Evaluating River Management Projects and Assessing Sustainable Development in Taiwan

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Abstract
With the short river and the frequent disaster such as typhoon, flood, and earthquakes, Taiwan is an island with fragile and isolated ecosystem. How to prevent and decrease the loss of natural disaster brought for sustainable utilization is the major subject for all people faced and aware in this isolated island. Wealth is regarded as intertemporal welfare indices and genuine investment is considered as measurement of sustainable development. As is widely recognized today, an economy's wealth is a linear combination of its capital stocks (manufactured capital, human capital and natural capital), the weights awarded to the stocks are referred to the latter's accounting prices. By adding net investment in human and natural capital to estimates of investment in manufactured capital, this paper presents phosphorus management to reflect the complexity of the river ecosystem in Taiwan in order to estimate intergenerational well-being. Two interesting questions are related (1) How should accounting prices of environmental natural services in the river ecosystem be estimated? (2) How should river management policy change in an imperfect economy be evaluated? With accounting price, genuine investment and resource allocation mechanism, the concept of sustainability is useful for judging the performance of river management projects evaluation and sustainable development assessment in imperfect economies. The results will be made available to country to assist it in its efforts to measure progress toward sustainable development.

Keywords
River Management, Sustainable Development, Phosphorus Balance

INTRODUCTION
Water is an important resource as well as a constraint to the development of Taiwan. Rivers, lakes, wetlands and watersheds are called liquid assets for the critical need to safeguard freshwater ecosystems, which provide a myriad of services that are essential to human welfare. Economic progress in Taiwan has led to greater public awareness of environmental protection affairs. Among the many environmental strains created by Taiwan's economic growth, water problems are perhaps felt most acutely and widely.

With the short river and the frequent disaster such as typhoon, flood, and earthquakes, Taiwan, located within the sub-tropical zone of the western Pacific Ocean, is an island with fragile and isolated ecosystem. With the mountains at the center of Taiwan, the rivers in this island have high slopes and a large carrying capacity of suspended solid. This situation has made the water resources management in Taiwan difficult. For high flow rates during the wet seasons (from May to October) and low flow rates during the dry seasons (form November to next April), the uneven distribution of rainfall results in many serious problems in water resource management such as shortage of fresh water during the dry season. In addition, flood control is important for enhancing the productivity of low-lying riparian lands. Many of the benefits of water resource development have been lost because of soil erosion. Largely because nutrients promoting eutrophication are attached to eroded solid, serious water quality problems have arisen throughout the tropics and subtropics like Taiwan. In order to provide high quality water for domestic use, the project of "Source Water Quality Protection Plan" is proposed to protect drinking water source for more than 12 million people. Even if the right investment projects were chosen, the returns could be abysmally low if prevailing institutions were weak. It is because of growing acknowledgement that governments have frequently not functioned in their citizens' interest.

Wealth is named for the value of an economy’s capital assets. A comprehensive notion of wealth is adopted with a listing of assets, which includes not only manufactured capital as machinery and human capital as knowledge, but also natural capital as ecosystems. Wealth increased means a net accumulation of capital assets. Genuine investment represented for any change in wealth can be negative if the economy accumulated manufactured and human capital, but destroyed or degraded natural capital at a fast rate (Dasgupta and Mäler 2000). Genuine investment is a key to sustained development. To ask whether collective well-being is sustained along an economic is to ask whether the economy's production possibility set is growing (Dasgupta and Mäler 2003). The concept of sustainability is useful for judging the performance of economies where the government dose not choose policies that maximize intergenerational welfare. Theory of intertemporal welfare indices is taken for judging whether countries have invested sufficiently to expand their productive bases. Calculation of national product is derived in a normative, optimizing framework as given that prices support the optimum path. When adjusting national accounts for the use of natural resources, the accounting prices should be used in the valuation. The theory of natural resources indicated that not only physical changes in the stock of capital but also changes reflected in the accounting price of a natural capital stock are important. The accounting prices support the optimum path and behave with respect to natural capital socks.

How to prevent and decrease the loss of natural disaster brought for sustainable utilization is the major subject for all people faced and aware in this isolated island. Wealth is regarded as intertemporal welfare indices and genuine investment is considered as measurement of sustainable development. As is widely recognized today, an economy's wealth is a linear combination of its capital stocks (manufactured capital, human capital and natural capital), the weights awarded to the stocks are referred to the latter's accounting price (Arrow, Dasgupta and Mäler 2003). By adding net investment is human and natural capital to estimates of investment in manufactured capital, this paper presents phosphorus management to reflect the complexity of the river ecosystem in Taiwan in order to estimate intergenerational well-being.

Eutrophication of lakes is a serious problem for water supply as well as for aquatic ecosystems. Phosphorus is a common indicator of lake eutrophication which destroys ecological balance. A key determinant of the overall state of a lake is phosphorus, which is necessary nutrient for such ecological services in the lake as those that provide a habitat for fish populations. But at high levels of concentration phosphorus is a pollutant, which causes increased plant growth, generation of toxic algae deoxygenation of water, bad odour and fish kills.

Two interesting questions are related: (1) How should accounting prices of environmental natural services in the river ecosystems be estimated? (2) How should river management policy change in an imperfect economy be evaluated? Both policy evaluation of river management in terms of phosphorus and assessment in whether or not intergenerational welfare along a given economic path will be sustained.

THE BASIC MODEL

The economy is assumed to be closed. Intergenerational welfare (social welfare) at t (≥ 0) is taken to be of the Ramsey-Koopmans form,

$$W_t = \int_0^\infty U(C_\tau) e^{-\delta(\tau - t)} d\tau \,, \qquad (1)$$

where $U(C)$: the utility function,
(strictly concave and monotonically increasing),
δ: the utility discount rate,
C: aggregate consumption into a single consumption good,
τ, t: time variable denoted respectively.

The state of the economy is represented by the vector **K**. Institutions like the character of various levels of government coevolve with the state of the economy. Given technological possibilities, resource availabilities, and the dynamics of the ecological-economic system, economic programme will be determined with the decisions made by individual agents and governments from t onwards.

Definition 1

economic programme, ξ_τ, is related to consumption, resource flows and capital assets.

$$\left(\xi_\tau\right)_t^\infty \equiv \left\{C_\tau, \mathbf{R}_\tau, \mathbf{K}_\tau\right\}_t^\infty \qquad \text{for} \quad t \geq 0\,, \qquad (2)$$

where $\left(\xi_\tau\right)_t^\infty$: the set of economic programmes from t to infinity;
$\mathbf{R}_\tau$: the vector of resource flows at date τ;
$\mathbf{K}_\tau$: the vector of capital assets at date τ;
C_τ : consumption at date τ.

Definition 2

A resource allocation mechanism, α, is a (many-one) mapping

$$\alpha : \left\{t, \mathbf{K}_t\right\} \rightarrow \left\{\left(\xi_\tau\right)_t^\infty\right\}, \qquad (3)$$

where $\{t, \mathbf{K}_t\}$: the set of possible t and $\mathbf{K}_t$ pairs.

While social welfare is considered as a function of initial capital stocks and the resource allocation mechanism, equation (1) is rewritten as the value function.

Definition 3

Social welfare reflected by the value function is rewritten as

$$W_t = V(\mathbf{K}_t, \alpha, t) = V_t = V(t)\,, \tag{4}$$

where W_t: social welfare (intergenerational welfare);

$\mathbf{K}_t$: the capital stock;

V_t: the value function.

Definition 4

The accounting price, p_{it} of the *i*th capital stock is defined as

$$p_{it} = \frac{\partial V(\mathbf{K}_t, \alpha, t)}{\partial K_{it}} \equiv \frac{\partial V_t}{\partial K_{it}}\,. \tag{5}$$

The accounting price of a capital asset is the present discounted value of the perturbations to *U*, which would arise from a marginal increase in the quantity of the asset. Given the resource allocation mechanism, accounting prices at *t* are functions of $\mathbf{K}_t$ and *t*, that is, $p_{it} = p_i(\mathbf{K}_t, t)$. If α is autonomous, accounting prices are not explicit functions of time, and so, $p_{it} = p_i(\mathbf{K}_t)$.

From (1) to (5), p_{it} satisfies the dynamical equation under that α is autonomous (see Appendix)

$$\frac{dp_{it}}{dt} = \delta\, p_{it} - \frac{U'(C_t)\partial C_t}{\partial K_{it}} - \sum_j p_{it} \frac{\partial(\frac{dK_{jt}}{dt})}{\partial K_i}\,. \tag{6}$$

Definition 5

Genuine investment (GI) is represented by the accounting value of the rate of change in the stocks of capital assets

$$GI = \frac{dV_t}{dt}\,. \tag{7}$$

Genuine investment is used to measure whether an economy's production possibility set is growing. The measure of sustainable development is based on the maintenance of social welfare rather than on the maintenance of economy's productive base. Then, the requirement that economic development be sustainable implies and is implied by the requirement that the economy's productive base be maintained.

Definition 6

A sustainable development path at *t* is represented by the economic programme $\{C_t, \mathbf{R}_t, \mathbf{K}_t\}_0^\infty$ if $\frac{dV_t}{dt} \geq 0$.

As equation (1) shown, $\frac{dV_t}{dt} > 0$ that arises from decreasing social welfare resulted in the utility discount rate too high. Furthermore, even if the government were bent on optimizing social welfare, the programme selected would not correspond to a sustainable path if the utility discount rate, δ, were too high.

Theorem 1

GI : $$\frac{dV_t}{dt} = \sum_i p_{it} \frac{dK_{it}}{dt} + \frac{\partial V_t}{\partial t}. \qquad (8)$$

If α is autonomous, then $\frac{\partial V_t}{\partial t} = 0$ and $\frac{dV}{dt} = \sum_i p_{it} \frac{dK_{it}}{dt}$.

Equation (8) indicates that at each date the rate of change in social welfare equals genuine investment. Integrating (8) from zero to T yields

$$V_T - V_0 = \sum_i \left[p_{it} K_{iT} - p_{i0} K_{i0}\right] - \int_0^T [\sum_i \frac{dp_{i\tau}}{d\tau} K_{i\tau}] d\tau. \qquad (9)$$

$V_T - V_0 > 0$ shows social welfare at date T has increased with the initial social welfare. Therefore, the "capital gains" on the assets should be deducted form difference in wealth between two dates. Genuine investment can be used to (1) judge whether or not an economy's production possibility set is growing, (2) assess whether or not social welfare has increased between two dates, (3) measure the present discounted value of the changes in future consumption services brought about by it, and (4) provide a criterion for social cost-benefit analysis of policy reforms.

PHOSPHORUS FLOW

To much phosphorus causes excessive algae growth, which can be harmful to fish and drinking water. Removing phosphorus from wastewater requires costly technology to meet expected environmental standards. To avoid this costly option, focusing primarily on implementing capital and operations improvements is necessary for improving and stabilizing phosphorus removal. The goal of phosphorus management is to reduce the phosphorus discharges to these water bodies and reduce the likelihood of water quality degradation and the appearance of algae blooms. The phosphorus management focused primarily on what improvements would upgrade the amount and consistency of phosphorus removal achieved.

Phosphorus is considered as a key element of the overall state of a shallow lake (Mäler, Xepapadeas and de Zeeuw 2003), which is a pollutant at high levels of concentration, causing as it does increased plant growth, decrease in water transparency, oxygen depletion, and fish kills. The quantity of phosphorus in the water column can be taken to evaluate sustainability of the state of a lake, rather than to be important indicator of ecosystems of a lake.

The resource allocation mechanism is for phosphorus inflow, C_t. A scalar S is denoted to be the quantity of phosphorus in the water column. A feedback of phosphorus from bottom sediments will generate as the density of algae in the lake is getting large. This feedback in the form of recycling is reflected from sediment to the water column. The recycling rate, $\frac{bS_t^2}{1+S_t^2}$, is a (sigmoid) function of S. with $b > 0$. The rate of input of phosphorus into the water column is therefore $[C_t + \frac{bS_t^2}{1+S_t^2}]$.

In time, phosphorus depleted from the water column is linked with sedimentation and water outflow. The rate of loss proportional to S is assumed as γS. The lake's dynamics in the phosphorus content are given by the equation

$$\frac{dS_t}{dt} = C_t + \frac{bS_t^2}{1+S_t^2} - \gamma S_t , \qquad \text{for} \quad t \geq 0 , \tag{10}$$

where S_0 is given as an initial condition.

The rate of phosphorus inflow into a lake as fertilizer runoff from farms is a byproduct of agriculture in the watershed. These considerations are postulated to be a strictly concave and differential utility function $U(C,S)$, where U is an increasing function of phosphorus inflow, $\frac{\partial U}{\partial C} > 0$. Phosphorus with a deleterious effect on the lake at all levels of concentration represents that U is a decreasing function of S for all S, $\frac{\partial U}{\partial S} < 0$ This assumption is taken to relief those economic problems where a produced good has positive social worth as a flow, even though it is a pollutant as a stock. Thus, social welfare at t is

$$V(S_t) = \int_t^{\infty} U(C_\tau, S_\tau) e^{-\delta(\tau - t)} d\tau , \text{ where } U_S < 0 \text{ and } U_C > 0 . \tag{11}$$

The problem is to choose $\{C_t\}_0^{\infty}$ so as to maximize (11), subject to (10), that is, how to find the optimum $C_t > 0$ phosphorus inflow to maximize social welfare.

The optimum resource allocation mechanism is clearly both autonomous and time consistent. Let p_t be the accounting price of phosphorus in the lake.

$$p_t = -U_C (< 0) , \text{ for all } t. \tag{12}$$

Based on the lake's dynamics in the phosphorus content, the analyses with (10) are developed to simulate the allocating phosphorus in the lake's water colume. For a range of parameter values C_t, b, and γ, the curves $\left[C_t + \frac{bS_t^2}{1+S_t^2} \right]$ and γS_t calculated with Mathematical Package intersect at three points as Figure 1 shown. The upper and lower intersects, S_1 and S_3, are stable stationary points, whereas the intersect, S_2 is unstable. If the rate of input of phosphorus is greater than the rate of phosphorus loss (if $C_t + \frac{bS_t^2}{1+S_t^2} > \gamma S_t$), then the phosphorus content in the lake's water column is increasing to S_1 or S_3. On the other hand, if the phosphorus input rate is less than the phosphorus loss rate (if $C_t + \frac{bS_t^2}{1+S_t^2} < \gamma S_t$), then the phosphorus content in the lake's water column is decreasing to S_1 or S_3. Thus, S_2 is the unique separatrix of the dynamical system. S_1 and S_3 should be considered as oligotrophic and eutrophic states, respectively.

On using (10), the resource allocation mechanism, α, governing the lake's quality can be expressed as,

$$\frac{dS_\tau}{d\tau} = C_\tau + \frac{bS_\tau^2}{1+S_\tau^2}, \quad \text{for } \tau \geq t, \tag{13}$$

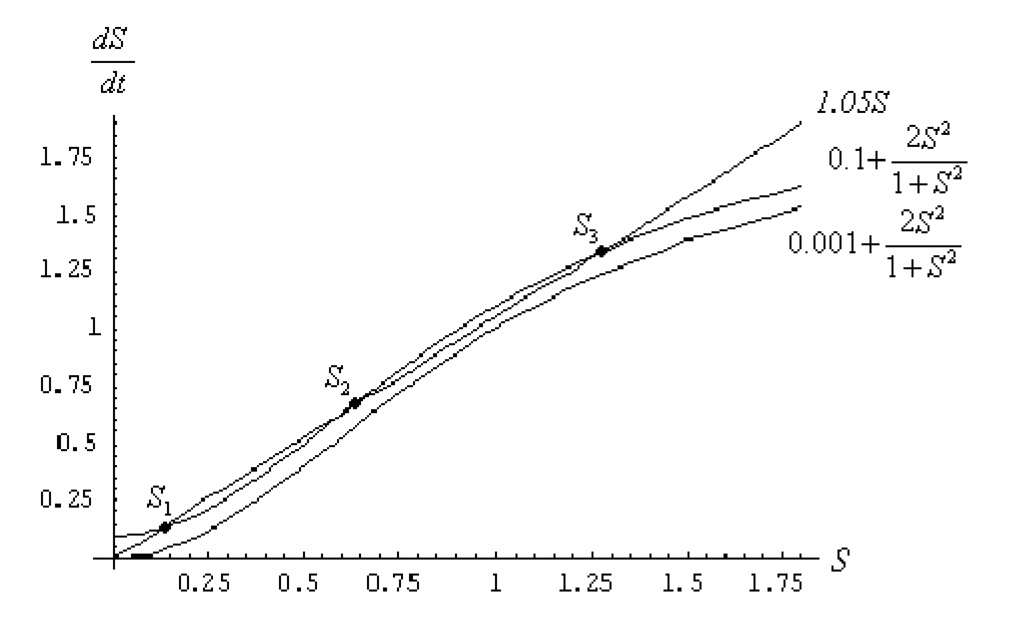
where S_0 is an initial condition.

For α autonomous and time consistent, *V*(*S*) is differentiable in *S* everywhere, excepting S_2. But *V*(*S*) is discontinuous at S_2, it possesses both right-and left-hand derivatives there. The accounting price of lake's quality is therefore defined to be $p(S) = \frac{\partial V}{\partial S}$ at all $S \neq S_2$. *p*(*S*)<0 should be noted because phosphorus is a pollutant in the lake. $-U_C \neq \frac{\partial V}{\partial S}$ should be also noted because the resource allocation mechanism is imperfect. The welfare theory will be locally for the purpose of project evaluation and sustainability assessment.

CONCLUSION

In this paper pursuing the maximum of social well-being subject to lake’s dynamics in terms of phosphorus flow in the resource allocation mechanism and exploiting the relations of phosphorus management and ecosystem health in the formulation of water quality, the welfare analysis with the accounting prices for evaluation of policy reforms and for assessing whether the economic programme being pursued sustains intergenerational welfare is introduced. The benefit of intergenerational welfare analysis in imperfect economies can be described in terms of the expected increase (the maximum value of intergenerational welfare) of project evaluated and sustainability assessed as a result of the properties of accounting prices of environmental natural resources such as phosphorus removal. The ecologic processes are driven by non-convex transformation possibilities (Murray, 1993; Arrow, Dasgupta and Mäler 2003). This paper is an illustration of the utility of modeling in evaluation of policy reforms for non-convex functional relationships between phosphorus intake and phosphorus status. In addition to phosphorus management, joint consideration on nutrient management, fishery policies and habitat improvement is likely to lead to greater confidence in decisions on monitoring of ecosystem health and human well-being. The methods developed in this paper will be of use for further environmental and resource research of these joint considerations.

Figure 1: Dynamics of phosphorus content in the water column.



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APPENDIX

$$\frac{dP_t}{dt} = \frac{dt}{d}(\frac{\partial V_t}{\partial K_{it}}) = \frac{d}{dt}\frac{\partial}{\partial K_{it}}\int_t^\infty U(C_\tau)e^{-\delta(\tau-t)}d\tau = \frac{d}{dt}\left[e^{\delta t}\frac{\partial}{\partial K_{it}}\int_t^\infty U(C_\tau)e^{-\delta\tau}d\tau\right]$$

$$= \delta e^{\delta t}\frac{\partial}{\partial K_{it}}\int_t^\infty U(C_\tau)e^{-\delta\tau}d\tau + e^{\delta t}\frac{d}{dt}\frac{\partial}{\partial K_{it}}\int_t^\infty U(C_\tau)e^{-\delta\tau}d\tau$$

$$= \delta P_{it} + e^{\delta t}\frac{d}{dt}\int_t^\infty U'(C_\tau)\frac{\partial C_\tau}{\partial K_{it}}e^{-\delta\tau}d\tau$$

$$= \delta P_{it} - e^{\delta t}\frac{d}{dt}\left[\int_0^t U'(C_\tau)\frac{\partial C_\tau}{\partial K_{it}}e^{-\delta\tau}d\tau + \int_\infty^0 U'(C_\tau)\frac{\partial C_\tau}{\partial K_{it}}e^{-\delta\tau}d\tau\right]$$

$$= \delta P_{it} - e^{\delta t}U'(C_t)\frac{\partial C_t}{\partial K_{it}}e^{-\delta t} - e^{\delta t}\frac{d}{dt}\int_\infty^0 U'(C_\tau)\frac{\partial C_\tau}{\partial K_{it}}e^{-\delta\tau}d\tau$$

$$= \delta P_{it} - U'(C_t)\frac{\partial C_t}{\partial K_{it}} - \int_\infty^0 U'(C_\tau)\frac{d}{dt}(\frac{\partial C_\tau}{\partial K_{it}})e^{-\delta(\tau-t)}d\tau$$

$$= \delta P_{it} - U'(C_t)\frac{\partial C_t}{\partial K_{it}} - \sum_j P_{jt}\frac{\partial(\frac{dK_{jt}}{dt})}{\partial K_{it}}$$