares of these products in private consumption. Regarding the agricultural sector of the Philippines, Singapore, and the United States, the decrease of China's demand for agricultural products is one of the causes for the output decline. In Singapore and the United States, demand for their products in domestic markets also decreases due to the deterioration of price competitiveness.

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[10] The signs of changes in endogenous variables cannot be pre-determined because the change depends on input and trade structure as well as the degree of economies of scale with respect to sectoral employment.

[11] Since economies of scale are included in the determination of sectoral employment, the decrease of employment is smaller than that of output. This results in the decline of labor productivity in the agricultural and services sectors of China.

5.2.2. Virtual Water Balance

Table 9 demonstrates the percent deviations of the three water use categories and their shares in the virtual water balance changes. Water use of China declines (-4.4%) whereas those of the rest of the nine economies rise. In this paper, we examine the results for China, Singapore, South Korea, and the United States in detail since the effects on Singapore and South Korea are the greatest whereas those on the United States are the smallest among the nine economies other than China.

China

As Panel A of Table 9 illustrates, water embedded in domestic products and imports (positive factors of the virtual water balance) decreases whereas that in exports (negative factor of the virtual water balance) increases. Panel B of Table 9 demonstrates that the decrease of water embedded in domestic products is a critical factor of the decrease in the virtual water balance of China since it accounts for approximately 99% of the change.

Details in the decrease of water embedded in domestic demand show that the main cause of the decrease is the decline of water embedded in final demand (Panel A of Table 10). As in Table 11, among final demand components, water embedded in private consumption of the agricultural products is greatly reduced. Since price in the agricultural sector of China declines more than those of the rest of the nine economies, the allocation of the agricultural demand into the source economies is not the cause. Rather, the cause is the decrease of the total demand for the agricultural products in China due to population aging.

Singapore and South Korea

Singapore and South Korea possess the greatest rates of increase in water use among the ten economies. For both economies, the increase in water embedded in imports explains most of the increase of the virtual water balance (Panel B of Table 9). In imports, intermediate and final demands have almost the same effects in Singapore whilst roughly 80% of the increase comes from intermediate demand in South Korea (Panel C of Table 10). As Tables 12A, 12B, and 13 show, the main factor for the outcome is the increase of industrial water use embedded in imports from China. Regarding Singapore, the increase of water embedded in agricultural products imported from China is also substantial. The increase in imports of Singapore and South Korea from China occurs due to the improvement of China's price competitiveness.

United States

The U.S. virtual water balance also increases; however, the rate of change is the smallest among the economies other than China. As Table 9 shows, the decrease of water use embedded in exports contributes positively to the increase of the virtual water balance. Panel B of Table 10 illustrates that water embedded in exports of final goods has a substantial effect, which explains 121.7% of the changes in water use embedded in exports. Specifically, water embedded in the U.S. agricultural products delivered to private consumption of China contributes 116 points of 121.7%

(Table 14A). The deterioration of the U.S. price competitiveness yields the decrease of the U.S. agricultural exports to China. Furthermore, this cause results in the decrease of the agricultural water use with respect to exports. Since water use embedded in exports is a negative factor of the virtual water balance, the U.S. virtual water balance goes up by the decrease of exports.

In the United States, water use embedded in imports is also an important factor in the determination of the U.S. virtual water balance (roughly 40% of the changes in the balance). In particular, approximately 63% of the changes in water use embedded in imports is explained by imports of final goods (Panel C of Table 10) and 62 points of 63% are imports from China (Table 14B). The U.S. imports from China increases due to the improvement of China's price competitiveness in the U.S. market.

By contrast, the decrease of water use embedded in domestic demand negatively affects the U.S. virtual water balance (Panels B of Table 9). As Table 14C shows, the main cause is the decrease of water use embedded in intermediate goods delivered from the agricultural sector to the agricultural sector. Since the allocation of agricultural products into the sources economies is determined by the actual share due to the wrong sign in its estimation, the output decrease in the agricultural sector leads to the decrease of water use embedded in domestic products.

6. Conclusions

In this paper, we analyzed the virtual water balance within the Asia-Pacific economies. To do this, we constructed the Asian International Input-Output Tables in constant prices and local currencies and built a local currency-based multi-country multi-sectoral model for the Asia-Pacific region. According to the results, China and the United States consume approximately 74% of the total water use in the region. Regarding the virtual water balance within the region, it is also found that Malaysia, Singapore, Taiwan, South Korea, and Japan are importers whereas Indonesia, the Philippines, Thailand, China, and the United States are exporters. In particular, Japan is the largest importer of water; the amount of water import almost corresponds to that of water embedded in exports of China and the United States.

We also assessed the effects of population aging in China on the virtual water balance within the Asia-Pacific economies. Basically, population aging in China has negative impact on the virtual water balance in China whereas positive impact on the balance for the other economies (large impact on Singapore and South Korea whilst small impact on the United States). Concerning China, the main cause for the decrease in the virtual water balance is the decrease in demand for services and the water-intensive agricultural products due to population aging. In Singapore and South Korea, the increase in the virtual water balance is largely explained by the increase in water embedded in imports (particularly from China) due to the improvement of China's price competitiveness. By contrast, the increase in the virtual water balance of the United States is limited because the use of water embedded in exports decreases owing to the deterioration of U.S. price competitiveness in the agricultural sector whilst the use of water embedded in domestic products also decreases due to the great contraction of output. These imply that the presence of

China is significant especially in the agricultural sector of the United States. As Table 4 shows, population aging is negatively correlated to demand for the agricultural products. At present, population aging is stagnant in the United States; however, it is ongoing in the Asian economies. In this sense, the level and structure of the U.S. virtual water balance might significantly change in the near future.

As simulation results show, sectoral price is quite important for the determination of the virtual water balance. Particularly, the sectoral wage rate and employment have significant effects on the formation of sectoral price. However, only employment is endogenously explained in the model. Inclusion of a full model of the labor market is our future task to improve the performance of the model.

Appendix A1: Data Sources

Item: Twenty-four-sector version of Asian International Input-Output Tables for 1985, 1990, 1995, and 2000 in current prices and U.S. dollars

Source: Institute of Developing Economies (1993, 1998, 2001) and Institute of Developing Economies-Japan External Trade Organization (2006a, 2006b)

Item: Imports of goods and services and sectoral value added in current and 1990 prices (evaluated in local currencies)

Source: United Nations' National Accounts Main Aggregates Database (http://unstats.un.org/unsd/snama/Introduction.asp; accessed August 4, 2008) and the Directorate General of Budget, Accounting and Statistics, Executive Yuan, R.O.C. (http://eng.stat.gov.tw/lp.asp?ctNode=3567&CtUnit=1179&BaseDSD=7; accessed August 4, 2008)

Item: Exchange rates (period average)

Source: International Monetary Fund's International Financial Statistics Online (accessed August 4, 2008) and the Central Bank of the Republic of China (http://www.cbc.gov.tw/Enghome/Eeconomic/Statistics/Category/Foreign.asp; accessed August 4, 2008)

Item: Employment by industry

Source: International Labor Organization's Key Indicators of the Labor Market, Fifth Edition (accessed May 7, 2009) and the Statistical Yearbook of the Republic of China 2007 (http://eng.dgbas.gov.tw/lp.asp?CtNode=2351&CtUnit=1072&BaseDSD=36&xq_xCat=03; accessed May 7, 2009)

Item: Total population and population aged over 65

Source: World Bank's World Development Indicators Online (accessed April 14, 2009) and the Statistical Yearbook of the Republic of China 2007 (http://eng.dgbas.gov.tw/lp.asp?CtNode=2351&CtUnit=1072&BaseDSD=36&xq_xCat=02; accessed April 14, 2009)

Item: Water use

Source: Food and Agriculture Organization's AQUASTAT (accessed March 15, 2009) and the Water Resource Agency, the Ministry of Economic Affairs, the Republic of China (http://eng.war.gov.tw/lp.asp?CtNode=5431&CtUnit=1047&BaseDSD=4; accessed March 17, 2009)

Appendix A2: Construction of Water Use Data for Singapore

Regarding Singapore, the agricultural, industrial, and domestic water use data are available only for 1975. Since we do not have input-output data in 1975, it is impossible to compute the sectoral water use coefficients, $WC_l^h(t^*)$ $(l = A, M, D)$. However, the sectoral GDP in constant prices are available from 1975. Hence, using these data, we compute the sectoral water use coefficients with respect to the corresponding sector's GDP in constant prices, $WCS_l^h(t = 1975)$ $(l = A, M, D)$, as:

$$WCS_l^{SGP}(t = 1975) = \frac{WTR_l^{SGP}(t = 1975)}{GDPR_l^{SGP}(t = 1975)} \qquad (l = A, M, D) \tag{A1}$$

where $GDPR_l^{SGP}(t)$ is GDP in the lth sector of Singapore (in constant prices and local currencies) and the superscript SGP denotes Singapore. Employing these coefficients, we can estimate the sectoral water use after 1976 as:

$$WTR_l^{SGP}(t) = WCS_l^{SGP}(t = 1975) \times GDPR_l^{SGP}(t) \qquad (l = A, M, D) \tag{A2}$$

As a result, we have the sectoral water use data for 2000. Hence, we can compute the sectoral water use coefficients in 2000 by the following equations (21) to (23).

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Table 1A. Layout of International Input-Output Tables in Constant Prices and Local Currencies: Variables Denominated in the Currency of the Source Countries

		Intermediate demand				Final demand				Exports to	Statistical	
		Country 1	Country 2	...	Country r	Country 1	Country 2	...	Country r	the ROW	discrepancy	Output
Intermediate input	Country 1	XHR^{11}	XHR^{12}	...	XHR^{1r}	FHR^{11}	FHR^{12}	...	FHR^{1r}	EHR^{1}	QHR^{1}	XXR^{1}
	Country 2	XHR^{21}	XHR^{22}	...	XHR^{2r}	FHR^{21}	FHR^{22}	...	FHR^{2r}	EHR^{2}	QHR^{2}	XXR^{2}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	Country r	XHR^{r1}	XHR^{r2}	...	XHR^{rr}	FHR^{r1}	FHR^{r2}	...	FHR^{rr}	EHR^{r}	QHR^{r}	XXR^{r}

Table 1B. Layout of International Input-Output Tables in Constant Prices and Local Currencies: Variables Denominated in the Currency of the Destination Countries

		Intermediate demand			
		Country 1	Country 2	...	Country r
Intermediate input	Country 1	XHR^{11}	$XHR^{12}\times(e^{2*}/e^{1*})$	...	$XHR^{1r}\times(e^{r*}/e^{1*})$
	Country 2	$XHR^{21}\times(e^{1*}/e^{2*})$	XHR^{22}	...	$XHR^{2r}\times(e^{r*}/e^{2*})$
	⋮	⋮	⋮	⋮	⋮
	Country r	$XHR^{r1}\times(e^{1*}/e^{r*})$	$XHR^{r2}\times(e^{2*}/e^{r*})$	...	XHR^{rr}
Freight and insurance		BK^1	BK^2	...	BK^r
Imports from the ROW		MK^1	MK^2	...	MK^r
Duties		DK^1	DK^2	....	DK^r
Value added	Wages	WGK^1	WGK^2	...	WGK^r
	Operating surplus	YCK^1	YCK^2	...	YCK^r
	Depreciations	DPK^1	DPK^2	...	DPK^r
	Indirect tax less subsidies	TXK^1	TXK^2	...	TXK^r
Output		XXR^1	XXR^2	...	XXR^r

Note: The symbol e^{k*} denotes the exchange rate of the kth country in the base year.

Table 2. The Sectoral Water Use Coefficients in 2000 (m^3 per local currency)

Economy	Agricultural use	Industrial use	Domestic use
Indonesia	0.00112	0.00000	0.00002
Malaysia	0.22915	0.00498	0.00668
Philippines	0.07225	0.00184	0.00401
Singapore	0.00871	0.00344	0.00265
Thailand	0.19713	0.00056	0.00077
China	0.32795	0.01939	0.01269
Taiwan	0.02968	0.00021	0.00047
South Korea	0.00035	0.00001	0.00002
Japan	0.00372	0.00004	0.00003
United States	0.65187	0.04497	0.00633

Table 3. Estimation Results of Equation (3′): The Manufacturing Sector of Indonesia

Parameter	Estimated coefficient	S. E.	p-value	Adj. R^2	OBS
$c(2)_{13}^{IDN}$	-0.30516	1.12455	0.78803	0.98302	40
$c(2)_{23}^{IDN}$	-0.83099	0.14986	0.00001	0.99514	40
$c(2)_{33}^{IDN}$	-1.47631	0.08117	0.00000	0.99145	40
$c(2)_{43}^{IDN}$	N.A.	N.A.	N.A.	N.A.	N.A.
$c(2)_{53}^{IDN}$	-0.60634	0.07964	0.00000	0.99620	38
$c(2)_{63}^{IDN}$	N.A.	N.A.	N.A.	N.A.	N.A.

Note: Economy-specific control is suppressed. N.A. denotes not available. S.E. is standard error. Adj. R^2 is adjusted R-squared. OBS is the number of observations. *IDN* denotes Indonesia.

Table 4. Estimation Results of Equation (7′)

	$k=$										
Parameter	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	South Korea	Japan	United States	Adj. R^2
$c(4)_1^k$	-0.73514	-12.88021	-3.92130	-3.45905	-1.77654	-1.32251	-1.31640	-1.43081	-0.57622	-0.87705	0.99636
	(0.70299)	(0.24808)	(0.56796)	(0.84748)	(0.59261)	(0.23518)	(0.13880)	(0.18641)	(0.06228)	(1.71169)	
	[0.30816]	[0.00000]	[0.00000]	[0.00058]	[0.00711]	[0.00002]	[0.00000]	[0.00000]	[0.00000]	[0.61399]	
$c(4)_2^k$	-0.11795	-5.35618	7.99081	-0.12030	2.73895	1.95534	-0.55579	1.24711	0.28173	-1.28482	0.96616
	(0.77677)	(2.41970)	(1.78535)	(0.41577)	(0.10074)	(0.33739)	(0.16400)	(0.31570)	(0.12426)	(0.54931)	
	[0.88083]	[0.03864]	[0.00023]	[0.77529]	[0.00000]	[0.00001]	[0.00291]	[0.00079]	[0.03462]	[0.02983]	
$c(4)_3^k$	0.22405	-5.70083	1.35699	-1.34202	0.08187	1.06921	-0.54543	-0.31476	-0.06783	-2.73322	0.98896
	(0.19256)	(3.30050)	(0.73218)	(0.19346)	(0.03946)	(0.44249)	(0.03688)	(0.31915)	(0.03646)	(0.30867)	
	[0.25831]	[0.09953]	[0.07864]	[0.00000]	[0.05113]	[0.02536]	[0.00000]	[0.33579]	[0.07760]	[0.00000]	
$c(4)_4^k$	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
$c(4)_5^k$	-1.09057	-21.16014	-4.09760	0.47347	0.49298	0.40452	-0.48199	-0.31841	0.32393	1.00623	0.93769
	(0.05678)	(7.19221)	(1.47135)	(0.37238)	(0.19009)	(0.45836)	(0.22453)	(0.25050)	(0.15801)	(1.27094)	
	[0.00000]	[0.00806]	[0.01143]	[0.21814]	[0.01737]	[0.38798]	[0.04426]	[0.21827]	[0.05370]	[0.43781]	
$c(4)_6^k$	0.68592	16.78422	1.45245	0.76246	-0.24584	-0.75660	1.00022	0.59114	-0.10771	0.81808	0.99061
	(0.51620)	(8.82534)	(0.19951)	(0.01645)	(0.11133)	(1.08100)	(0.12939)	(0.35273)	(0.08788)	(0.43618)	
	[0.19889]	[0.07170]	[0.00000]	[0.00000]	[0.03907]	[0.49205]	[0.00000]	[0.10932]	[0.23457]	[0.07539]	

Note: Economy-specific control is suppressed. N.A. denotes not available. The number of observations is 40 for each estimation. Adj. R^2 is adjusted R-squared. Standard errors and p-values are in parentheses and brackets, respectively. The subscript denotes the number of sector.

Table 5. Estimation Results of Equation (17′): South Korea

Parameter	Estimated coefficient	S. E.	p-value
$c(6)^{KOR}$	0.70939	0.04170	0.00000
$c(7)^{KOR}$	0.24924	0.04041	0.00001
Adj. R^2	0.98784		

Note: Economy-specific control is suppressed. The number of observations is 24. S.E. is standard error. Adj. R^2 is adjusted R-squared. *KOR* denotes South Korea.

Table 6. Scale of the Model: Number of Equations

	Type of equation			
Economy	Identities	Stochastic	Exogenous	Total
Indonesia	729	102	0	831
Malaysia	639	192	0	831
Philippines	619	212	0	831
Singapore	629	202	0	831
Thailand	639	192	0	831
China	649	182	0	831
Taiwan	619	210	2	831
South Korea	629	202	0	831
Japan	579	251	1	831
United States	679	152	0	831
Total	6,410	1,897	3	8,310

Table 7. Results of the Baseline Simulation

Economy	Water embedded in domestic products (billions m^3)	Water embedded in exports (billions m^3)	Water embedded in imports (billions m^3)	Water embedded in statistical discrepancy (billions m^3)	Virtual water balance (billions m^3)	Share in the total virtual water balance of the region (%)
Indonesia	83.007	2.723	0.863	-0.701	80.446	6.222
Malaysia	6.346	1.314	1.893	0.070	6.995	0.541
Philippines	26.233	1.985	0.436	-0.060	24.624	1.904
Singapore	0.666	0.236	1.510	-0.017	1.922	0.149
Thailand	85.875	3.031	0.765	-0.276	83.334	6.445
China	529.438	8.414	2.203	-2.743	520.484	40.254
Taiwan	17.100	0.851	2.682	-0.150	18.781	1.452
South Korea	14.893	0.481	3.739	-0.025	18.126	1.402
Japan	90.450	1.586	13.105	0.012	101.980	7.887
United States	443.268	13.181	6.607	-0.394	436.301	33.743
Total	1,297.277	33.803	33.803	-4.284	1,292.993	100.000

Table 8. Percent Deviations of Sectoral Price and Output from the Baseline

	Panel A: Percent deviation of price					
Economy	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
Indonesia	-0.02202	-0.03282	-0.02069	-0.02516	-0.01873	-0.01850
Malaysia	-0.02237	-0.01903	-0.02528	-0.02037	-0.01557	-0.02709
Philippines	-0.01718	-0.02881	-0.03167	-0.02841	-0.01839	-0.01793
Singapore	0.00349	-0.00167	-0.00355	-0.00155	-0.00147	-0.00147
Thailand	-0.00548	-0.00123	-0.00810	-0.00828	-0.00513	-0.00631
China	-1.11542	-1.55360	-1.26447	-1.29432	-1.43806	-1.37135
Taiwan	-0.05179	0.00000	-0.05512	-0.04390	0.00000	-0.04303
South Korea	-0.06257	-0.08505	-0.06944	-0.05360	-0.05026	-0.04835
Japan	-0.01667	-0.01911	-0.02212	-0.01712	-0.01179	0.00000
United States	0.00029	-0.00656	-0.00761	-0.00651	-0.00704	-0.00732
	Panel B: Percent deviation of output					
Economy	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
Indonesia	0.02137	0.13404	0.03306	0.02746	0.03293	0.01448
Malaysia	0.01135	0.08215	0.07694	0.03210	0.04917	0.00524
Philippines	-0.01913	0.01003	0.01401	0.00493	0.00693	0.00145
Singapore	-0.13185	0.02081	0.06245	0.02093	0.01349	0.01215
Thailand	0.00527	0.03489	0.02607	0.02265	0.01641	0.00614
China	-7.62141	4.53803	3.67584	1.45928	1.92465	-2.16609
Taiwan	0.08099	0.08426	0.15092	0.08201	0.07859	0.03197
South Korea	0.06372	0.05953	0.10337	0.05133	0.04557	0.03037
Japan	0.02398	0.02347	0.04682	0.03166	0.02266	0.01058
United States	-0.02489	0.00381	0.00438	0.00353	0.00473	0.00343

Note: Sectors 1, 2, 3, 4, 5, and 6 denote agriculture, mining and utilities, manufacturing, construction, trade and transportation, and services, respectively.

Table 9. Percent Deviations of the Three Water Use Categories from the Baseline and Their Shares in the Virtual Water Balance Changes.

	Panel A: Percent deviations			
Economy	Water embedded in domestic products	Water embedded in exports	Water embedded in imports	Virtual water balance
Indonesia	0.023	0.036	0.110	0.024
Malaysia	0.019	0.079	0.270	0.075
Philippines	0.005	-0.244	0.227	0.029
Singapore	0.014	0.146	0.151	0.105
Thailand	0.016	-0.349	0.500	0.034
China	-4.325	1.206	-1.791	-4.426
Taiwan	0.076	0.307	0.282	0.095
South Korea	0.056	0.368	0.334	0.105
Japan	0.020	0.360	0.394	0.063
United States	-0.001	-0.258	0.288	0.012
	Panel B: Share in changes of the virtual water balance			
Economy	Water embedded in domestic products (WD)	Water embedded in exports (WE)	Water embedded in imports (WI)	Total (WD – WE + WI)
Indonesia	100.137	5.122	4.985	100.000
Malaysia	22.675	19.566	96.891	100.000
Philippines	17.734	-68.323	13.943	100.000
Singapore	4.603	17.069	112.466	100.000
Thailand	48.641	-37.730	13.629	100.000
China	99.388	-0.440	0.171	100.000
Taiwan	72.265	14.599	42.334	100.000
South Korea	43.860	9.296	65.436	100.000
Japan	27.960	8.944	80.984	100.000
United States	-5.554	-67.676	37.878	100.000

Note: The virtual water balance is equal to water embedded in domestic products – that in exports + that in imports.

Table 10. Ratio of Changes in Intermediate and Final Demand Factors to Water Use Changes (%)

	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	South Korea	Japan	United States
Panel A: Water embedded in domestic products										
ID	75.182	119.446	98.078	117.613	101.821	-10.767	94.332	80.349	102.910	126.143
FD	24.818	-19.446	1.922	-17.613	-1.821	110.767	5.668	19.651	-2.910	-26.143
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Panel B: Water embedded in exports										
	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	South Korea	Japan	United States
ID	455.263	167.600	-11.247	62.673	-10.717	50.056	84.663	82.642	75.150	-21.699
FD	-355.263	-67.600	111.247	37.327	110.717	49.944	15.337	17.358	24.850	121.699
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Panel C: Water embedded in imports										
	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	South Korea	Japan	United States
ID	93.541	74.132	86.319	48.364	83.975	-47.564	88.835	78.107	42.641	37.204
FD	6.459	25.868	13.681	51.636	16.025	147.564	11.165	21.893	57.359	62.796
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

Note: ID and FD denote intermediate and final demands, respectively.

Table 11. Ratio of Changes in Private Consumption and Investment to Changes in Water Use Embedded in Domestic Final Demand of China (%)

Water use category	Private consumption	Investment	Total
Agricultural use	123.852	-0.068	123.784
Industrial use	-13.121	-0.423	-13.545
Domestic use	1.335	-0.808	0.528
Total	112.066	-1.299	110.767

Table 12A. Decomposition of Water Embedded in Imports of Intermediate Goods: Singapore (%)

	Panel A: Singapore's imports of intermediate goods from China			
Water use category	Agricultural use	Industrial use	Domestic use	Total
Agricultural use	3.725	15.978	19.373	39.076
Industrial use	-0.009	4.934	14.581	19.507
Domestic use	0.001	0.230	1.733	1.964
Total	3.717	21.142	35.688	60.547

	Panel B: Singapore's imports of intermediate goods from other than China			
Water use category	Agricultural use	Industrial use	Domestic use	Total
Agricultural use	-3.926	-10.558	-7.869	-22.352
Industrial use	-0.038	9.664	-0.613	9.013
Domestic use	-0.010	0.938	0.228	1.156
Total	-3.974	0.045	-8.253	-12.182

Table 12B. Decomposition of Water Embedded in Imports of Final Goods: Singapore (%)

	Panel A: Singapore's imports of final goods from China		
Water use category	Private consumption	Investment	Total
Agricultural use	35.272	0.000	35.272
Industrial use	15.974	16.985	32.959
Domestic use	2.116	0.276	2.391
Total	53.361	17.261	70.622

	Panel B: Singapore's imports of final goods from other than China		
Water use category	Private consumption	Investment	Total
Agricultural use	-15.985	0.000	-15.985
Industrial use	-0.993	-2.136	-3.130
Domestic use	0.065	0.063	0.128
Total	-16.914	-2.073	-18.987

Table 13. Decomposition of Water Embedded in Imports of Intermediate Goods: South Korea (%)

	Panel A: South Korea 's imports of intermediate goods from China			
Water use category	Agricultural use	Industrial use	Domestic use	Total
Agricultural use	0.190	7.471	3.694	11.355
Industrial use	0.052	53.888	3.672	57.613
Domestic use	0.003	4.767	0.253	5.023
Total	0.245	66.126	7.620	73.991
	Panel B: South Korea's imports of intermediate goods from other than China			
Water use category	Agricultural use	Industrial use	Domestic use	Total
Agricultural use	0.399	6.253	-0.032	6.620
Industrial use	0.006	-1.788	-0.814	-2.596
Domestic use	0.001	0.091	0.001	0.093
Total	0.406	4.556	-0.846	4.116

Table 14A. Decomposition of Water Embedded in Exports of Final Goods: United States (%)

	Panel A: U.S. exports of final goods to China		
Water use category	Private consumption	Investment	Total
Agricultural use	129.491	-0.001	129.490
Industrial use	-8.827	-4.509	-13.336
Domestic use	-0.041	-0.038	-0.079
Total	120.624	-4.549	116.075

	Panel B: U.S. exports of final goods to other than China		
Water use category	Private consumption	Investment	Total
Agricultural use	1.219	0.062	1.281
Industrial use	2.096	2.302	4.398
Domestic use	0.007	-0.063	-0.056
Total	3.322	2.301	5.623

Table 14B. Decomposition of Water Embedded in Imports of Final Goods: United States (%)

	Panel A: U.S. imports of final goods from China		
Water use category	Private consumption	Investment	Total
Agricultural use	5.487	0.000	5.487
Industrial use	45.724	5.279	51.002
Domestic use	4.671	0.445	5.116
Total	55.882	5.723	61.606
	Panel B: U.S. imports of final goods from other than China		
Water use category	Private consumption	Investment	Total
Agricultural use	0.406	0.000	0.406
Industrial use	0.422	0.263	0.686
Domestic use	0.079	0.020	0.099
Total	0.907	0.283	1.191

Table 14C. Decomposition of Water Embedded in Domestic Demand for Intermediate Goods: United States (%)

Water use category	Agricultural use	Industrial use	Domestic use	Total
Agricultural use	375.500	-126.786	16.418	265.132
Industrial use	17.179	-74.838	-54.628	-112.288
Domestic use	2.734	-8.002	-21.434	-26.701
Total	395.412	-209.625	-59.644	126.143

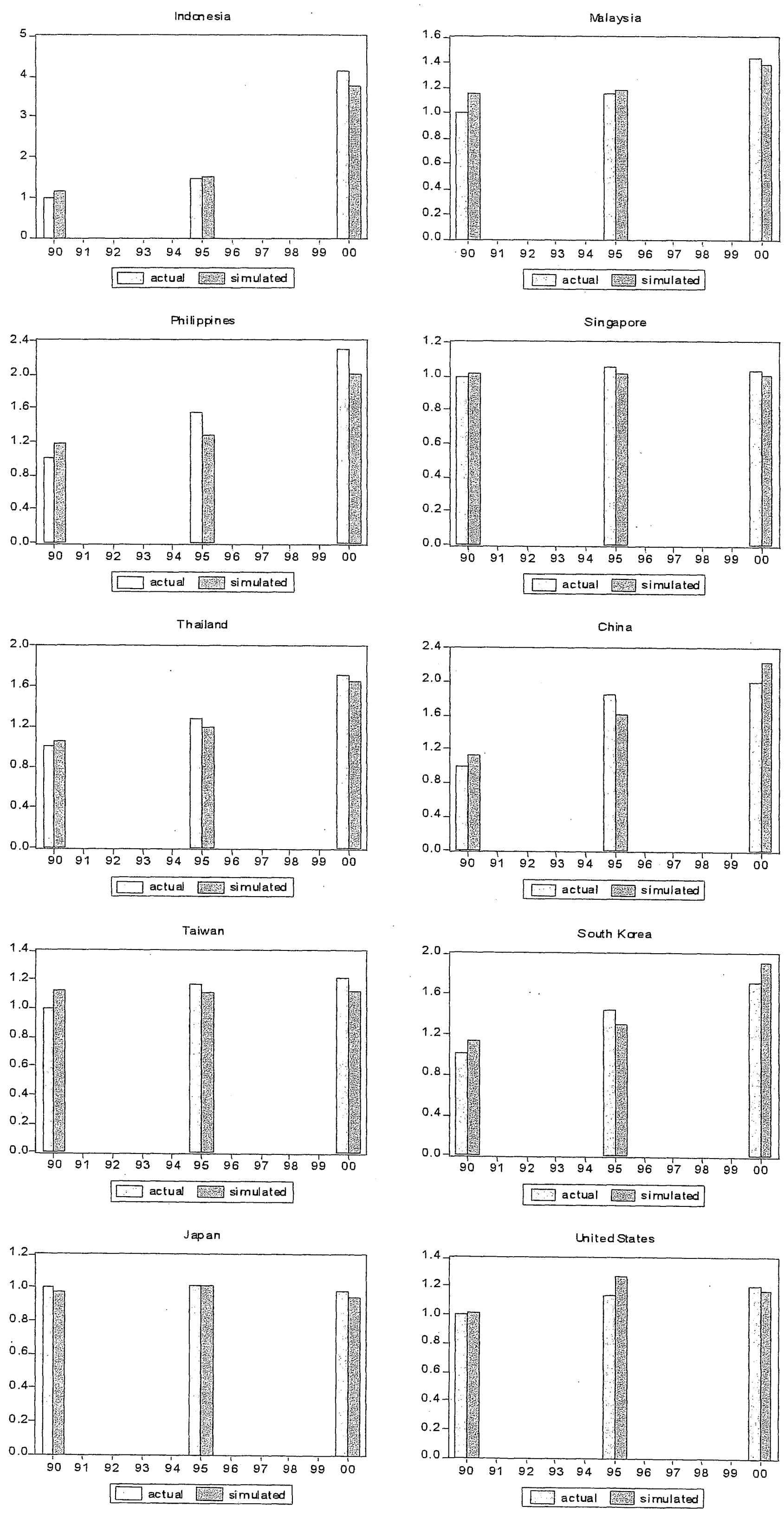

Figure 1. Final Test Results of the Weighted Average of Sectoral Prices

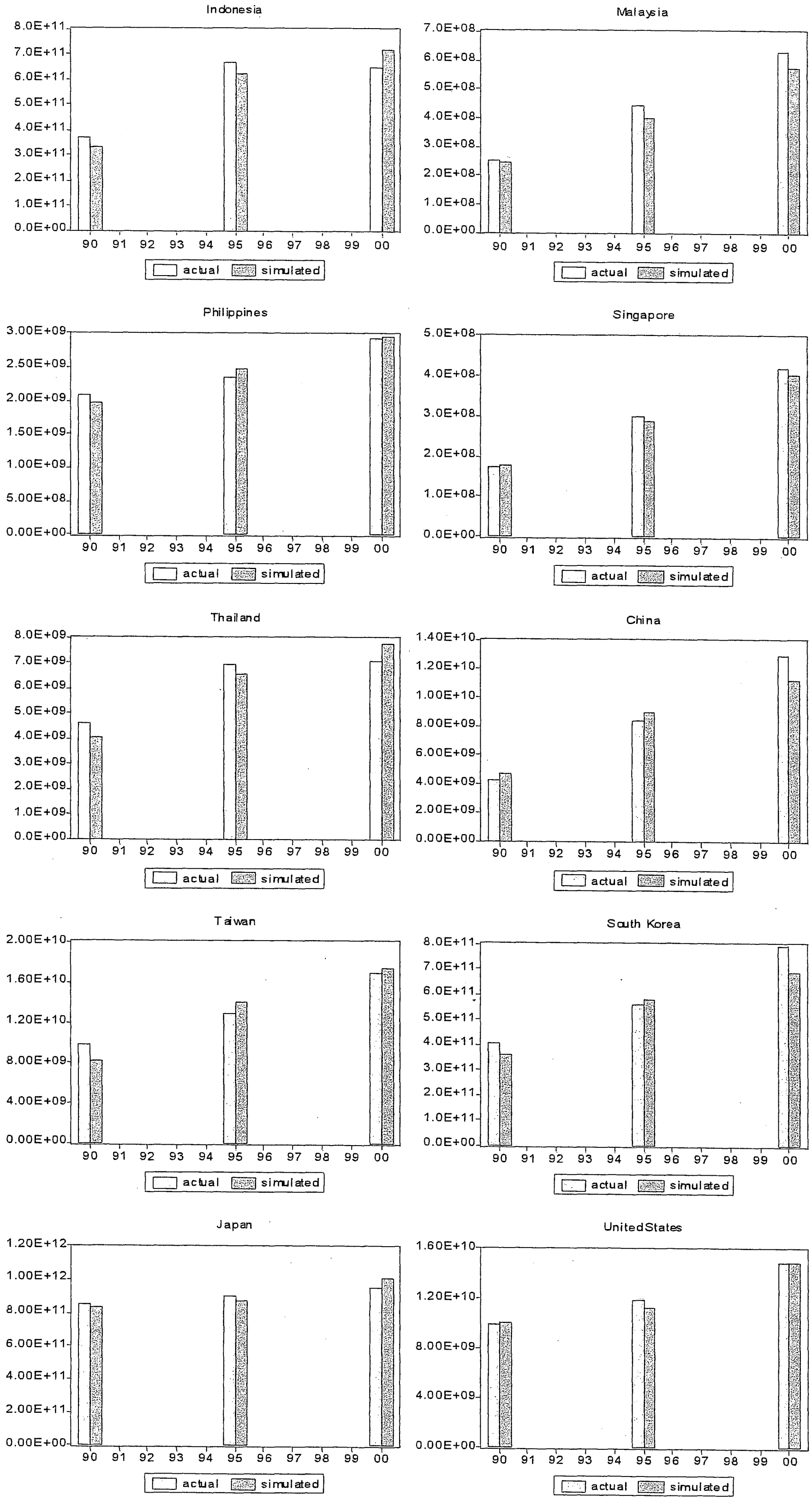

Figure 2. Final Test Results of Output in Total