



Industrial water use, income, trade, and employment: environmental Kuznets curve evidence from 17 Taiwanese manufacturing industries

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Abstract

This paper investigated the relationships between industrial water use, income, trade, and employment for 17 Taiwanese industries from 1998 to 2015. We explored cross-sectional dependent unit root, panel cointegration, and causality tests to estimate their long-term relationships and causal nexus. There existed long-term equilibrium relationships among the variables. The long-term elasticity estimates of industrial water use with respect to income, squared income, trade, and employment are 4.27, -0.15 , 0.22, and 0.92, respectively. The results do not confirm an inverted U-shaped environmental Kuznets curve. A unidirectional causal relationship is found between water use and income, and a bidirectional causal relationship is identified between water use and employment. Exports cause industrial water use. As expected, both employment and exports lead to income. Hence, policy makers should promote investment into water efficiency and water recycling. Various governments reward firms for water efficiency and lower consumption without negative long-term effects on economic growth.

Keywords Industrial water use · Trade · Income · Environmental Kuznets curve · Causality test · Panel cointegration test

Introduction

Water use has been rapidly increasing around world. Drought and unstable rainfall create more serious water-use problems. Water shortages already affect every country. According to Mekonnen and Hoekstra (2016), four billion people face severe water scarcity where approximately two thirds of the global population live under conditions of severe water scarcity. WWDR (2009) also indicated that including arid and semi-arid regions, between 24 million and 700 million people will be displaced by 2030. Besides drought and insufficient rainfall, water pollution and industrial development are the two major driving forces of water demand. Increases in water use will put greater pressure on national development. Therefore, ample freshwater becomes a vital resource to

maintain economic and human development. Various governments are carrying out water sustainability and management policies to overcome the water scarcity challenge. The purpose of this study is to explore the long-term equilibrium relationships and causalities among industrial water use, income, trade, and employment. A quadratic environmental Kuznets curve (EKC) is used to examine their relationships. Because a few studies use industrial or sectoral data to examine this issue, this study focuses on the linkages between water use (as an environmental indicator), income, trade, and employment for 17 industries via EKC studies. Based upon our empirical analyses, some policy implications are put forward in this work, which are significant for industrial water management for the future.

Most EKC studies have investigated energy consumption, which is closely related to income (i.e., Sardorsky 2012; Lean and Smyth, 2010; Lu 2016). The existing studies in the past two decades have seen an emerging line of literature that has analyzed the nexus of CO₂ –energy–growth–trade (Kyophilavong et al. 2015; Shakeel et al. 2014). Additionally, several studies have focused on the causal relationship between renewable energy, CO₂ emissions, and economic growth (Destek 2016; Jebli et al. 2015). Meanwhile,

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many studies have focused on the CO₂–energy–growth–FDI nexus (Peng et al. 2016; Omri et al. 2014). Some empirical studies on EKC have considered the evolution of economic structure, for example, the relationship between energy and technological innovation (Sohag et al. 2015), energy efficiency and energy technologies (Linares and Labandeira 2010), and investment in pollution abatement (Dinda 2004). A few works have examined the relationship between income and water use at the national level, such as biological oxygen demand (Lee et al. 2010), water withdrawal per capita (Duarte et al. 2013), industrial water use per capita (Jia et al. 2006; Gu et al. 2017), water use per capita (Katz 2015), and annual water use (Sun and Fang 2018). The EKC studies on water resources have mixed results and are unclear. There is little published on EKC examination for water and income at the industrial level. Thus, this study focuses on the links among water use, income, trade, and employment at the industrial level which is worth investigating.

As mentioned earlier, previous studies have investigated the relations between water use, income, and other relevant determinants for the EKC hypothesis. However, those studies still have scope for refinement. The motivations of this study are as follows: First, the industrial use of water has recently been increasing and sewage is directly disposed of into the water. Most water scarcity issues are focused on agricultural irrigation, and few studies concentrate on industrial water use. This study sheds light on the relation between industrial water use, income, trade, and employment. Income, trade, and employment are all important social–economic variables and are related to water consumption and environmental protection. Second, many existing studies applied the time series or panel data models to investigate this issue. However, cross-sectional dependence may exist when the number of cross-sectional units becomes large. Therefore, this study extends previous empirical methods considering cross-sectional dependence and utilizes a new econometric method for empirical research. This present study contributes to literature on industrial water use, income, trade, and employment in several ways. First, most of the previous studies have focused on the water–income–trade–employment nexus for agriculture or the country-level; however, few have focused on manufacturing. Manufacturing is more important for a developing country, especially one in Asia. The evidence of the water–income–trade–employment nexus can fill the gap in literature. Second, this study applies a new panel cointegration model to estimate the relationships among water use, income, trade, and employment. By estimating the model, a better understanding of the long-term and cointegration relationships between those variables can be obtained. The causalities between industrial water use, income, trade, and employment also help us to explain the causal direction and to provide economic evaluation. Then, various governments can set up water management policies and plans based upon the findings. Third, because the sample

size of previous studies and the time periods have been relatively small (usually 9 years: 1900, 1940, 1950, 1960, 1970, 1980, 1990, 1995, and 2000 from the UNESCO database and country-level data), the results of previous empirical studies are mixed due to data choices, model specification, and econometric approach. This study used panel data which combined a relatively long annual time series from 1998 to 2015 and 17 manufacturing industry data. As Gujarati (2003) mentioned, panel data analysis can enhance the data quality and quantity; the estimated results using the panel data method in this study are more reliable than single equation time series techniques. Fourth, previous empirical studies often measure macroeconomics variables (such as GDP, water withdrawal, trade, etc.) per capita. These macroeconomics variables on a per capita basis do not actually reflect the real situation. For example, water use (withdrawal) per capita is the total consumption of water divided by the population. If total consumption of water increases, then the population will increase more and the water use per capita will drop. However, this real situation does not save water; thus, we obtain the wrong statistical inference. Hence, this study uses the consumption of water use for various industries which is more reasonable. These contributions and results are helpful for establishing economic and water management policies.

The main findings of this study are as follows: First, based upon our empirical framework for balanced panel data over the period 1998–2015, there exists long-term equilibrium relationships among industrial water use, income, trade, and employment. The long-term elasticity estimates of industrial water use with respect to income and squared income are 4.27 and -0.15 , respectively. The results also do not confirm the inverted U-shaped environmental Kuznets curve. The long-term elasticity estimates of industrial water use with respect to exports and employment are 0.22 and 0.92, respectively. Hence, export and employment positively contribute to water use. Growth of exports and employment brings heavy water consumption and pressure upon water use. Policy makers will face the challenge of water related to employment and exports and will seek to promote a balance between economic growth and environmental protection. A unidirectional causal relationship exists between water use and income, and a bidirectional causal relationship is found between water use and employment. The causality relationship between industrial water use, income, and exports is in accordance with the cointegration results. Regarding exports and water use, we find that exports cause industrial water use. Not surprisingly, both employment and exports cause income. Hence, policy makers should promote investment into water use efficiency and water recycling. Various governments reward firms for water efficiency and lower consumption without negative long-term effects on economic growth.

Literature review

Background of water use efficiency

As income rises, the amount of water use increases. However, water is an important and scarce input for production, especially for agriculture and manufacturing. Many countries face severe shortages of water. Because of climate change, extreme rainfall varies widely both by region and season. Apart from water quantity concerns, water conservation through efficiency upgrades is vital for agriculture because it is the sector that has been directly related to water use in the past. Some researchers have analyzed irrigation water use efficiency for the agriculture sector (Van Halsema and Vincent 2012; Hong and Yabe 2016; Dutta 2014; Molden et al. 2010). Because the dry season becomes longer, plant growth relies on irrigation instead of rainfall. The water use efficiency of irrigation is important for those areas and countries. The appropriate econometric method such as stochastic frontier analysis (SFA) or DEA applied to investigate relevant empirical issues. This strand of literature focuses on the following contributions. First, the input–output relationships are analyzed and efficiency scores are obtained. Those analyses attempt to justify whether or not the decision-makers operate with effectiveness. Second, the analyses emphasize that the socio-economic factors must take into account efficiency determinants. If water use efficiency has been examined, an adequate program or policy could be carried out to improve water shortage. The subsequent research has not been limited to the analysis of agricultural water use.

Based on the above analysis, we found that most of the previous literature was focused on water use efficiency in agriculture or utilized country-level data. Various SFA or DEA models were usually applied to investigate the water efficiency score and its determinants and then provide some insights regarding water consumption. Both of DEA and SFA model were easy to calculate water efficiency scores and compare with that of every decision-maker. However, previous studies suffered from some drawbacks; for example, the assumption of functional form is very arbitrary in SFA whereas confidence intervals of efficiency in DEA highly depend on the model choices.

Background of the EKC hypothesis

Another strand of literature investigates the environmental Kuznets curve (EKC) between pollution indicators (i.e., carbon dioxide emissions, greenhouse gas emissions, etc.), and income. On the whole, all previous studies have examined the existence of an inverted-U curve between

various pollutants and income. For example, many previous studies examined the EKC including carbon dioxide–GDP (Kais and Sami, 2016; He and Richard 2010; Lu 2016), greenhouse gas emissions–GDP (Dogan and Seker 2016; Bilgili et al. 2016; Lu 2017), deforestation–GDP (Culas, 2007; Waluyo and Terawaki, 2016), PM₁₀ – GDP (Akbostancı et al. 2009), and land–GDP (Al-Mulali et al. 2015). There are many econometric methods including the time series model, panel cointegration method, and causal analysis which are used for examining the existence of an EKC. Up to this moment, the EKC hypothesis has not yet drawn a consistent conclusion while the debate of EKC is still ongoing.

As far as empirical studies are concerned, there are a few studies which have analyzed the link between water resources and income (relevant studies are summarized in Table 1). Similarly, the empirical results also remain mixed. The reasons for this are not only the lack of sufficient water data (between six and nine data points from the World Bank database (WDI)) but also various kinds of econometric methods applied. For example, Sun and Fang (2018) applied a non-parametric method to deal with the examination of EKC to avoid the linear specifications between variables. Sun and Fang (2018) found that only a few countries demonstrated an inverted U-shaped EKC; a majority of countries presented randomness in water use most likely because of limited data. For evidence of data in the provinces of China, Sun and Fang (2018) found that the results supported EKC in 11 out of 31 provinces. Duarte et al. (2013) presented a panel smooth transition regression approach to examine the EKC for water use; they found that there existed a non-linear link between water use per capita and income. Their results also showed that water use tended to increase with the lowest income observations; however, the trend reversed when income became greater. Lee et al. (2010) applied the dynamic generalized method of moments (GMM) approach to investigate the EKC hypothesis; their empirical results showed

Table 1 Summary statistics

| Variables | Mean | Standard deviation | Minimum | Maximum |
|----------------|--------|--------------------|---------|---------|
| $W_{i,t}$ | 3.82 | 1.38 | 0.34 | 5.92 |
| $GDP_{i,t}$ | 12.44 | 1.24 | 9.93 | 15.31 |
| $EXPORT_{i,t}$ | 11.75 | 1.35 | 8.67 | 14.93 |
| $L_{i,t}$ | 11.45 | 0.79 | 10.21 | 13.75 |
| $GDP^2_{i,t}$ | 156.22 | 30.84 | 98.57 | 234.54 |

Industrial water use is measured in millions of cubic meters. Industrial employment is measured in thousands of people. Exports and gross domestic product (GDP) of various industries are measured in US dollars and in New Taiwan dollars (in millions), respectively. Employment, export, and GDP help explain water consumption. All variables are expressed in the form of natural logarithms

evidence of an inverted U-shaped EKC in Europe and America, but not in Asia, Africa, and Oceania. Zhang et al. (2017) presented an extra water quality index, namely with chemical oxygen demand (COD) discharge and ammonia nitrogen ($\text{NH}_3 - \text{N}$) as a proxy of water pollution. By using a widely applied panel cointegration method, their results showed that a long-term bidirectional causality between economic growth and COD/ $\text{NH}_3 - \text{N}$ existed in China and found evidence in support of an inverted U-shaped EKC curve. Cole (2004) used a reduced-form model to study the EKC hypothesis, and found evidence of the inverted U-shaped EKC. Katz (2015) aimed to elucidate the link between income growth and water use and found that the existence of an EKC depended upon the choice of datasets. Katz (2015) also found the existence of an EKC in the case of agriculture, but it monotonically increased with respect to income by using a nonparametric density regression. The application of a variety of empirical methods has led to more mixed and unclear results.

The mixed evidence for EKC hypotheses also appeared in various kinds of water use. Some scholars have paid attention to different types of water use especially in the case of industrial water use. For example, Gu et al. (2017) investigated industrial water use and economic growth for various regions in China. The industrial water use and GDP showed an inverted U-shaped curve, and the GDP per capita at the turning point of the inverted U-shaped curve was 18,000–30,000 yuan. Further evidence of industrial water use and GDP such as Jia et al. (2006) also showed an inverted U-shaped EKC in their OECD sample. According to the results of Jia et al. (2006), the income threshold corresponding to the turning point of industrial water use varied across the OECD countries in the range of 10,000–25,000 USD/capita (1995 constant prices). The conclusions of Hemati et al. (2011) also proved the existence of an inverted U-shaped EKC between industrial water use and income that was similar to that of Jia et al. (2006) or Gu et al. (2017). For the evidence of water use in agriculture, Bhattarai (2004) showed an inverted U-shape between irrigation and income using country-level annual data from 66 tropical countries for the time period from 1972 to 1991. Regarding other indicators for water use, some scholars have used water footprints instead of water withdrawal. Hence, Miglietta et al. (2017) investigated the EKC hypothesis using a given country's water footprint as an index of water usage and found that the EKC did not hold. As above-mentioned, the relationship between water use and income remains mixed and is worthy of further investigation to consider additional control variables. Based on our discussion, the empirical analysis of EKC hypothesis has been applied to various pollutants. Various time series or panel data models have been used to investigate the $\text{CO}_2 - \text{GDP} - \text{GDP}^2$ nexus. The mixed evidence regarding EKC hypotheses is partly due to differences in econometric methods and datasets. Future research

could exploit new econometric methods to proceed with the relevant research. Recently, some studies have focused on the water use – GDP – GDP^2 relation and evidence of inverted U EKCs was found. (Gu et al. 2017; Jia et al. 2006; Hemati et al. 2011). However, most studies list drawbacks, namely econometric issues such as heterogeneity (Vollebergh et al., 2009) and spatial dependence (Aslanidis, 2009). Hence, the empirical results may lead to erroneous conclusions. For this study, an econometric method that considers cross-dependence may be more efficient in capturing the inverted-U EKC for water use. Thus, the main motivation of this study is to extend econometric methods considering cross-sectional dependence to investigate the relation between water use, income, trade, and employment.

Literature review on water use, exports, and employment nexus

Water footprints are a well-known concept. Water is an extremely valuable resource that enables the production of various commodities such as food and agricultural products. The water footprint concept, first introduced and calculated by Hoekstra (2003), refers to the water resources used to produce commodities and the export of water to other countries. Water-rich countries export water-intensive products to countries with water scarcity. Chen and Chen (2013), Hoekstra and Hung (2005), and Hoekstra and Mekonnen (2012) provided global evidence regarding the relation between virtual water consumption and exports. Additionally, several studies focused on a specific country or region, for example, China (Zhang et al. 2016), Kenya (Mekonnen and Hoekstra, 2014), Germany (Sonnenberg et al. 2009), Spain (Garrido et al. 2010), and India. The evidence from these studies shows that international trade may have an overall positive impact on water consumption/scarcity.

Regarding the relation between water consumption and employment, several studies have analyzed how employment affects water consumption. First, it is widely known that water resources are increasingly important for economic and population growth. Water resources are required not only to meet industrial or agricultural demand but also to meet household and electricity generation needs. According to the UN Water Report (2016), the industrial and service sectors account for the increase in employment along with the global population growth over the period 1991–2014. Additionally, Davijani et al. (2016) introduced a theoretical model for the reallocation of water resources to water-demand sectors and found that it could create an additional 1096 jobs compared to a non-optimal water utilization situation. Another view regarding the link between water consumption and employment is that eco-innovations may have a positive influence on employment (Horbach and Rennings 2013; Horbach 2010; Pfeiffer and Rennings 2001). The development of green technology

could lead to water conservation and a subsequent increase in labor demand. Thus, it is worth mentioning that water use is relevant to employment. When we consider the relation between industrial water use, income, and trade, employment must be included as suggested by previous literature.

Econometric methodology

Following the empirical literature, the EKC model can be used to analyze the links between water use, income, employment, and exports. The panel econometric framework is written as

$$W_{i,t} = \alpha_0 + \alpha_1 Y_{i,t} + \alpha_2 Y_{i,t}^2 + \alpha_3 EXPORT + \alpha_4 L_{i,t} + \varepsilon_{it} \quad (1)$$

In Eq. (1), the subscript i ($i = 1, \dots, 16$) denotes industries and the subscript t denotes the time period ($t = 1, 2, \dots, T$). W denotes industrial water use. Y and Y^2 represent income and income squared, respectively. $EXPORT$ and L represent exports and employment for a given industry, respectively. The coefficient of income and income squared are expected to be positive and negative, respectively. The environmental Kuznets curve predicts that as the income rises, the natural resources tend to increase; then, the pressure on the natural resources tends to decrease after reaching an income threshold. According to the pollution haven hypothesis, developed countries export pollution to developing countries. Developed countries have built more severe environmental laws to decreasingly produce pollution-intensive commodities. So we anticipate α_3 to be positive. Along with economic development and rising income, employment brings job opportunities; however, it may deteriorate environmental quality. We expect α_4 to be positive. This study used Eq. (1) to estimate the relationships between water use, income, exports, and employment. The relationships between those variables have received great attention in the recent three decades while the discussion continues today. Panel cointegration methods are widely used to investigate their relationships. In addition, panel estimation models have many merits which are attractive because they have more degrees of freedom and efficiency than individual time series. First of all, we use the unit root test to check if the data is stationary and investigate the cross-sectional dependence. Second, we utilize Pedroni’s panel cointegration test to explore the long-term equilibrium between variables. Finally, this study provides the details of the Granger causality test.

Panel cross-sectional dependent test and unit root test

Recent econometric research has concluded that panel data models are likely to exhibit substantial cross-sectional

dependence in the errors, which may arise because of common shocks, spatial dependence, and unobserved components. Phillips and Sul (2003) showed that if sufficient cross-sectional dependence exists in the data and dependence is ignored in the estimation, then the estimator will be biased and inconsistent, especially when time periods are rather small and cross-section units or series are large. Pesaran (2004) provided the following statistic based on the LM statistic proposed by Breusch and Pagan (1980):

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \quad (2)$$

where $\hat{\rho}_{ij}$ is the sample estimate of the pairwise correlation of the residuals and is defined as follows:

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t=1}^T \hat{u}_{it} \hat{u}_{jt}}{\left(\sum_{t=1}^T \hat{u}_{it}^2 \right)^{\frac{1}{2}} \left(\sum_{t=1}^T \hat{u}_{jt}^2 \right)^{\frac{1}{2}}} \quad (3)$$

The null hypothesis is no cross-sectional dependence (i.e., $H_0 : \rho_{ij} = cor(u_{it}, u_{jt}) = 0$ for $i \neq j$). Under the null hypothesis of no cross-sectional dependence, $CD \rightarrow^d N(0, 1)$ for $N \rightarrow \infty$ and T is sufficiently large.

As a next step, we have to check the existence of the unit root for all variables used in this paper. Econometric literature suggests that panel-based unit root tests have higher power than unit root tests based on individual time series. As a recent unit root test approach, Pesaran (2007) proposed a cross-sectional dependence IPS test; it allows the existence of cross-section dependence. As Pesaran (2007) mentioned, ignoring the existence of cross-section dependence in panel unit root tests will lead to considerable size distortions and misleading conclusions. Because the industrial data is used to investigate our issue, every industry shared common factors in the given country and we suspect the existence of cross-sectional dependence between various industries. In this paper, we also apply the panel unit root test which is proposed by Pesaran (2007) and we consider cross-sectional dependence between the sections. The cross-sectional augmented version of the IPS test proposed by Pesaran (2007) is formed below:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t} + \delta_i \bar{y}_{t-1} + \sum_{j=0}^k \delta_{ij} \Delta \bar{y}_{i,t-j} + \sum_{j=0}^k \varphi_{ij} \Delta y_{i,t-j} + \epsilon_{i,t} \quad (4)$$

where $\bar{y}_{t-1} = \frac{1}{N} \sum_{i=1}^N y_{i,t-1}$ and $\Delta \bar{y}_t = \frac{1}{N} \sum_{i=1}^N \Delta y_{i,t}$. Pesaran (2007) proposed a cross-sectional augmented version of the IPS test (CIPS) as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^N CADF_i \quad (5)$$

where $CADF_i$ is the $CADF$ statistic for the i th cross-sectional unit given by the t statistic of the estimate of ρ_i . If the null hypothesis of the unit root is rejected, then one can claim that $y_{i,t}$ is stationary and has no unit root.

Westerlund’s (2007) panel cointegration test

This study applies Westerlund’s (2007) panel cointegration tests, which include two group-mean tests and two panel tests. The merit of this new cointegration test is that it is free from common factor restriction and addresses the problems of cross-sectional dependence by bootstrapping the critical values of the test statistics. Based on Eq. (1), the error correction model (ECM) can be presented as follows:

$$\Delta W_{i,t} = \delta'_i d_t + b_i \left(W_{i,t-1} - \alpha_{1i} Y_{i,t-1} - \alpha_{2i} Y_{i,t}^2 - \alpha_{3i} EXPORT_{i,t} - \alpha_{4i} L_{i,t} \right) + \sum_{j=1}^{p_i} \varphi_{1ij} \Delta W_{i,t-j} + \sum_{j=1}^{p_i} \varphi_{2ij} \Delta Y_{i,t-j} + \sum_{j=-q_i}^{p_i} \varphi_{3ij} \Delta Y_{i,t}^2 + \sum_{j=-q_i}^{p_i} \varphi_{4ij} \Delta EXPORT_{i,t-j} + \sum_{j=-q_i}^{p_i} \varphi_{5ij} \Delta L_{i,t-j} + e_{i,t} \tag{6}$$

where b_i determines the speed at which the system returns to the equilibrium relation $W_{i,t-1} - \alpha_{1i} Y_{i,t-1} - \alpha_{2i} Y_{i,t}^2 - \alpha_{3i} EXPORT_{i,t} - \alpha_{4i} L_{i,t}$ after a sudden shock. If $b_i < 0$, then $W_{i,t}$, $Y_{i,t}$, $EXPORT_{i,t}$, and $L_{i,t}$ are cointegrated; if $b_i = 0$, then no error correction has occurred. We can depict the null hypothesis of no cointegration as $H_0 : b_i = 0$ for all i . The alternative hypothesis depends on assumptions about the homogeneity of b_i . According to Westerlund (2007), the statistics of group-mean tests can be computed as follows:

$$D_\tau = \frac{1}{N} \sum_{i=1}^N \frac{\hat{b}_i}{SE(\hat{b}_i)} \tag{7}$$

$$D_\alpha = \frac{1}{N} \sum_{i=1}^N \frac{T\hat{b}_i}{\hat{b}_i^*} \tag{8}$$

The other pair of Westerlund’s (2007) tests is called panel tests. These tests assume that b_i is equal for all i and are designed to test H_0 versus $H_1^p : b_i = b < 0$ for all i . The panel statistics are as follows:

$$P_\tau = \frac{\hat{b}}{SE(\hat{b}_i)} \tag{9}$$

$$P_\alpha = T\hat{b} \tag{10}$$

The first two tests are designed to examine the alternative hypothesis that the entire panel is cointegrated, while the latter two tests examine an alternative hypothesis wherein at least one unit is cointegrated.

The coefficients of Eq. (1) are interpreted as long-term elasticities. Previous panel data studies assumed cross-sectionally independent errors; however, if the cross-section dimension is larger, the problem of cross-sectional dependence becomes significant. As mentioned earlier, cross-sectional dependence exists in this study. Several possible estimators in econometric literature, such as the common correlated effects mean group (CCEMG) estimator (Pesaran 2006), can be utilized for estimation. The econometric model is assumed as follows:

$$W_{i,t} = \alpha_{0i} + \alpha_{1i} Y_{i,t} + \alpha_{2i} Y_{i,t}^2 + \alpha_{3i} EXPORT_{i,t} + \alpha_{4i} L_{i,t} + \varepsilon_{i,t} \tag{11}$$

$$\varepsilon_{i,t} = \omega_i f_t + \mu_{i,t} \tag{12}$$

where f_t is an unobserved common factor, ω_i is the factor loading, and $\mu_{i,t}$ is the assumed white noise. The average dependent and independent variables for all observable variables were computed and then included as explanatory variables in each of the N regression equations. Pesaran (2006) suggested using the CCEMG estimator, which is a simple average of the estimators of the individual slope coefficients (For a good accessible discussion, see Eberhardt (2012)). The advantage of the CCEMG estimator is that it does not require an a priori knowledge of the number of unobserved common factors. Additionally, Pesaran (2006) showed that the CCEMG estimator is asymptotically unbiased for true parameters.

Panel causality test

In this paper, we continue to perform the panel Granger causality to examine the causal relationships between water use, income, exports, and employment. We apply the panel causality test developed by Dumitrescu and Hurlin (2012) (DH) to detect the causal relationships between variables. The panel data model is considered as follows:

$$y_{i,t} = \alpha_i + \sum_{k=0}^K \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^K \beta_i^{(k)} x_{i,t-k} + \epsilon_{i,t} \tag{13}$$

where K represents the lag length; x and y denote each variable under the consideration of variables observed for N individuals in T periods in our model; α_i are the fixed individual effects; $\gamma_i^{(k)}$ are the autoregressive parameters; and $\beta_i^{(k)}$ represent the regression coefficients varied across industries. The homogeneous non-causality hypothesis and its null are defined as

$$H_0 : \beta_i = 0, \forall i = 1, \dots, N \text{ with } \beta_i = (\beta_i^1, \beta_i^2 \dots \beta_i^{(k)})$$

$$H_1 : \beta_i \neq 0, \forall i = 1, \dots, N$$

$$\beta_i \neq 0, \forall i = N_1 + 1, N_1 + 2, \dots, N$$

Dumitrescu and Hurlin (2012) put forward the average statistic $W_{NT}^{HNC} = \frac{1}{N} \sum_{i=1}^N W_{i,t}$, where $W_{i,t}$ are the individual Wald statistical values for the each country. Under the null hypothesis of non-causality, each individual Wald statistic converges to a chi-squared distribution. The average statistic (W_{NT}^{HNC}) has an asymptotic distribution associated with the null hypothesis. The standardized test statistic Z_{NT}^{HNC} for $T, N \rightarrow \infty$ is as follows:

$$Z_{NT}^{HNC} = \sqrt{\frac{N}{2K}} (W_{NT}^{HNC} - K) \rightarrow N(0, 1) \tag{14}$$

For fixed T samples, the standardized test statistic Z_{NT}^{HNC} is as follows:

$$Z_{NT}^{HNC} = \sqrt{\frac{N}{2K} \times \frac{T-2K-5}{T-K-3}} \times \left[\frac{T-2K-3}{T-2K-1} W_{NT}^{HNC} - K \right] \rightarrow N(0, 1) \tag{15}$$

The statistics of the DH test are asymptotically well-behaved using Monte Carlo simulations and follow a standard normal distribution.

Data and sources

This study employs balanced panel data (composed of time series and cross-sectional data) for 17 Taiwanese manufacturing industries, namely beverages and tobacco, textile mills, clothing apparel and accessories, leather fur and related products, wood and bamboo products, pulp, paper, paper products, chemical materials, chemical products, petroleum and coal products, rubber products, plastic products, non-metallic mineral products, basic metals, fabricated metal products, machinery and equipment, computers, electronics and optical products, and transportation equipment produced from 1998 to 2015. The data is collected from the Directorate-General of Budgets, Accounting and Statistics, National Statistics and Trade Statistics from the Bureau of Trade in Taiwan. In order to find the relationships between industrial water use, income, exports, and employment, the specifications of the empirical model and variables included refer to previous studies. The dependent variable is industrial water use which is measured by millions of cubic meters. The explanatory variables include industrial employment (measured by thousands of people), exports of various industries (calculated by USD), and gross domestic product (GDP) for various industries (measured by millions in NTD). Summary data for all variables are reported in Table 2. Logarithmic transformation of data was performed.

Empirical results

This study analyzed the long-term relationships of industrial water use, income, exports, and employment for 17 industries

in Taiwan. First, in order to test the hypothesis of cross-sectional dependence, we used Pesaran’s (2004) CD test. As the result reported, the statistic of the CD test was 5.88 which strongly rejected the null hypothesis of no cross-sectional dependence. To avoid the possible pitfall of the CD test, we also computed the average absolute value of the off-diagonal elements of the cross-sectional correlation matrix of residuals. Here, the average absolute correlation was 0.34, which was a very high value. Thus, enough evidence suggested the presence of cross-sectional dependence for 17 industries. Second, we used the CIPS test to examine the series for industrial water use (W), income (Y), squared income (Y^2), exports ($EXPORT$), and employment (L) during 1998–2015. The test results of the panel unit root are shown in Table 3. The results show that all variables did not reject the null hypothesis of the unit root but that all variables rejected the null hypothesis of the unit root after taking the first difference. These results indicated that all variables were nonstationary at that level; however, they became stationary after considering the first difference. Therefore, all variables had unit roots and were $I(1)$. Given the results of the panel unit roots, the application of the Westerlund (2007) cointegration approach was appropriate. We set the optimum lag term to 1 and then calculated Westerlund’s (2007) four statistics to verify the long-term relation between industrial water use, income, exports, and employment. The results of the panel cointegration tests for both the group-mean tests and the panel tests are reported in Table 4. There were two group-mean statistics, namely D_τ and D_α , and two panel statistics, namely P_τ and P_α . Both D_τ and P_τ were significant at the 1% level. These tests rejected the null hypothesis of no cointegration at the 1% level. This means that a cointegration relation or long-term equilibrium exists between water use, income, exports, and employment for the 17 industries in Taiwan.

After confirming the long-term relation between water use, income, exports, and employment, the next step was to estimate the long-term relations using CCEMG. The CCEMG estimation results are reported in Table 5. The sign of coefficients of the regressors was as expected. A 1% increase in income will lead to a 4.27% increase in water use. However, a 1% increase in squared income will insignificantly decrease

Table 2 Results of cross-sectional dependence tests

| | Test statistic |
|---|-------------------|
| Pesaran’s CD test | 5.88*** (0.00) |
| Average absolute correlation of the residuals | 0.34 |

The null hypothesis is cross-sectional independence (H_0 : cross-sectional independence). If we reject H_0 (null hypothesis), it implies that cross-section dependence exists

**Statistical significance at the 5% level and the p value is reported in parentheses

Table 3 CIPS test results

| Variables | CIPS test statistics | |
|----------------|----------------------|-------------------------|
| | Level series | First difference series |
| $W_{i,t}$ | -2.04 | -4.01*** |
| $GDP_{i,t}$ | -1.70 | -3.01*** |
| $EXPORT_{i,t}$ | -1.22 | -3.03*** |
| $L_{i,t}$ | -7.70 | -2.84*** |
| $GDP^2_{i,t}$ | -1.98 | -3.02*** |

If we reject the null hypothesis of the unit root, then we can claim that the variable is stationary and has no unit root

***Statistical significance at the 1% level

water use by 0.15%. These results suggest that an increase in income leads to a deterioration in environmental quality (more water use); however, a given industry does not seek to improve its water use efficiency after a certain level of economic growth. The coefficient of income is significant, but the coefficient of squared income is not; this result suggests that an inverted-U EKC does not exist. This finding is not consistent with previous studies such as Duarte et al. (2013) and Cole (2004). The coefficient of exports ($EXPORT_{i,t}$) was positive but insignificant; this means that water consumption was not influenced by export trade. There is no evidence for these industries to support that exports lead to the environmental degradation. The evidence of the exports–water use nexus was not consistent with Lee et al. (2010) and Gassebner and Lamla (2006). The coefficient of employment ($L_{i,t}$) was positive and significant, suggesting that water consumption may have been affected by employment. Some manufacturing processes rely on water use. Heavily water-dependent sectors, including the manufacturing (food, textiles, beverages, etc.) sector, require a labor force to produce commodities, which is consistent with evidence from the agriculture, forestry, and fisheries sectors.

The evidence of the water–income–trade–employment linkage for the various industries considered in this study has some implications: First, the results are quite different

Table 4 Panel cointegration test results

| | Westerlund panel cointegration test | |
|------------|-------------------------------------|-----------------|
| | Statistic | <i>p</i> values |
| D_τ | -2.41*** | 0.00 |
| D_α | -0.68 | 1.00 |
| P_τ | -8.89*** | 0.01 |
| P_α | -0.96 | 0.98 |

If we reject the null hypothesis of no cointegration for group-mean tests, we can claim that the variables are cointegrated for the entire panel. If we reject the null hypothesis of no cointegration for panel tests, we can claim that at least one unit is cointegrated

***Significant at the 1% level

Table 5 CCEMG estimation results

| | CCEMG estimators | |
|----------------|------------------|-----------------|
| | Coefficient | <i>p</i> values |
| $Y_{i,t}$ | 4.27* | 0.09 |
| $Y^2_{i,t}$ | -0.15 | 0.55 |
| $EXPORT_{i,t}$ | 0.22 | 0.38 |
| $L_{i,t}$ | 0.92*** | 0.01 |

***Significant at the 1% level

*Significant at the 10% level

from those obtained for the country-level data. Various governments could design different environmental policies for every industry. While there is substantial historical country-level evidence for the water use–income relation, it does not imply that this relation exists at the industrial level. Second, this study found that a cross-sectional dependence exists; consequently, we used more suitable econometric approaches to investigate the water–income–trade–employment nexus in comparison with previous studies. Third, two important variables—export and employment—are of great concern in developing countries. Some economists have highlighted that resource overexploitation could damage the environment. Regarding the water footprint, if one industry (for example, agriculture) exports water-related products, this industry may be exposed to water risk during a period of unstable rainfall. Scarcity of water resources affects the economic growth of a country. Additionally, the results of this study indicate that there is a strong relation between employment and water use; this means that water conservation, particularly in traditional manufacturing, may lead to unemployment. Thus,

Table 6 Panel causality test results

| | W^{HNC} | Z^{HNC}_{NT} |
|---|-----------|----------------|
| Y does not homogeneously cause W | 3.22 | 1.04 |
| W does not homogeneously cause Y | 4.13** | 2.27** |
| L does not homogeneously cause W | 5.89*** | 4.64*** |
| W does not homogeneously cause L | 4.22** | 2.39*** |
| $EXPORT$ does not homogeneously cause W | 3.69* | 1.67* |
| W does not homogeneously cause $EXPORT$ | 3.28 | 1.13 |
| L does not homogeneously cause Y | 6.49*** | 5.44*** |
| Y does not homogeneously cause L | 3.07 | 0.85 |
| $EXPORT$ does not homogeneously cause Y | 3.77* | 1.78* |
| Y does not homogeneously cause $EXPORT$ | 2.41 | 0.03 |
| $EXPORT$ does not homogeneously cause L | 3.08 | 0.85 |
| L does not homogeneously cause $EXPORT$ | 7.54*** | 6.85*** |

The optimum lag is 2 which is chosen by the Schwarz information criterion

***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level

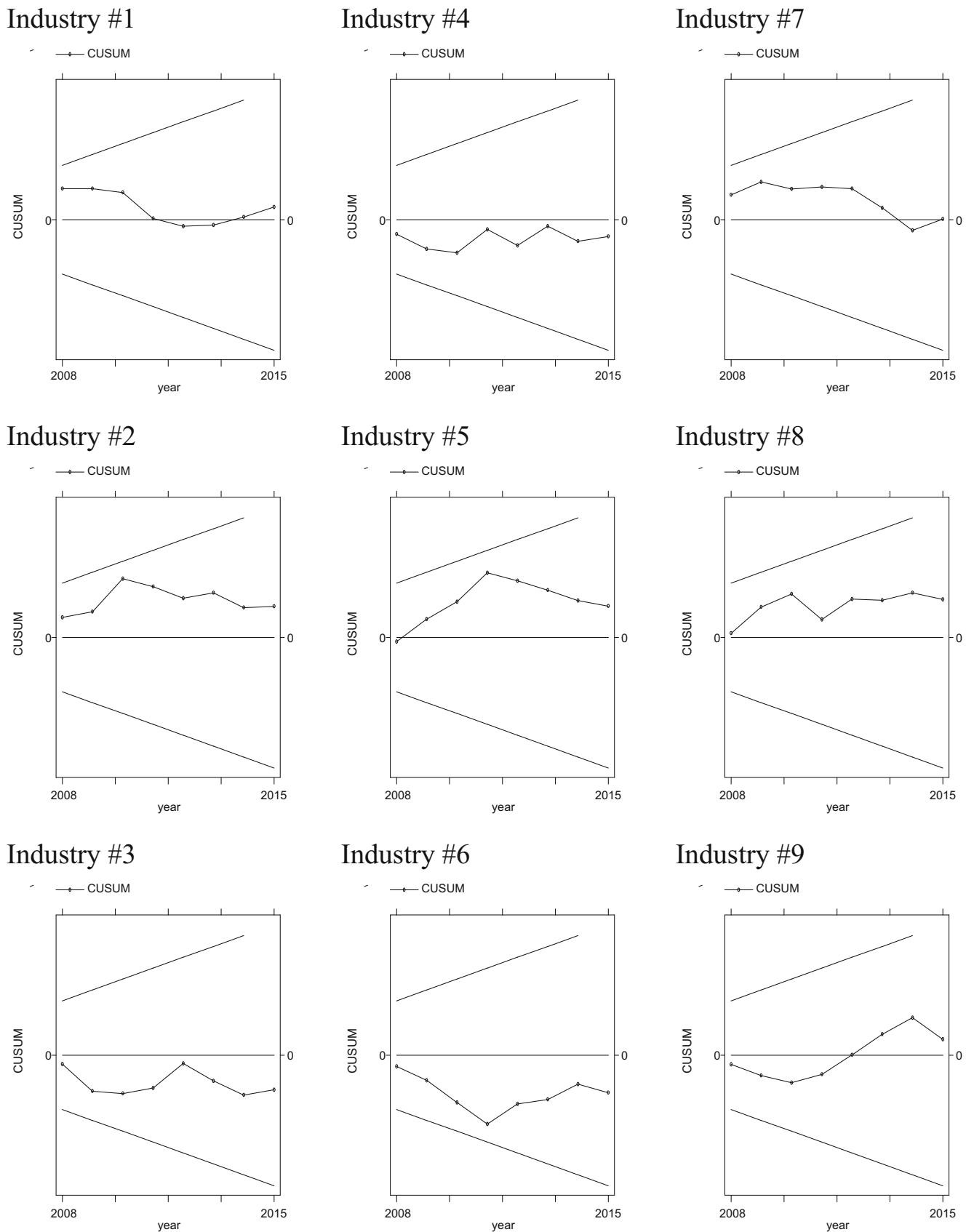
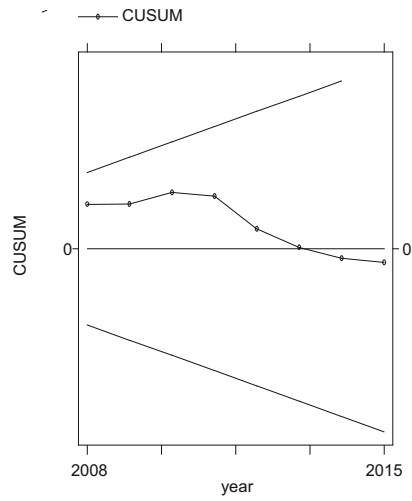
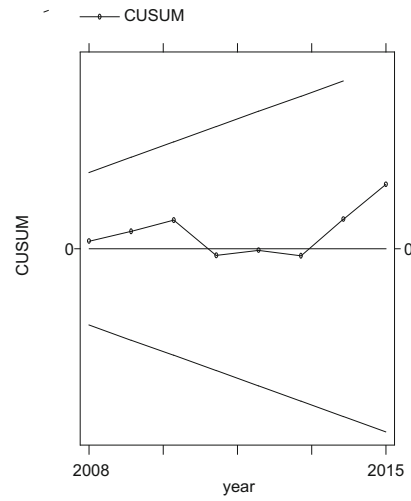


Fig. 1 CUSUM test results

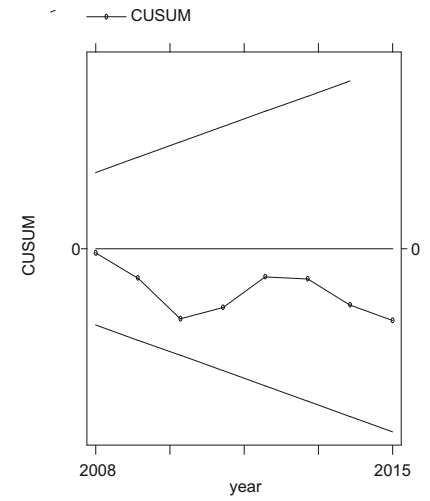
Industry #10



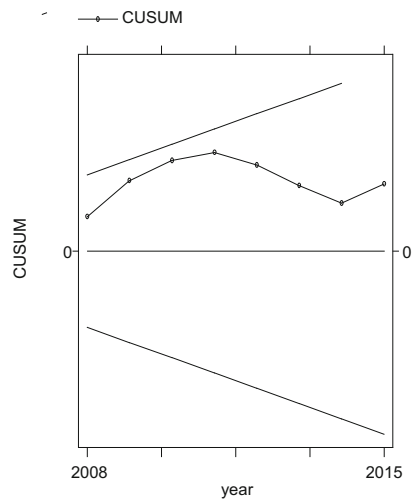
Industry #13



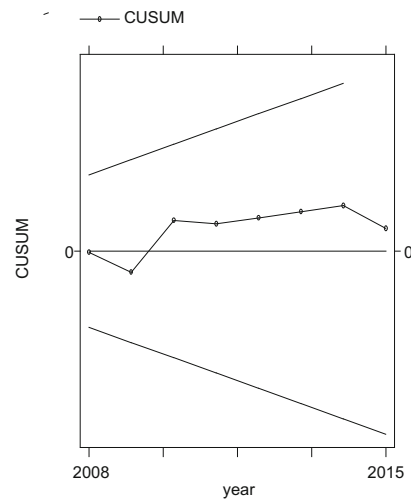
Industry #16



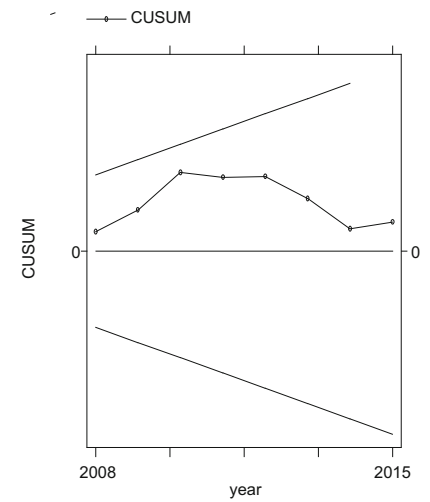
Industry #11



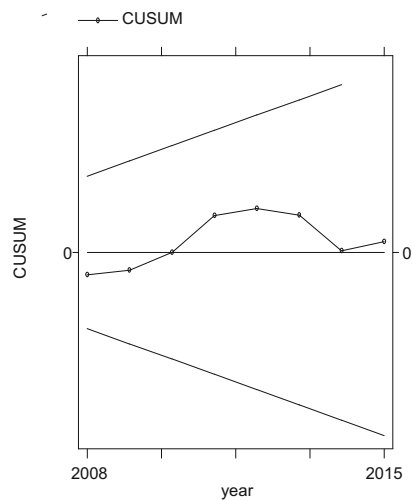
Industry #14



Industry #17



Industry #12



Industry #15

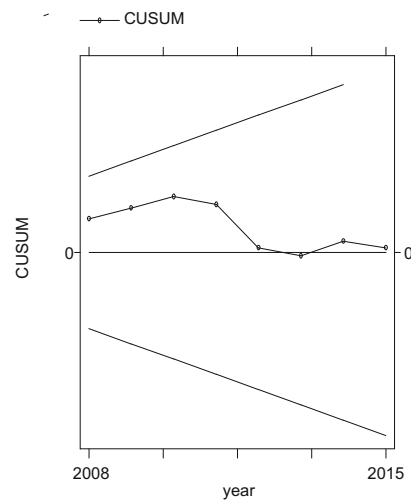


Fig. 1 continued.

industrial executives face two main tasks: First, water scarcity will increase the risk of rising water prices. Many environmental groups and institutions have argued that the water price in Taiwan is too low to enable sustainable development. Therefore, policy makers must solve the problems of water pricing and water-use efficiency. Second, since the EKC hypothesis does not hold, the Taiwanese government should help the various industries to gradually reduce their water use as their income increases over time. This would involve providing more suitable water pricing and other incentives.

We estimated W_{NT}^{HNC} and Z_{NT}^{HNC} proposed by Dumitrescu and Hurlin (2012) to determine the directions of causality between water use, income, employment, and export. The results of the Granger causality test are reported in Table 6. A unidirectional causal relationship existed between water use and income. This result supported that water use played an important role in increasing income. It was not surprising that many industries needed water resources for production. According to the report of the Water Resources Agency in Taiwan, the price of one unit of water in Taiwan is just NT\$ 9, while by comparison in the USA, the price is NT\$ 40. The water price in Taiwan is cheaper than those of most regions of the world. The cheaper water price relates to an average Taiwanese person's consumption of 350 L of water per day. The average water usage in Taiwan is also higher than those in most of the developed countries. Low water prices for a long time provide no incentive for manufacturing firms to produce with water-saving technologies. A bidirectional causal relationship was found between industrial water use and employment; this means that boosting employment brings industrial development and growth, and then followed by higher water use. Water conservation may lead to unemployment as evidenced in the case of our 17 Taiwanese industries. The policy makers in Taiwan need to improve water use efficiency; otherwise, water conservation will reduce employment. As a result of the trade–water use causality relationship, this study found that exports caused greater water use for the Taiwanese industries. The previous empirical studies showed evidence for exports–water use relationships. First, from the evidence of the pollution haven hypothesis (PHH), developed countries have established more serious environmental laws to reduce pollution-intensive products and to import those products from developing countries. Second, per water footprints, water-scarce countries export water-intensive commodities via international trade. Those two points allege the linkage between exports and water use. The causality between water use and exports coincides with those two viewpoints. In addition, Table 6 also shows that both employment and exports cause income. It is not surprising that exports and employment are both important determinants to expand foreign markets and to produce commodities. Our result of the employment–income nexus was similar to those of Apergis and Payne

(2010) and Sardorsky (2012), in which employment was strongly related to output. Besides, we shed light on the causal relationship running between employment and exports. The finding of causality between employment and exports was consistent with Heckscher-Olin factor endowment theory.¹

Finally, this article conducts a diagnostic check. Based on Born and Breitung's (2016) heteroscedasticity-robust test for serial correlation test, the null hypothesis of no first-order serial correlation was not rejected. Additionally, the Lagrange multiplier (LM) test and likelihood ratio (LR) test for heteroscedasticity in residuals were conducted. The statistical results of the LM and LR tests support the absence of heteroscedasticity. In essence, the CUSUM test based on recursive residuals is usually applied to the null hypothesis of parameter stability. When a structural change exists, the estimated residual will become abnormally large. Thus, econometric literature suggests that the CUSUM test is recognized as an essential diagnostic test for time series data. If the CUSUM squared statistics for various industries strays out of the 95% confidence bands, we can reject the null hypothesis of parameter stability. The results of the CUSUM test (reported in Fig. 1) for each industry reveal no structural change.

Conclusions

With the approach used in this study, which includes industrial water use, exports, employment, and income, we find the following results. First, all variables are nonstationary after considering cross-section dependence. Second, there exists a cointegration relationship between industrial water use, exports, employment, and income. After carrying out panel cointegration tests, the four variables used in this work demonstrated long-term equilibrium relationships. Third, the long-term elasticity estimates of industrial water use with respect to income and squared income are 4.27 and -0.15 , respectively. According to the discussion above, we found that as income increases, industrial water use increases as well until some threshold level of income is reached after which industrial water use starts to decline. The water–income–squared income nexus does not confirm the EKC hypothesis. Fourth, the long-term elasticity estimate of industrial water use with respect to exports is positive but insignificant. This result supports that exports do not harm water resources. Actually, most of the water demand is concentrated on agriculture (about 71% in 2012) and is not concentrated on manufacturing, whereas industrial water use accounts for 22% in Taiwan. Fifth, the long-term elasticity of the estimate of industrial

¹ Heckscher-Olin factor endowment theory provides an explanation of trade based on the differences in relative factor endowments. A country or region that is well endowed with labor is expected to produce labor-intensive goods in exchange for capital-intensive goods.

water use with respect to employment is 0.92. Forcing industrial water use reduction for manufacturing may result in unemployment. In practice, Taiwan's ratio of employment in manufacturing to total employment was approximately 27% in 2015. As we expected, such a large share of employment will be affected by saving water. Sixth, the empirical results of causality analysis show that a unidirectional causal relationship exists between water use and income and a bidirectional causal relationship is found between water use and employment; these results also show that the goal between water conservation, economic growth, and employment presents somewhat of a contradiction. Policy makers need to deploy the water conservation programs and promote water use efficiency to avoid detriments to economic development. In addition, export causes industrial water use. This result is in line with the pollution haven hypothesis. It is not surprising that export and employment result in income, which is in agreement with many studies in macroeconomics literature.

For a full view of the links among industrial water use, exports, employment, and income, we recommend several suggestions to various governments. First, policy makers should promote investment into water use efficiency and water recycling. Governments provide rewards for the water-efficient manufacturers. Water recycling equipment also plays an important role in saving water. In practice, water recycling can increase water use efficiency and reduce water waste and the reliance on water resources. Another water conservation solution is to introduce new water-saving technology. New technology can be used to reduce the dependence of water resources and for water saving purposes.

The results have the following policy implications: First, industrial water management is the most important aspect of water resource management due to the increasing risk of water shortage. Policy makers should encourage investment in water conservation technology or water recycling and provide incentives to water-efficient manufacturers. In fact, many industries in Taiwan, such as the semiconductor industry, have staved off water scarcity by utilizing water reclamation equipment while the technology sector has a water recycling rate ranging between 65 and 85%. Several nationwide laws, such as the Reclaimed Water Resources Development Act of December 2015, were passed to mitigate water shortage. Recently, the Taiwanese government announced plans to further develop desalination facilities to ensure a stable water supply for residential and industrial customers. The government expects total water reuse and recovery to become higher than the water consumption. With the passage of water resource acts, the government believes that the water supply will become more stable. Second, exports and employment are both important socio-economic variables. The results indicate that both exports and employment are positively related to industrial water use. A drawback of decreasing water use is that it may lead to reduced exports and unemployment. To

avoid this drawback, water-use efficiency must be increased. Policy makers should encourage higher investment in water conservation technologies or processes. New technologies can be used to reduce the dependence on water resources and increase water conservation.

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