Journal of Hydrology 394 (2010) 347–356

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Estimating the value of El Niño Southern Oscillation information in a regional water market with implications for water management

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ARTICLE INFO

Article history:
Received 22 September 2009
Received in revised form 10 September 2010
Accepted 15 September 2010

This manuscript was handled by Geoff Syme

Keywords:
ENSO
Water transfer
Stochastic water economic model

SUMMARY

This study employs both a stochastic programming without recourse model and a regression approach to estimate the value of the El Niño Southern Oscillation (ENSO) information in the Northern Taiwan regional water market. The empirical estimation results provide several useful implications for water resource management. First, the precipitation of this region is significantly affected by El Niño Southern Oscillation events, which increases the uncertainty of regional water supply. Secondly, the damage caused by the El Niño Southern Oscillation events to this regional water market could reach up to NT$ 146 million (i.e., US$ 4.56 million). Finally, the possible water management strategies, which include water transfer activities among different demand groups, with a perfect El Niño Southern Oscillation forecast could substantially mitigate the damage and result in a benefit of NT$ 370 million (i.e., US$ 11.56 million).

1. Introduction

The El Niño Southern Oscillation (ENSO) is a pervasive climatic phenomenon that has been found to be associated with regional variations in climate throughout the world. Changes in the thermal profile of ocean currents alter wind, sea surface temperature and precipitation patterns in the tropical Pacific, and drive climatic effects throughout much of the world (IPCC, 2001). ENSO is comprised of three phases, a warm-El Niño, a cold-La Niña, and a Neutral phase. El Niño and La Niña events are associated with both drought and flooding in many regions of the world. Although the strength and the frequency of ENSO events cannot be linked for certain with global warming, strong ENSO events have been found by Timmermann et al. (1999) to be increasingly frequent. Such increases in the strength and frequency of ENSO events may enhance the variability of precipitation and streamflow in many ENSO-affected areas and lead to greater risk of droughts and floods (IPCC, 2001; Adams and Peck, 2002).

The resulting economic impacts due to the ENSO phases have been widely discussed in recent years. Many studies have, for instance, estimated ENSO impacts on crop yields, water resources, and agricultural income or sectoral performance (e.g., Adams et al., 1995; Mjelde, 1997; Solow et al., 1998; Chen and McCarl, 2000; Chen et al., 2001, 2005). ENSO forecasting accuracy is the major factor that could mitigate the damage caused by ENSO events. Once the accuracy of such forecasting information could be established, the adaptation strategies including cropmix, storage and water transfer activity could be applied to both the agricultural sector and water markets. For instance, improving the accuracy and lead-time of drought forecasts can reduce the risks of decision-makers and decrease economic losses due to drought (Adams and Peck, 2002).

Since ENSO events have significantly affected regional monthly precipitation and resulted in water supply uncertainty, such knowledge of ENSO forecast information would mitigate the impacts of ENSO on the water market. In other words, if ENSO information could be provided before farmers plant their crops, the water authority (or an appropriate government agency) would be able to transfer water resources from the agricultural sector to meet the demand from the non-agricultural sector. Farmers would be paid based on the amount of water transferred and the society would also benefit from such a water allocation management. Therefore, a water transferring management that incorporates ENSO information could be utilized to mitigate the economic damage caused by ENSO events.

Taiwan has enjoyed a growing and prosperous economy since the 1970s. Taiwan's economy has posted a respectable performance in the last two decades. In 2008, the GDP of Taiwan was US$ 443 billion and it ranked the 19th largest economy and the

Abbreviations: ENSO, El Niño Southern Oscillation; SOI, Southern Oscillation Index; OLS, Ordinary Least Squares; AIC, Akaike's Information Criterion.

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doi:10.1016/j.jhydrol.2010.09.008

16th largest trading nation in the world. Taiwan also had the fourth largest foreign exchange reserves in the world in 2008. To support such economic growth, a good investment environment with a reliable supply of primary factors including electricity and water plays a very important role. However, Taiwan is a subtropical island and its climate changes a great deal and may result in significant variations in precipitation. Therefore, water supply becomes uncertain and thus how to maintain reliable water supply to support economic development is a challenging job that policy-makers must face.

The agricultural irrigation, industrial, and municipal sectors are the three major users of water in Taiwan. They account for about 70%, 21%, and 10% of the total water demand, respectively (Taiwan Municipal Water Demand Report, 2007; Taiwan Industry Water Demand Report, 2007; Taiwan Agricultural Water Demand Report, 2007). The total demand for water has increased by about 4.6% in the last decade in Taiwan. Among the three major water consumers, municipal and industrial water demand have increased significantly by about 45.72% and 14.86%, respectively. On the contrary, agricultural irrigation demand for water has decreased by about 4.0%. The high growth rates in the industrial and municipal sectors are due to the rapid economic development and population growth, while the reduction in irrigation water demand is caused by the decline in planted acreage. In spite of increasing total water demand, the total water supply has not kept in step with demand due to environmental factors. In the meantime, the supply of water has varied significantly with the changes in climate in Taiwan. The major sources of water supply are dams, rivers, and underground water, which account for 33%, 44%, and 23% of the total water supply, respectively. The usage of underground water has been restricted by the government due to the severe land subsidence problem in recent years. At the same time, no new dams have been built since the 1990s due to environmental concerns. Therefore, the total water supply was unable to meet the total water demand, especially in drought seasons.

Transferring water among different sectors has been widely recognized as one the effective strategies to reduce the impact of water shortages. The emphasis in discussions on water transfer and allocation has mostly been on the use of water resources to secure water supplies to meet the demand. Such water supply management can be applied to distribute scarce water resources according the value of water for different uses without the need to develop costly new sources of supply. The compensation for water transferred from low-value users provides an incentive to accept water transfer activities which have been in operation in many places. For instance, the Colorado Water Transfer Agreements were established in 2003 and have provided an additional 277,700 acre-feet of water annually to the San Diego region. As another example, a market for allocating water in Chile was established in 1981 that allows water to be transferred from one region to another. Such water transfer activity is able to support the regional economy as well as the quality of life of its residents.

The main purpose of this study is to estimate the economic impacts of ENSO on the regional water market in Taiwan and then evaluate how ENSO information could be used to reduce the economic impacts. The remainder of this paper is organized as follows. The effects of ENSO on precipitation in Taiwan are estimated in Section 2, while Section 3 presents the regional water economic model with endogenized water price. The ENSO effects on precipitation are incorporated into this water market in Section 4 to simulate the economic impacts of ENSO events. In Section 5, the value of ENSO information is estimated by incorporating the complete ENSO information into the regional water economic model in order to execute possible water management strategies. Finally, concluding remarks are provided in Section 6.

2. The effects of ENSO on Taiwan's precipitation

To estimate the effects of ENSO on Taiwan's precipitation, an econometric regression approach is adopted. ENSO includes three phases, El Niño, La Niña, and Neutral, which could be defined through the Southern Oscillation Index (SOI). Therefore, the first step in this econometric approach is to find out how the SOI affects precipitation. Then the second step is to categorize the estimates of the SOI in relation to precipitation into three ENSO phases. We illustrate these two steps as follows.

Both monthly Southern Oscillation Index data and the monthly precipitation data in the Northern Taiwan region were collected. The time period of the dataset ranges from years 1981 to 2000. The estimation function can be defined as:

$$Rain_m = f_m(SOI_{m-1}, \ldots, SOI_1, LSOI_m, \ldots, LSOI_{m+p}) + \varepsilon_m \tag{1}$$

where m is a monthly index, $m = 1$ is for January; … ; $m = 12$ is for December, p is the optimal lag period, $Rain_m$ is the mth monthly precipitation, SOI_{m-1} is the $m-1$th monthly SOI, $LSOI_m$ is the mth monthly SOI in the previous year, and ε_m is an error term.

Under a linear function assumption in Eq. (1), the parameters can be estimated using Ordinary Least Squares (OLS) regression. Eq. (1) shows that the precipitation will be affected by the current period of SOI as well as the lag periods of SOI. The optimal lag periods of SOI can be determined using the following three statistical criteria: Adjusted R-Square, Log Likelihood Ratio Test, and Akaike's Information Criterion (AIC). The empirical estimation results of Eq. (1) indicate that the monthly precipitation in the Northern Taiwan region is significantly affected by monthly SOI with 12 lag periods.

After the optimal SOI lag period is determined, the estimated equation can be written as:

$$Rain_m = \sum_{j=1}^{m-1} \hat{\beta}_j * SOI_j + \sum_{j=m}^{p} \hat{\beta}_j * LSOI_j$$

The estimated coefficients of Eq. (1) represent the effects of the SOI on precipitation. To estimate the effects of each ENSO year on precipitation, the estimated coefficients have to be multiplied by the difference between the mean of the SOI and the SOI in that particular ENSO year. For instance, to estimate the impacts of the 1982 El Niño year on precipitation in Taiwan, the following calculations are applied:

$$\frac{\partial Rain_m}{\partial SOI_{1982}} = \sum_{j=1}^{m-1} \hat{\beta}_j (SOI_{j,1982} - MSOI_j) + \sum_{j=m}^{p} \hat{\beta}_j (LSOI_{j,1981} - MLSOI_j) \tag{2}$$

where $MSOI_j$ is the average monthly SOI in month j, $LMSOI_j$ is the average monthly SOI in month j for the previous year and $SOI_{j,1982}$ is the month j SOI in the 1982 El Niño year.

Eq. (2) is used to calculate the effects of each ENSO year on precipitation. Later, the effects of the three ENSO phases (El Niño, La Niña, and Neutral) on precipitation can be calculated from Eq. (2). For example, there were six El Niño years during the 1981–2000 period. The estimated results for these six El Nino years are summed and then divided by six. So the calculated number can be used to represent the effects of the El Niño phase on precipitation. Similarly, the calculation procedure is applied for the La Niña and Neutral phases.

Table 1 shows that the effects of the El Niño phase on the precipitation in the Northern Taiwan region are positive during spring season, while the La Niña phase causes negative effects on spring rainfall in this region. The spring rainfall during the La Niña phase would be reduced by as much as 13.09%. Such estimation results have important policy implications for water supply management in Taiwan because the most productive science park is located in

Table 1
The ENSO effects on precipitation in the Northern Taiwan region (unit: %).

	El Niño	La Niña	Neutral
January	15.01	−13.09	−2.25
February	6.49	−8.70	0.25
March	13.83	−7.80	−3.81
April	−14.74	28.52	−4.02
May	22.94	−8.05	−8.25
June	−7.67	−7.38	6.76
July	−20.74	23.48	0.99
August	13.32	−4.32	−4.93
September	−7.44	16.21	−2.75
October	−6.14	−43.91	19.99

Note: The relationships between ENSO and the rainfall in November and December are not significant.

this region. A reliable water supply is crucial for the production activities of these high-tech industrial sectors in the science park. Therefore, if the La Niña phase can be predicted, especially in a forecasted dry year, then the water scheduled to be supplied to less productive agricultural sector could be transferred to the high-tech industrial sectors to reduce the economic impacts of water shortages. This implies that the estimation of the effects of ENSO on rainfall and the forecast of ENSO phases could substantially mitigate the economic impacts of ENSO events.

3. The regional water economic model

The regional water economic model is built to estimate the impacts of ENSO on the water market and the economic values of the water transferring activities between sectors when ENSO information is provided. The economic modeling of the water market in this study is based on Samuelson's (1952) study which shows that the endogenous price could be derived from the social welfare maximization under a perfectly competitive market assumption. Takayama and Judge (1964) adopted the same approach and developed a spatial equilibrium model using mathematical programming. Since then, many studies have applied the spatial equilibrium modeling approach to simulate the economic impacts of policy changes or the shift in the demand or supply side for the agricultural sector (e.g., Plessner and Heady, 1965; Yaron, 1967; Baumes, 1978; Burton and Martin, 1987; Adams et al., 1986; Chang et al., 1992). In this paper, we also adopt the spatial equilibrium modeling approach to build the regional water economic model. Furthermore, the spatial equilibrium model is a price endogenous model where both the aggregated demand and supply functions are incorporated into this model. The aggregated water demand function is the summation of each individual's demand function, while the aggregated water supply function is the aggregation of the supply functions for all water resources.

3.1. Water demand

There are three major water consumption sectors in Taiwan, including municipal sector, agricultural sector, and industrial sector. Suppose the monthly water demand of the municipal sector in a particular region is assumed to be as in:

$$QD^{mu} = f_1(P^{mu}) \tag{3}$$

where QD^{mu} and P^{mu} are the monthly water demand and price for the municipal sector. Similarly, the monthly water demand function for the industrial sector can be written as:

$$QD^{in} = f_2(P^{in}) \tag{4}$$

where QD^{in} and P^{in} are the monthly water demand and price for the industrial sector.

To simulate the changes in agricultural water demand, the derived demand for water from producing agricultural commodities is adopted here. The major reason why we apply this derived demand approach is because the activity of transferring water from the agricultural sector to the non-agricultural sector is implemented by forcing crop acreage to be set aside. That is, farmers could either plant crops and then sell these crops to commodity markets or set-aside acreage to sell the irrigation water to non-agricultural sectors. Therefore, the profit maximization function can be defined as Eq. (5) where the first three terms represent the profit from planting crops and the last term is the set-aside payment.

$$\begin{aligned} &\underset{X,Aside}{Max}\ \pi = P_c \times X \times Q - TC^{ag} \times X - P^{ag} \times X + WP * Aside \\ &\text{s.t.} \qquad X + Aside \leqslant \overline{X} \end{aligned} \tag{5}$$

where P_c is the agricultural product price, X is the rice planted acreage, $Aside$ is the set-aside acreage, $\overline{X}$ is the land endowment, Q is the rice production quantity per hectare, TC^{ag} is the rice production cost per hectare excluding the land rent and irrigation cost, P^{ag} is the demand price for irrigation water (i.e., irrigation cost per hectare), WP is the water transfer payment per hectare, and q^{ag} is the monthly quantity of irrigation water demanded.

The first-order conditions for Eq. (5) are as follows:

$$\frac{\partial \pi}{\partial Aside} = WP - \lambda = 0 \quad \text{and} \quad \frac{\partial \pi}{\partial X} = P_c Q - TC^{ag} - P^{ag} - \lambda = 0$$

where λ is the shadow price of the land endowment.

The above first-order conditions show that irrigation water transfer occurs when the payment is greater than the shadow price of land. This shadow price of land is referred to as land rent which equals the marginal revenue of producing rice minus the production cost and irrigation cost (i.e., $P_cQ - TC^{ag} - P^{ag}$). Therefore, the irrigation water demand of a particular producer in the agricultural sector can be calculated by multiplying the rice production acreage with the irrigation amount ($IRRIG$) per hectare. The summation of Eq. (6) for all producers represent the total water demand of the agricultural sector as shown in:

$$q_i^{ag} = X * IRRIG = h(P_c, P^{ag}, X, WP) \tag{6}$$

$$QD^{ag} = \sum_{i=1}^{M} q_i^{ag} = f_3(P_c, P^{ag}, X, WP) \tag{7}$$

Eq. (7) shows that the water demand of the agricultural sector is a function of the agricultural product price, irrigation demand price, rice planted acreage, and water transfer payment. Higher agricultural commodity prices or higher plant acreages will increase water demand, while higher water prices or water transfer payments will reduce the demand for water.

3.2. Water supply

As for the water supply side, there are three major water supply sources in Taiwan, including water dams, rivers, and underground water. The supply functions for these three sources can be specified as:

$$QS^w = g_1(P_k^w) \tag{8}$$

$$QS^r = g_2(P^r) \tag{9}$$

$$QS^g = g_3(P^g) \tag{10}$$

where QS_k^w is the monthly water supply by the kth water dam, QS^r is the monthly water supply by rivers, QS^g is the monthly water supply by underground water, P^w_k, P^r, and P^g are the water supply price of dams, rivers, and underground water, respectively.

Suppose there exist integrated inverse functions for the demand functions and the supply functions. Then the inverse demand functions of Eqs. (3) and (4) and the inverse supply functions of Eqs. (8)–(10) can be written as follows:

$$P^{mu} = f_1^{-1}(QD^{mu}), \quad P^{in} = f_2^{-1}(QD^{in}), \quad P^w_k = g_1^{-1}(QS^w_k),$$
$$P^r = g_2^{-1}(QS^r), \quad P^g = g_3^{-1}(QS^g)$$

3.3. The regional water economic model

There are there important characteristics embedded in the regional water economic model, including water marketing structure, water transferring activity, and irrigation derived demand mechanism. The model assumes a perfectly competitive market structure and hence the social welfare will be maximized at the intersection of the demand and supply curves. In other words, the equilibrium price is determined endogenously at the intersection of the demand and supply curves when welfare is maximized. This is referred to as a price endogenous model which is based on the studies by Samuelson (1952), Takayama and Judge (1964), Mendelsohn and Bennett (1997), Keplinger et al. (1998), Chen et al. (2001, 2005), and Chen and Hsu (2010).

The water transferring activity from the agricultural sector to the non-agricultural sector is incorporated into this regional water economic model in order to re-allocate water resources. Such a modeling approach related to water transferring activity is based on the studies by Fisher et al. (2002, 2005) and Chen and Hsu (2010). The irrigation derived demand as well as set-aside activities are incorporated into the model in order to allow the water transfer activity to take place. The detailed mathematical functional forms of this regional water economic model are shown as follows:

$$\begin{aligned}
\text{MAX } SW = & \sum_{r=1}^{3}\sum_{m=1}^{12}\left[\int_0^{QD^{mu*}_{rm}} f_1^{-1}(QD^{mu}_{rm})dQD^{mu}_{rm} + \int_0^{QD^{in*}_{rm}} f_2^{-1}(QD^{in}_{rm})dQD^{in}_{rm}\right] \\
& - \sum_{r=1}^{3}\sum_{m=1}^{12}\left[\left(\sum_{k=1}^{K}\int_0^{QS^{w*}_{rkm}} g_1^{-1}(QS^w_{rkm})dQS^w_{rkm} + \int_0^{QS^{r*}_{rm}} g_2^{-1}(QS^r_{rm})dQS^r_{rm} + \int_0^{QS^{g*}_{rm}} g_3^{-1}(QS^g_{rm})dQS^g_{rm}\right)\right] \\
& + \sum_{r=1}^{3}\sum_{m=1}^{12} P_c X_r Q_r - \sum_{r=1}^{3}\sum_{m=1}^{12} TC^{ag}_r X_r \\
& - \sum_{r=1}^{3}\sum_{m=1}^{12} IRRIGCOST_{rm} * X_r \\
& - \sum_{r=1}^{3}\sum_{m=1}^{12}\sum_{j=1}^{2} TRANCOST * WTRAN_{rmj}
\end{aligned} \tag{11}$$

s.t.

$$QD^{mu}_{rm} + QD^{in}_{rm} + IRRIG_{rm} * X_r - \sum_{k=1}^{K} QS^w_{rkm} - QS^r_{rm} - QS^g_{rm} - \sum_j WTRAN_{rmj} \leqslant 0 \quad \forall\, r, m \tag{12}$$

$$-IRRIG_{rm} * Aside_r + \sum_j WTRAN_{rmj} \leqslant 0 \qquad \forall\, r, m \tag{13}$$

$$QS^g_{rm} \leqslant Q^{gu}_{rm} \quad \forall\, r, m \tag{14}$$

$$X_r + Aside_r \leqslant L_r \quad \forall\, r \tag{15}$$

where r is the index for the region, m is the index for the month, j is the index for the water demand sector including the municipal and industrial sectors, QD^{mu}_{rm} is the municipal water demand in month m in region r, QD^{in}_{rm} is the industrial water demand in month m in region r, $P^{mu}_{rm} = f_1^{-1}(QD^{mu}_{rm})$ is the inverse demand function for the municipal sector, $P^{in}_{rm} = f_2^{-1}(QD^{in}_{rm})$ is the inverse demand function for the industrial sector, QS^w_{rkm} is the total water supply in month m form the kth water dam in region r, QS^r_{rm} is the water supply from the rivers in month m in region r, QS^g_{rm} is the water supply from underground water in month m in region r, $g_1^{-1}(QS^w_{rkm})$ is the inverse supply function for the water dam, $g_2^{-1}(QS^r_{rm})$ is the inverse supply function for the river, $g_3^{-1}(QS^g_{rm})$ is the inverse supply function for underground water, Q^{gu}_{rm} is the pumping limit for underground water in month m in region r, $WTRAN_{rmj}$ is the amount of water transferred from the agricultural sector to the non-agricultural sector j, $TRANCOST$ is the water transferring cost, P_c is the agricultural product price, X_r is the rice planted acreage for region r, Q_r is the rice production quantity per hectare in region r, $IRRIG_{rm}$ is the irrigation demand for rice production per hectare, $IRRIGCOST_{rm}$ is the irrigation cost per hectare, $Aside_r$ is the set-aside acreage in region r and L_r is the endowment of cropland acreage in region r.

Eq. (11) is the objective function which maximizes the social welfare. The value of the social welfare is defined as the area under the demand curves minus the area under the supply curves as shown in the first two lines of the objective function. The third line in the objective function is the total revenue minus the production cost for agricultural production activities which represents the net profit for farmers and could also be defined as the producer's surplus. In the case when the water transferring activity occurs, the water transferring cost (i.e., the last term of the objective function) needs to be deducted from the social welfare.

Eqs. (12)–(15) are the constraints. Eq. (12) is the water demand and supply balance constraint. It requires that the total water demand including municipal demand (QD^{mu}_{rm}), industry demand (QD^{in}_{rm}), and irrigation derived demand ($IRRIG_{rm} * X_r$) cannot exceed the total water supply from water dams (QS^w_{rkm}), rivers (QS^r_{rm}), underground water (QS^g_{rm}) and the amount of water transfer ($WTRAN_{rmj}$) in month m in region r. Therefore, the shadow price derived from this demand and supply balance equation can be defined as a water transfer price when the social welfare is maximized. Eq. (13) indicates that the source of the water transferring activity is the activity of cropland being set aside. It requires that the irrigation water usage per hectare times the set-aside acreage ($IRRIG_{rm} * Aside_r$) equals the amount of water transfer ($WTRAN_{rmj}$). From Eqs. (12) and (13), it is shown that the water transferring activity not only serves as a source of supply in a regional water market, but also generates demand due to the competition for irrigation water in the agricultural sector. Eq. (14) shows that the underground water supply cannot exceed the pumping limit regulated by the government. Eq. (15) is the land endowment constraint, which requires that the total planted acreage cannot exceed the land endowment.

3.4. The stochastic regional water economic model

To incorporate the information about ENSO events into the model, the deterministic model described in Section 3.3 needs to be modified into a stochastic model in order to estimate the economic impacts of ENSO events on the water market. The stochastic regional water economic model is based on a stochastic mathematical program with recourse following McCarl and Parandvash (1988), Lambert et al. (1995), Chen and McCarl (2000), and Chen et al. (2005) and is modified here to reflect the uncertainty from ENSO events. The model formulation for this stochastic regional water economic model is as follows:

$$\begin{aligned} \text{MAX } SW = & \sum_f Fprob(f) * \sum_e prob(f|e) \\ & * \Bigg\{ \sum_{r=1}^{3}\sum_{m=1}^{12}\left(\int_0^{QD_{rm}^{mu^*}} f_1^{-1}(QD_{rmef}^{mu})dQD_{rmef}^{mu} \right.\\ & \left. + \int_0^{QD_{rm}^{in^*}} f_2^{-1}(QD_{rmef}^{in})dQD_{rmef}^{in}\right) \\ & - \sum_{r=1}^{3}\sum_{m=1}^{12}\Bigg[\sum_{k=1}^{K}\int_0^{QS_{rkm}^{w^*}} g_1^{-1}(QS_{rkm}^{w} * (1+ERAIN_e))dQS_{rkm}^{w} \\ & + \int_0^{QS_{rm}^{r^*}} g_2^{-1}(QS_{rm}^{r} * (1+ERAIN_e))dQS_{rm}^{r} \\ & + \int_0^{QS_{rm}^{g^*}} g_3^{-1}(QS_{rm}^{g})dQS_{rm}^{g})\Bigg] + \sum_{r=1}^{3}\sum_{p=1}^{2} P_c X_r Q_r \\ & - \sum_{r=1}^{3}\sum_{m=1}^{12} TC_r^{ag} X_r - \sum_{r=1}^{3}\sum_{m=1}^{12} IRRIGCOST_{rm} * X_r \\ & - \sum_{r=1}^{3}\sum_{m=1}^{12}\sum_{j=1}^{2} TRANCOST * WTRAN_{rmjef}\Bigg\} \end{aligned} \tag{16}$$

s.t.

$$\begin{aligned} & QD_{rmef}^{mu} + QD_{rmef}^{in} + IRRIG_{rm} * X_r - \sum_{k=1}^{K} QS_{rkm}^{w}(1+ERAIN_e) \\ & - \sum_{k=1}^{K} QS_{rm}^{r} * (1+ERAIN_e) - QS_{rm}^{g} \\ & - \sum_j WTRAN_{rmjef} \leqslant 0 \quad \forall\ r, m, e, f \end{aligned} \tag{17}$$

$$-IRRIG_{rm} * Aside_r + \sum_j WTRAN_{rmjef} \leqslant 0 \quad \forall\ r, m, e, f \tag{18}$$

$$QS_{rm}^{g} \leqslant Q_{rm}^{gu} \quad \forall\ r, m \tag{19}$$

$$X_r + Aside_r \leqslant L_r \quad \forall\ r \tag{20}$$

where e is the index of ENSO events, f is the forecast of ENSO events, $ERAIN_e$ is the percentage impact of ENSO events on precipitation from Table 1, $prob(f|e)$ is the posterior probability of an ENSO event forecast given the occurrence of ENSO event, $Fprob(f)$ is the forecast probability of ENSO events.

Eq. (16) is the expected social welfare, while Eq. (17) is the water supply and demand balance constraint for each ENSO event as well as for each ENSO forecast event. The Lagrange functions together with the Kuhn-Tucker conditions for Eqs. (16)–(20) are as follows:

$$\begin{aligned} L = & SW + \mu_{rmef} * \left\{\sum_{k=1}^{K}\left[(QS_{rkm}^{w} + QS_{rm}^{r}) * (1+ERAIN_e) + QS_{rm}^{g}\right] \right.\\ & \left. + \sum_j WTRAN_{rmjef} - QD_{imef}^{mu} - QD_{imef}^{in} - IRRIG_{rm} * X_r\right\} \\ & + \gamma_{rmef} * \left[IRRIG_{rm} * ASIDE_{rm} - \sum_j WTRAN_{rmjef}\right] \\ & + \theta_{rm} * \left[Q_{rm}^{gu} - QS_{rm}^{g}\right] + \lambda_r * \left[L_r - X_r - Aside_r\right] \frac{\partial L}{\partial QD_{rmef}^{mu}} \\ & = P_{rmef}^{mu} - \mu_{rmef} \leqslant 0, QD_{rmef}^{mu} \geqslant 0, \text{ and } \frac{\partial L}{\partial QD_{rmef}^{mu}} * QD_{rmef}^{mu} = 0 \end{aligned} \tag{21}$$

$$\frac{\partial L}{\partial QD_{rmef}^{in}} = P_{rmef}^{in} - \mu_{rmef} \leqslant 0, QD_{rmef}^{in} \geqslant 0, \text{ and } \frac{\partial L}{\partial QD_{rmef}^{in}} * QD_{rmef}^{in} = 0 \tag{22}$$

$$\begin{aligned} & \frac{\partial L}{\partial WTRAN_{rmjef}} = -TRANCOST + \mu_{rmef} - \gamma_{rmef} \leqslant 0, WTRAN_{rmjef} \geqslant 0, \\ & \text{and } \frac{\partial L}{\partial WTRAN_{rmjef}} * WTRAN_{rmjef} = 0 \end{aligned} \tag{23}$$

$$\begin{aligned} & \frac{\partial L}{\partial X_r} = P_c Q_r - TC_r^{ag} - \mu_{rmef} * IRRIG_{rm} - \lambda_r \leqslant 0, X_r \geqslant 0, \\ & \text{and } \frac{\partial L}{\partial X_r} * X_r = 0 \end{aligned} \tag{24}$$

$$\begin{aligned} & \frac{\partial L}{\partial Aside_r} = -\lambda_r + \gamma_{rmef} * IRRIG_{rm} \leqslant 0, Aside_r \geqslant 0, \\ & \text{and } \frac{\partial L}{\partial Aside_r} * Aside_r = 0 \end{aligned} \tag{25}$$

where μ_{rmef} is the shadow price for each ENSO event of the water supply and water demand balance constraints in Eq. (17), while γ_{rmef}, θ_{rm}, and λ_r are the shadow prices for Eqs. (18)–(20), respectively.

Under the assumption of all positive activities, the equilibrium conditions in Eqs. (21) and (22) show that the shadow price of the water supply and demand balance constraint (μ_{rmef}) equals the municipal and industrial water demand price for each ENSO event with and without ENSO information. Eq. (23) indicates that a water transferring activity occurs if the water demand price equals the irrigation cost plus the transferring cost (i.e., $\mu_{rmef} = \gamma_{rmef} + TRANCOST$). In other words, the potential water transferring price will be the transferring cost plus the opportunity cost of irrigation water. On the other hand, the agricultural production activity (X) occurs when the marginal revenue product ($P_C * Q_r$) equals the marginal cost. The marginal cost is calculated as the summation of production cost per hectare, irrigation cost ($\mu_{rmef} * IRRIG_{rm}$) and land rent (λ_r) as shown in Eq. (24). Eq. (25) shows that the set-aside activity occurs when the land rent equals the water transferring payment ($\gamma_{rm} * IRRIG_{rm}$).

Our stochastic regional water economic model has four important characteristics. First, the water transferring price is estimated under the assumptions of social welfare maximization and a perfectly competitive market structure. The water transferring price is derived from the shadow price of the water demand and supply balance constraints. Therefore, the price of water is an endogenous variable which can reflect the water transferring price from the point of view of the water efficiency allocation.

Secondly, all regional demand and supply functions are incorporated into the model. Therefore, changes in the demand or supply functions as well as policy adjustments in the water market can be appropriately simulated. Thirdly, agricultural production activities with their derived demand for water can be incorporated into this model. Therefore, the economic impacts of water transfer activities from the agricultural sector to the non-agricultural sector can be adequately estimated. Besides, the water transferring price can be used as a compensation index when water is transferred from the agricultural sector to the non-agricultural sector.

Last, the decision trees with and without ENSO information in this regional stochastic water model can be illustrated explicitly. Without employing any ENSO information in the water market, a two-stage decision will be made in this stochastic model. In the first stage, rice farmers decide how many acres of rice (X_r) will be planted while the water supply variables ($QS_{rkm}^{w}, QS_{rm}^{r}, QS_{rm}^{g}$) are decided without any information regarding the impact of ENSO on precipitation. In the second stage, the municipal and industrial demand for water ($QD_{rmef}^{mu}, QD_{rmef}^{in}$) will be influenced by the precipitation due to ENSO events ($ERAIN_e$), but irrigation water demand is fixed due to the planted acreage determined in the first stage. Therefore, the water demand and price of the municipal and industrial sectors will be significantly affected by each ENSO event.

When the information about the effects of ENSO on the precipitation are provided, a three-stage decision will be made in this stochastic model. The first stage of the decision is to determine the planting acreage, the acreage to be set aside in order to allow water to be transferred from irrigation water to the non-agricultural sector. Once the water supply and water transferring activities with respect to each ENSO event take place in the second stage, the demand for water on the part of the municipal and industrial sectors will be influenced by ENSO events in the third stage. In the third stage, water demand and water price will be determined based on each ENSO event with ENSO forecast information. Therefore, our stochastic regional water economic model could be used to estimate the value of the ENSO information in the water market.

4. Data sets and model validation

In this study, the geographical area includes three counties in the northern part of Taiwan: Taoyuan, Hsinchu, and Miaoli counties. Taoyuan and Hsinchu counties contain the most important industrial cities in Taiwan where most of the semiconductor and information technology companies are located. On the contrary, Miaoli county is a traditional agricultural production area. The water demand of these three counties share the same water supply sources. Any shortage of water in a particular county could be met by transferring water from the other counties given a limited water resource endowment.

Since the regional water economic model in this study includes three water demand groups and three water supply sources, the data sets related to both the demand for and supply of water need to be collected. The main data sets are retrieved directly from several reports including the Taiwan Agricultural Annual Statistics (Various years), the Taiwan Agricultural Production Investigation Report (2007), the Taiwan Municipal Water Demand Report (2007), the Taiwan Industry Water Demand Report (2007), and the Taiwan Agricultural Water Demand Report (2007).

The data set is briefly introduced as follows. The quantities of water demand in each month in the municipal, industrial, and agricultural sectors are listed in Table 2. Table 2 shows that Taoyuan county is the largest county and it consumes more water in both the municipal and industrial sectors than the other two counties. However, the water demand of these two sectors does not vary with seasons. The water price for the municipal and industrial sectors is about NT$ 10.14 per m^3 without seasonal adjustment. The water price for the agricultural sector is about only NT$ 0.28 per m^3 which is much lower than that for the non-agricultural sector.[1] This low price in the agricultural sector may give rise to inefficiency in irrigation usage. The monthly water demand of the agricultural sector are listed in the bottom rows of Table 2. The data show that the major water demand periods extend from February to May and from June to September mainly because rice planting usually occurs during these two seasons.

In terms of the water supply, the water supply from water dams, rivers and underground pumping are shown in Table 3. Table 3 indicates that Shih Men reservoir is the major water source in this region. The water supply in the late spring and summer is greater than that in the other months, which is consistent with the rainfall season in Taiwan. The bottom row of Table 3 shows

Table 2
Monthly water demand by region (unit: million m^3).

Month/region	Municipal			Industry		
	Taoyuan	Hsinchu	Miaoli	Taoyuan	Hsinchu	Miaoli
January	19.917	9.717	5.885	22.411	18.162	5.326
February	19.168	8.953	5.336	24.401	17.403	5.763
March	21.307	9.827	5.935	26.735	19.083	6.323
April	20.374	9.533	5.765	24.964	18.268	5.883
May	21.757	10.047	5.935	26.846	19.448	6.342
June	21.134	9.833	5.685	25.235	18.890	5.933
July	22.077	9.967	5.985	26.098	19.044	6.165
August	22.267	10.337	6.235	26.957	19.944	6.365
September	19.244	9.733	6.035	24.131	18.490	5.671
October	21.837	10.177	6.065	25.431	19.362	5.977
November	21.224	9.693	6.025	25.945	18.622	6.110
December	21.347	9.867	5.655	25.371	18.660	5.983
Total	251.651	117.685	70.542	304.525	225.376	71.841

Month/region	Agriculture		
	Taoyuan	Hsinchu	Miaoli
January	77.315	0.926	0.000
February	80.220	15.413	55.908
March	62.707	18.014	38.886
April	58.812	18.517	44.846
May	72.112	15.968	33.958
June	139.047	3.900	17.375
July	104.475	18.776	46.125
August	91.213	12.137	36.348
September	73.775	16.761	36.929
October	60.972	7.885	9.385
November	0.000	0.000	0.000
December	0.000	0.000	0.000
Total	820.648	128.297	319.760

that the majority of the water supply is from water dams followed by rivers. The underground water supply is only about 18% of total water supply because it has been restricted by the government due to the severe land subsidence problem in recent years.

The water supply price for underground water is about NT$ 4.0 per m^3 which is calculated based on the average cost of pumping. Similarly, the costs of operating a water dam and an agricultural water association are used as the approximate supply prices for the dam and the river, respectively. The costs of water supply from rivers in the Taoyuan, Hsinchu, and Miaoli counties are NT$1.90, NT$ 0.91, and NT$ 0.92 per m^3, respectively. The average costs of water supply from different water dams are listed in Table 4. Tables 3 and 4 show that the water supply prices in these three counties range from NT$ 0.92 to NT$ 10.98 per m^3 depending on the water supply sources.

The regional water economic model employs a nonlinear programming approach. To run this model empirically, the data from both the demand and supply sides have to be incorporated into the model. All demand functions as well as supply functions are assumed to have constant elasticity functional forms. Therefore, the quantities and prices included in the demand and supply sides need to be collected in order to estimate the constant elasticity functions. The data sets from Tables 2–4 are incorporated into the model and the model validation results are shown in Table 5. Table 5 shows that the model solutions are close to the observed data, which implies that the regional water economic model is validated and can be used for policy simulations.

Table 6 presents the economic outcomes from the regional water economic model. It shows that water prices range from NT$ 2.89 to NT$ 4.21 per m^3. The water price in the Hsinchu region is higher than that in the other two regions because the most productive science park is located in this region and it has a strong demand for water. The price of water in the Miaoli region is much lower than that in the other two regions because it is an

[1] The exchange rate used in this study is one US dollar equals 32 New Taiwan dollars (1 US$ = 32 NT$).

Table 3
Monthly water supply (unit: million m^3).

Month/water dam	Water dam						
	Shih Men	Pao Shen	Younhoua Shen	Da Bou	Ming Te	Cheng Tan	Liyu Tan
January	41.540	1.972	7.144	1.339	1.183	0.000	16.958
February	78.190	2.056	6.839	1.989	1.051	0.000	14.323
March	93.630	2.342	7.765	3.008	12.228	1.338	15.082
April	67.100	2.160	7.025	2.331	3.180	0.953	18.338
May	86.310	2.319	7.381	3.084	4.963	1.108	18.655
June	78.190	2.267	7.749	3.439	4.673	0.773	19.203
July	85.250	2.224	7.294	3.372	5.746	0.372	19.749
August	95.010	2.253	7.531	2.430	4.820	1.193	21.769
September	49.990	2.187	6.886	2.273	2.945	1.114	19.086
October	65.790	2.009	7.371	2.810	4.599	0.945	21.808
November	90.790	1.773	7.054	1.748	3.492	0.193	20.047
December	52.910	1.801	6.987	0.778	2.603	0.000	17.578
Total	884.700	25.363	87.026	28.601	51.483	7.989	222.596

Month/ region	River			Underground Water		
	Taoyuan	Hsinchu	Miaoli	Taoyuan	Hsinchu	Miaoli
January	4.240	3.170	2.096	17.318	14.259	5.401
February	33.994	2.981	2.092	19.389	13.776	5.819
March	30.915	22.167	72.513	21.152	15.120	6.378
April	35.806	26.976	48.555	19.648	14.431	5.928
May	22.286	27.199	54.342	21.113	15.345	6.397
June	32.739	22.680	40.699	19.659	14.853	6.008
July	56.671	5.989	13.861	20.255	15.012	6.200
August	31.906	25.880	42.120	21.044	15.661	6.320
September	46.897	17.531	34.717	19.205	14.512	5.627
October	34.111	23.139	33.353	19.668	15.189	5.992
November	17.915	12.906	8.569	20.339	14.695	6.065
December	0.485	4.270	0.373	19.777	14.697	6.028
Total	347.970	194.892	353.294	238.566	177.551	72.162

Table 4
Water supply cost for water dams (unit: $NT/$m^3$).

Water dam	Average cost	Water dam	Average cost
Shih Men	1.71	Ming Te	2.95
Pao Shen	6.74	Cheng Tan	6.74
Younhoua Shen	10.98	Liyu Tan	1.71
Da Bou	6.74		

Table 5
Model validation in quantity (unit: thousand m^3, %).

Region	Demand	Observations (1000 m^3)	Solution (1000 m^3)	Deviation (%)
Taoyuan	Industry	304,520	315,451	3.59
	Municipal	251,660	262,299	4.23
	Agriculture	472,730	472,730	0.00
	Total demand	1028,910	1050,482	2.09
Hsinchu	Industry	225,400	224,134	−0.56
	Municipal	117,690	120,270	2.19
	Agriculture	170,332	170,332	0.00
	Total demand	513,422	514,737	0.25
Miaoli	Industry	71,820	73,908	2.91
	Municipal	70,600	73,343	3.89
	Agriculture	364,845	364,845	0.00
	Total demand	507,265	512,097	0.95

agricultural production region where the irrigation water is about 70.44% of the total water demand in this region.

The water prices are derived from the shadow prices of the water demand and supply balance constraint which could be considered as the optimal water transferring prices. In other words, these prices could serve as an index for the transfer of water between the agricultural and non-agricultural sectors. The water surplus, which is derived from the water market, ranges from NT$4, 048 million to NT$11,013 million. We also found that higher industrial and municipal demand will result in larger water surplus.

5. The Impacts of ENSO and information values on a water market

To estimate the effects of ENSO on the regional water market, the impacts of ENSO on precipitation from Table 1 will be incorporated into this regional stochastic water economic model. However, the results generated by such studies typically represent the effects of ENSO under average events. Timmermann et al. (1999) have found that global climate change could have altered the ENSO characteristics with more frequent and extreme episodes. Trenberth and Hoar (1996, 1997) have also found that the frequency of El Niño has increased and the frequency of La Niña has declined over the period 1976–1995. In this study, we also estimate the impacts of both the current ENSO probability and the change in the frequency of ENSO events on the regional water market. Based on historical observations, the current probabilities of the El Niño and La Niña phases are about 0.263 and 0.210, respectively. Timmermann et al. (1999) have found that global warming has the potential to increase the frequencies of these two phases to 0.339 and 0.310, respectively. On the other hand, alternative prediction accuracies including modest, high, and perfect ENSO information are also simulated to reflect the potential forecast value under different degrees of forecast accuracy. The posterior probability of these alternative prediction accuracies is shown in Appendix A. Therefore, seven scenarios are simulated here.

Table 6
Economic outcomes of model solution.

		Taoyuan	Hsinchu	Miaoli	Total
Price		3.48	4.21	2.89	3.52[a]
Demand (thousand m^3)	Agri.	472,730	170,332	364,845	1007,907
	Indu.	315,450	224,135	73,908	613,493
	Muni.	262,300	120,270	73,343	455,913
Total demand (thousand m^3)		1050,481	514,738	512,097	2077,316
Welfare (NT$ million)	Consumer's Surplus	17,517	9929	3591	31,037
	Producer's Surplus	1448	1084	457	2990
	Total	18,965	11,013	4048	34,027

Welfare is defined as the consumer's surplus plus the producer's surplus from the regional water market.
[a] The average price.

- *Scenario 1*. Ignoring the ENSO impacts.
- *Scenario 2*. Considering the ENSO effects on precipitation without any ENSO information.
- *Scenario 3*. Considering the changes in the magnitudes and frequencies of the El Niño and La Niña events.
- *Scenario 4*. Scenario 2 with modest ENSO prediction.
- *Scenario 5*. Scenario 2 with high ENSO prediction.
- *Scenario 6*. Scenario 2 with perfect ENSO prediction.
- *Scenario 7*. Scenario 3 with perfect ENSO information.

The economic impacts of the average and the change in the frequency of ENSO events (i.e., Scenarios 1–3) are shown in Table 7. Table 7 indicates that the occurrences of ENSO events will decrease the water supply and, therefore, the water price will be increased while water demand will be decreased. Total social welfare and the consumer's surplus from this regional water market will be reduced, while the change in the producer's surplus will depend on the supply and demand elasticities. Since the demand elasticity is small due to water being a necessary good, the producer's surplus will be increased as the water supply curve shifts to the left. The empirical results in Table 7 indicate that the social welfare decreases by NT$ 112 million when the average ENSO effect is taken into consideration. However, such damage will be increased to NT$ 146 million when the frequency of ENSO events changes (i.e., Scenario 3), which indicates that more damage will occur in the water market as the frequency of El Niño and La Niña events increase.

However, if the information regarding ENSO events could be forecasted and provided, farmers could set water aside early with a subsidy payment and then transfer irrigation water to the non-agricultural sector. These economic impacts of alternative forecast accuracies of ENSO information on this regional water market are shown in Table 8. As we could observe that water price goes down when water is transferred from the agricultural sector to industrial and municipal sectors if the prediction accuracy of ENSO information is increased. Taking perfect ENSO Information (i.e., Scenario 6) as an example, price falls by 6.61% when 41,315 thousand m^3 of water is transferred. Therefore, social welfare increases. Total social surplus is increased by NT$ 120, 201, and 228 million when prediction accuracy is modest, high, and perfect prediction (i.e. Scenarios 4–6). Such weather information value is from a water management strategy by water transferring activity with a combination of ENSO forecast information.

As the frequency of ENSO events changes and such information is also perfectly forecasted (i.e., Scenario 7), the social welfare could be improved by NT$ 370 million. The major reason for generating such a positive benefit from ENSO perfect information forecasts comes from the adoption of water transferring management combined with a cropland setting aside activity. As the authority of this regional water market obtains the ENSO information prior to the crop planting season, farmers can set aside their acreages with subsidiary payments. Increase in set-aside acreages will reduce the irrigation water demand and the saved irrigation water can be

Table 7
Economic impact of ENSO events.

Economic items		Scenario 1: Without ENSO effects	Scenario 2: With ENSO effects	Scenario 3: With ENSO effect and frequency change
Price (NT$/m^3)		3.52	3.63 (0.11) [3.12%]	3.67 (0.14) [3.97]
Total water demand (thousand m^3)		2077,316	2071,481 (−5835) [−0.28%]	2070,228 (−7088) [−0.34%]
Welfare (NT$ million)	Consumer's Surplus	31,037	30,885 (−152) [−0.49%]	30,839 (−198) [−0.64%]
	Producer's Surplus	2990	3030 (40) [1.34%]	3042 (52) [1.74%]
	Total Surplus	34,027	33,915 (−112) [−0.33%]	33,881 (−146) [−0.43%]

Notes: 1. The numbers in the parentheses represent the differences between Scenarios 2 and 3 and scenario 1 while the numbers in the brackets represent the percentage changes. 2. The Total Surplus is defined as the summation of the Consumer's Surplus and Producer's Surplus.

Table 8
Economic impacts of ENSO information and water management.

Economic items		Base line (Scenario 2)	With modest ENSO information (Scenario 4)	With high ENSO information (Scenario 5)	With perfect ENSO information (Scenario 6)	With ENSO information and frequency change (Scenario 7)
Price (NT$/m^3)		3.63	3.51 (−0.12) [−3.30%]	3.42 (−0.21) [−5.78]	3.39 (−0.24) [−6.61%]	3.25 (−0.38) [−10.46%]
Demand (thousand m^3)	Agri.	1007,909	987,251 (−20,658) [−2.04]	974,856 (−33,053) [−3.27]	966,593 (−41,316) [−4.10%]	941,804 (66,105) [−6.55%]
	Indu.	609,239	613,402 (4163) [0.68%]	616,488 (7249) [1.18%]	617,542 (8303) [1.36%]	623,447 (14,208) [2.33%]
	Muni.	454,333	456,004 (1671) [0.36%]	457,211 (2878) [0.63%]	457,622 (3289) [0.72%]	459,918 (5585) [1.23%]
	Total	2071,481	2077,316 (5835) [0.28%]	2081,609 (10,128) [0.48%]	2083,074 (11,593) [0.56%]	2091,273 (19,792) [0.95%]
Water transfer amount (thousand m^3)		0	20,657	33,052	41,315	66,104
Water transfer payment (NT$ million)		0	30	49	62	99
Welfare (NT$ million)	Consumer's Surplus	30,885	31,038 (153) [0.49%]	31,145 (260) [0.84%]	31,176 (291) [0.94%]	31,367 (482) [1.56%]
	Producer's Surplus	3030	2997 (−33) [−1.08]	2971 (−59) [−1.94]	2967 (−63) [−2.08%]	2917 (−113) [−3.73%]
	Total Surplus	33,915	34,035 (120) [0.35%]	34,116 (201) [0.59%]	34,143 (228) [0.67%]	34,285 (370) [1.09%]

Notes: The numbers in the parentheses represent the percentage changes with respect to the Base Line while the numbers in the brackets represent the percentage changes.

transferred to the non-agricultural sectors. Therefore, the social welfare and the consumer's surplus will be increased due to the water transferring activity when such ENSO information is provided, but the producer's surplus will be decreased due to the small supply and demand elasticities. When perfect ENSO information is provided, Table 8 shows that the water transferring amount is about 41,315 and 66,104 thousand m^3 under Scenarios 6 and 7, respectively. The amount of water transfer will be increased as the frequency of ENSO event changes and has been perfectly predicted. Comparing with the damage caused by ENSO to the regional water market (i.e., a NT$ 112 million to 146 million loss due to ENSO events), the incorporation of perfect ENSO information into the water market would not only mitigate the damage caused by ENSO events but also increase social welfare from water transferring activities. It should be noted that such a value of ENSO information is the maximum value since the ENSO information is assumed to have been perfectly predicted.

6. Conclusions and policy implications

The main purpose of this study is to evaluate the economic impacts of ENSO on the regional water markets in Taiwan and then to evaluate the information value of the effect of ENSO on this regional water market through water management. When the correct ENSO information is provided, the water transferring strategy could be applied to mitigate the impact of ENSO on the regional economy. Three major findings are obtained. The first one is that the effects of an El Niño year on the precipitation in the Northern Taiwan region are positive during spring season, while La Niña causes negative effects on spring rainfall in this region. Such estimation results have important policy implications for water supply management in Taiwan because the most productive science park is located in this region. A reliable water supply is crucial for the production activities of these high-tech industrial sectors in the science park. Therefore, if the La Niña phase can be predicted, especially in a forecasted dry year, then the water scheduled to be supplied to less productive agricultural sector could be transferred to the high-tech industrial sectors to reduce the economic impacts of water shortages. This implies that the estimation of the effects of ENSO on rainfall and the forecast of ENSO phases could substantially mitigate the economic impacts of ENSO events.

The second major contribution of this paper is that it establishes a stochastic regional water economic model. This empirical model has several advantages over other models. The model has endogeneous prices and can apply three-stage decision trees to evaluate the economic impacts of ENSO events on a regional water market as well as evaluate the economic benefit when such ENSO information is provided correctly. Last, the empirical results of this study indicate that the ENSO events would cause NT$ 146 million economic damage in the Northern Taiwan water market, however, the damage could be substantially mitigated through water management when ENSO forecast information is provided. A water management strategy based on transferring water among different groups is simulated in this paper. The simulation results show that water transferring activities could potentially increase social welfare by as much as NT$ 370 million in this regional water market.

Acknowledgements

This work was partially supported by National Science Council of Taiwan. We do appreciate two anonymous reviewers and editor for their valuable comments and suggestions.

Appendix A. Posterior probability for different ENSO forecast accuracy

	ENSO event occurring								
	Modest prediction			High prediction			Perfect prediction		
Event Forecast	El Niño	Neutral	La Niña	El Niño	Neutral	La Niña	El Niño	Neutral	La Niña
El Niño	0.52	0.36	0.12	0.74	0.20	0.06	1	0	0
Neutral	0.15	0.65	0.20	0.07	0.83	0.10	0	1	0
La Niña	0.08	0.32	0.60	0.04	0.16	0.80	0	0	1

Notes: The posterior probability is calculated based on Bayes Theorem using both the likelihood probability and prior ENSO information while the prior ENSO information is obtained based on the ENSO year observations for last 50 years.

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