THE IMPACTS OF PESTICIDE USE IN RICE PRODUCTION ON AQUACULTURE IN THE MEKONG DELTA: A DYNAMIC MODEL

Dang Minh Phuong

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Comments should be sent to: Dang Minh Phuong, Faculty of Economics, University of Nong Lam, Thu Duc, Ho Chi Minh City, Vietnam. Tel 84-8- 8961708. Fax 84-8-8960713.

Email phuongm@hcm.fpt.vn

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THE IMPACTS OF PESTICIDE USE IN RICE PRODUCTION ON AQUACULTURE IN THE MEKONG DELTA: A DYNAMIC MODEL

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EXECUTIVE SUMMARY

Both rice production and fish culture in the Mekong Delta, Vietnam have a close mutual relationship with the use of water and land resources. First, they are competitive in the use of land and water. Second, rice production discharges pesticides into water bodies causing an external cost to fish culture, which, in turn, leads to an increase in fish cost and price. A dynamic model for maximizing the social surplus is developed for optimal management of resources as well as production. Its first-order conditions provide some important quantitative as well as qualitative interpretation that explains the dynamic relationships among prices, water quality, and shadow price. The time paths and phase diagrams of the model show the variations and the changes in prices, outputs, and water quality over time, and the initial position in regions leading to divergence or convergence. As a result, effective policies are set up to maximize social welfare. Data are collected and used in estimations of demand functions of rice and fish, the function of assimilative capacity, the fish cost function, and the parameter of pesticide discharge. The total loss of fish culture (total external cost in the year 2001) due to pesticide use is about $US 9 billion. Two cases of linear and nonlinear forms are simulated with scenarios of initial values for the year 2001. The simulation shows optimistic results with prices going down and water quality going up over time, meaning the social surplus will rise. The phase diagram shows that the social manager should look for policies to raise the initial value of water quality to get an optimal solution. A comparative analysis of the model simulation shows the directions of change in parameters leading to a change in the steady state values. How to change the parameter values is analyzed and the analysis suggests different policies such as a minimum tax on pesticide input about 123%, change in priority in industry development that aquaculture must be considerable, expansion of fish/rice or shrimp/rice pattern, changes in pesticide regulations, training and transfer of technology to the farmer how to raise fish efficiently, and policies for aquacultural development.

1.0 INTRODUCTION

1.1 Problem Statement

Rice production has rapidly developed in Vietnam since 1989 and the country exported about 4 million tons of rice in 1998. However, the more rice is produced, the more pesticide and other chemicals are used resulting in a rapid deterioration of the water environment, negative impacts on the health of farmers and consumers, along with a loss of biodiversity. These damages are not internalized by rice production. Meanwhile, aquaculture is considered a friend of the environment (except for coastal fish culture which negatively impacts on the ecosystem) (FAO, 1997), but fish culture is still not developed to its full potential viewed in light of the advantages of natural conditions for aquaculture development. Both rice and fish culture have substantially contributed to Vietnam's economic development in recent years. They have a close mutual relationship with water and land resources. First, they are competitive in the use of land and water; this means that flooded rice fields can be converted into fish ponds and vice versa. Second, rice production discharges agricultural chemicals into water bodies causing water contamination that impacts on fish productivity. These impacts have been evaluated by some researchers. Nguyen's (1990) research showed that, after spraying Decis on rice plant for 1 hour, 71.3% of the shrimp died; after 6 hours, 100% of the shrimp died. Only Monitor and Azodrin were less deadly, but the other pesticides killed all shrimp within the 24-hour period. Vo's (1995) research showed that all water samples in fish ponds contained pesticide residuals. Lindan was found in 81% of the samples, Methamidophos in 100%, M.parathion in 40%, Dimethoate and Endosulfan in 28%, and so on. Dang (1998) used the contingent valuation method to evaluate the quality of rural water environment, and found that pesticide pollution is a major source degrading the water quality in the Mekong Delta. Nguyen (1998) showed damage to the health of farmers resulting from pesticide practices. In general, much of the evidence demonstrates pesticide use as the main cause of environmental water pollution in the Mekong Delta, and the consequent adverse effects on fish culture as well as fish capture. Thus, rice production (2 million hectares in the Mekong Delta) creates the externality to fish-culture and capture. Moreover, natural conditions for both productions such as abundant water sources, suitable weather, and fertile soils enjoy a comparative advantage in the Mekong Delta, the Red River Delta, and the Mid Vietnam Delta. These advantages are not fully used to develop aquaculture due to this externality.

Statistics shows that there is considerable increase in total yield of rice and its real price has decreased over time. On the other hand, the growth rate of fish production is less than that of rice production, but the growth rate of fish price is relatively high compared with rice and other commodities. The gap between the two relative prices has increased over time. This possibly shows that fish is becoming increasingly scarce due to the changes in water quality as well as from depletion in fish stock due to open access. These issues pose a few intriguing questions from the perspective of economics: How much social welfare is lost on account of changes in fish price due to changes in water quality? What is the relationship among price, output, and water quality in both rice production and fish culture over time? What can be done to improve this situation?

This research focuses on answering these three questions. Social welfare can be measured by social surplus, including producer's and consumer's surplus, an indicator in the measurement of social welfare. The relationships among price, output, and water quality is identified by a dynamic model, from which social welfare is measured. Moreover, simulation of the model will yield different scenarios for optimal management of water and land use as well as alternative policies for improving the situation.

1.2 Research Objectives

The general objective is to model and simulate dynamic economic relationships of rice and fish production for socially-optimal management of water and land resources and suggest changes in policy for pesticide use.

The specific objectives are:

- to set up a model of the dynamic relationship of price and output with water quality by which the shadow price of water quality is identified and the social welfare loss is measured.
- to simulate the model for different scenarios of optimal management in order to identify optimal time-paths of price and water quality and measure other benefits from the development of aquaculture.

to suggest changes in policies for water and land resource use and policies for pesticide and chemical use in agricultural production.

2.0 THE MODEL

2.1 Literature Review

Dynamic models for optimal management of natural resources have been of long- standing interest to resource economists. The first simple, well-known model is Faustmann's (1849) model for optimal harvest of timber. The second is Hotelling's (1960) model for optimal exploitation of minerals and it embodies the fundamental principle of exhaustible resource economics (see Gopalakrishnan, 2000). Gordon (1954) provides the first open access model of fishing. The early and mid-1970s saw a series of papers that applied the optimal control problem of the theory of dynamics to optimal management of forestry, fisheries, minerals, and water. These include the Ehui *et al.* (1990) model for socially-optimal rate of deforestation, Crabbe and Long's (1989) model for optimal forest rotation, and Arnason's (1990) model for social optimum in competitive fishery. Clark (1985) provides bioeconomic modeling and fishery management. Berck (1981) provides a model of optimal fishery exploitation with endogenous price and Kishi *et al*. (1991) present a management simulation model for quantitative management of aquaculture. Dynamic models for optimal management of stock pollutants and residual wastes are developed by Plourde (1972), Smith (1972) and Foster (1977). The model for optimal exploitation and contamination of underground water is presented in Krulce *et al*. (1994), and Conrad and Olson (1992). Dynamic models which are most closely related to this research are briefly reviewed here.

Conrad and Olson (1992) set up a dynamic model of pesticide application and groundwater contamination. Its objective function is to maximize the present net social benefits, subject to a state equation, a constraint implying that pesticide concentration in time t+1 equals the concentration in time t minus its degradation plus pesticide discharge in time t.

An optimal steady state for this problem is characterized by the two equations. The first equation requires that the marginal net benefit of pesticide application be equated to the present value (in perpetuity) of the marginal social cost. The second equation states that, in steady state, the pesticide concentration in discharge must be equal to the proportion of degradation. The authors simulated the model for the pesticide aldicarb on eastern Long Island, New York. The results are very useful for optimal management of pesticide use.

Rinaldi, Sanderson and Gragnani's (1996) model of pollution policies and natural resource dynamics without an objective function include three differential equations of resource abundance, pollution, and control capital which interact and vary over time.

The policy maker knows the available budget, the shape of the pass-through function, and the amount of pollution control capital that is on line. The authors show that the behavior of the model can be analyzed graphically using the singular perturbation approach. The model produces two types of behavior, static and cyclic. In the latter case, the resource goes through periods of growth and collapse punctuated by long periods of abundance or scarcity.

These models are very useful for optimal management of resources and are well documented in research studies in fisheries, rangelands, aquaculture, and forest-ecosystems. Often the dynamics of the resources and the contamination of a given system influence the actions taken by institutions responsible for environmental protection and exploitation. Institutions and the economy interact with the environment, making the prediction of the dynamics of the resulting system a highly complex problem (Walters, 1986). These problems have been studied under many different circumstances and the models used share some common features. However, each model is often suitable for the purpose of a specific problem rather than for all problems in general. Thus, the above models are not completely suitable for the problem of water use for rice and fish production in Vietnam. A new model that shares some common features must be set up, which at the same time would contain its own relationship of the problem addressed.

2.2 Assumptions and the Scope of Research

- Social surplus is limited to rice and fish and does not include biodiversity losses, impacts on farmers' health from pesticide use, or on consumers' health from food contaminated by pesticide.
- Pesticides include insecticide, herbicide, and fungicide, each of which has many commercial names e.g., commercial names for insecticide include Bassa, Decis, Sherpa, M.parathion, Monitor, Sumithion, Azodrin, DDVP and so on.
- Bioaccumulation is ignored because the quantity of the residue in water bodies is adequate to represent water quality.
- The type of fishery for this research is fishpond culture in fresh water regions and *does not* include capture fish, coastal fishpond culture (where water is salt or brackish, rice cannot be produced), catfish, and basafish in cage culture.
- Externality from fish- pond culture is negligible, and feeds supplied to raise fish are often less than demanded. Therefore there is no nutritional surplus in water causing the phenomenon of "algae- blooms".
- The simulation of the model is focused on production and fish culture in the Mekong Delta, the largest delta in Vietnam.

2.3 Water Quality Variable

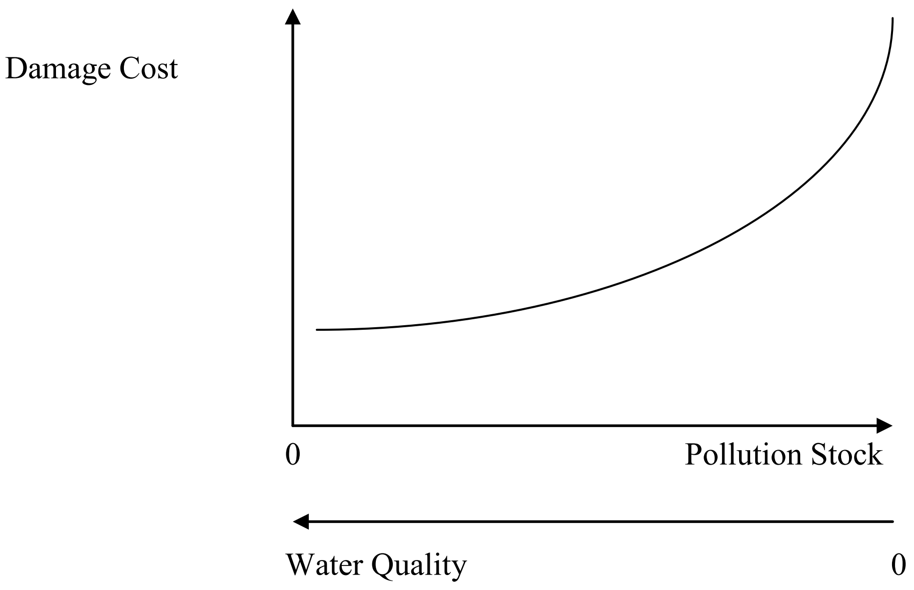


Figure 2.1 Relationships between Pollution Stock and Water Quality

Most papers or books on pollution economics often mention the term "environmental quality", but do not mention the "environmental quality variable", except in contingent valuation (CVM) research that ranks environmental quality as a qualitative variable such as A, B,C and D. In existing research, variables such as "pollutant stock" or "waste residue" are popularly used. In this research, "the water quality variable", z_t, is conceptually defined and used, instead. According to the Arrow-Mangasarian theorem (Chiang, 1992), in optimal control problem, shadow price, λ, should be positive or equal to zero. If the "pollutant stock variable" is used in the Hamiltonian problem, then $\lambda < 0$, which would violate the theorem. The higher the pollution is, the lower is the environmental quality. From this relationship, the pollutant stock can be converted into water quality. Thus the water quality variable is inversely related to the pollutant stock (pesticide residue stock) variable on the particular scale as in Figure 2.1 typically.

2.4 Notations

Notations used in the model are the following:

$y_t^1 \equiv$ output of rice in year t,

$y_t^2 \equiv$ output of fish in year t,

$c^1(W^1, X^1) \equiv$ average cost equation of rice production,

W^1, $W^2 \equiv$ input price vector of rice and fish production, respectively,

X^1, $X^2 \equiv$ input vectors of rice and fish production, respectively,

$c^2(W^2, X^2, z_t) \equiv$ average cost equation of fish culture,

$z_t \equiv$ water quality in year t,

$p_t^1 \equiv$ rice price in time t,

$p_t^2 \equiv$ fish price in time t

$r \equiv$ social discount rate, and

$D(p_t^1)$ and $D(p_t^2) \equiv$ the demand functions for rice and fish, respectively.

2.5 Setting the Model

2.5.1 Objective Function

The objective is to maximize the social surplus subject to the change in water environment quality. The proposed model differs from Conrad and Olson's (1992) model in some important aspects. The structure of this model includes two control variables, each one impacting the other, instead of one control variable of the amount of pesticide; the objective function is social surplus instead of total net profit; the Hamiltonian optimal control problem is used instead of the Lagrangian problem; and the state variable, z_t, is conceptually defined as the environmental water quality variable instead of the pesticide pollution stock variable. The price variables, $p^i{}_t$, are endogenous instead of exogenous. As a change in water quality leads to a change in fish cost, i.e. change in supply side, which, in turn, impact the fish price.

The hypothetical social planner chooses the level of water environment quality, z_t, for rice production and fish culture to maximize the present value of social surplus. Given a constant discount rate $r > 0$, this can be posed as the following autonomous optimal control problem with bounded controls: Choose y^1 and y^2 to maximize:

$$(2.1)\qquad \int_0^\infty e^{-rt}\left[\int_0^{y^1} D^{-1}(m^1)dm^1 + \int_0^{y^2} D^{-1}(m^2)dm^2 - c^1(W^1,X^1)y^1 - c^2(W^2,X^2,z).y^2\right]dt$$

Note that are areas under the demand curves i.e., the consumers' total willingness to pay for rice and fish and $c^1(W^1,X^1).y^1 + c^2(W^2,X^2,z).y^2$ is the total cost of producers.

2.5.2 State Equation

Let βy^1 be the amount of pesticide discharged into the water environment, where β, the ratio of pesticide discharge resulting reduction in water quality, is linear with rice output and $a(z)$ is the assimilative capacity of water environment that improves water quality. The term "assimilative capacity" is adapted from Kerry *et al.* (1993) and it refers to the many functions of the natural environment. Tietenberg (1984) defines this in more detail: "We call this ability of the environment to absorb pollutants its *absorptive capacity*. If the emissions load exceeds the absorptive capacity, then the pollutant accumulates in the environment."

So an additional increase in water quality can be expressed as follows:

$$(2.2)\qquad \dot{z} = a(z) - \beta y^1 .$$

This is also called the balance equation of water quality or the state equation of water quality.

Initial conditions for the problem include both the initial prices, $p^1{}_0, p^2{}_0,$ and water quality, z_0, which is already degraded by a history of rice production where externality was not taken into account.

2.5.3 Current Value Hamiltonian Problem

Maximizing (2.1) subject to (2.2) and $y^1 \geq 0$, $y^2 \geq 0$, given $z(0) = z_0$, $p^1(0) = p^1{}_0$ and $p^2(0)=p^2{}_0,$ we have the current- value Hamiltonian

$$H = \left[\int_0^{y^1} D^{-1}(m^1)dm^1 + \int_0^{y^2} D^{-1}(m^2)dm^2 - c^1(W^1,X^1)y^1 - c^2(W^2,X^2,z)y^2\right] + \lambda[a(z) - \beta y^1]$$

2.5.4 First Order Conditions and Interpretations

Following the approach by Kamien and Schwartz (1991), the optimal necessary conditions for the problem are

$$(2.3)\qquad \dot{z}_t = \frac{\partial H}{\partial \lambda_t} = a(z_t) - \beta y_t^1$$

$$(2.4)\qquad \dot{\lambda}_t = r\lambda_t - \frac{\partial H}{\partial z_t} = r\lambda_t + c_z^2(W^2,X^2,z)y^2 - \lambda_t a_z(z_t)$$

$$(2.5)\qquad \frac{\partial H}{\partial y^1} = D_t^{-1}(y^1) - c^1(W^1,X^1) - \beta\lambda_t \leq 0$$

If < then $y^1 = 0$

(2.6) $\frac{\partial H}{\partial y^2} = D_t^{-1}(y^2) - c^2(W^2, X^2, z) \le 0$

If < then $y^2 = 0$

By definition of inverse demand function

$p_t^1 \equiv D_t^{-1}(y^1)$

$p_t^2 \equiv D_t^{-1}(y^2)$

Substitute these into Equations (2.5) and (2.6), and the condition of Equation (2.5) holds with equality and then it can be rewritten as

$$\frac{1}{\beta}[p_t^1 - c^1(W^1, X^1)] = \lambda_t$$

(2.5') $\Rightarrow p_t^1 = c^1(W^1, X^1) + \beta\lambda_t$

Thus, the *in situ* shadow price of water environmental quality, λ_t, is proportional β to resource rent (i.e., price less unit cost). The second line says that the price must optimally be included in the cost of using the environment. In the case that farmers maximize their profit, then at optimal level, $c^1 = mc^1$ implies that price must be equal to marginal social cost plus marginal private cost. This is the condition for Pareto optimality.

As water resources are considered open-access, rice producers ignore the shadow price; this implies that $\lambda_t = 0$.

For simplicity, let us denote

$c^1(W^1, X^1) = c^1$

$c^2(W^2, X^2, z_t) = c^2$

To get the system of differential equations for optimal control problem, taking the partial derivative of Equation (2.5') with respect to time and after a few mathematical steps, we have

(2.7) $\dot{z}_t = a(z_t) - \beta y^1$

(2.8) $\dot{p}_t^1 = [r - a_z(z)](p_t^1 - c^1) + \beta c_z^2 y^2$

(2.9) $\dot{p}_t^2 = c_z^2(a(z) - \beta y^1)$

Equation (2.7) is the water quality balance as noted to above- the additional increase in environmental quality is equal to the assimilative capacity of environment minus the amount of discharge into water bodies in period t. $\dot{z} > 0$ as the assimilative capacity of environment is greater than the emission, and vice versa.

The left side term of (2.8) is the additional increase in rice price over time, the first right side term is the increase in foregone resource rent in the next period at the rate r less a_z due to using water resource in this period. In other words, this term is the additional increase in the cost of water resource use in the next period due to discharge of pesticide during this period. The second term is the additional increase in foregone benefit of fish culture per unit in the next period due to pesticide pollution in rice production in the current period. Hence, Equation (2.8) states that the additional increase in rice price over time is optimally equal to the additional increase in the cost of water resource use in the next period and in the damage cost to fish culture in the following period due to the use of water resource in the current period.

Equation (2.9) states that an additional increase in fish price over time is optimally equal to the product of the marginal average cost of fish culture with respect to water quality, z_t, and the additional increase in the water quality. If $\dot{z} > 0$, then $\dot{p}_t^2 < 0$ (by $c_z^2 < 0$), this implies that the better the environment is, the cheaper the fish price is, dynamically.

The system of differential equations describes and explains the dynamic interactions between rice price and fish price over time through the state variable z_t. The social planner chooses the level of the state variable to control the prices such that he/she maximizes the social surplus.

In steady state (dynamic optimal equilibrium),

$$\dot{\lambda} = \dot{z} = \dot{p}_t^1 = \dot{p}_t^2 = 0$$

Inverse demands have parameters such as k_i, m_i with $i = 1, 2,$ respectively and solving these for optimal values p^{*1}, p^{*2} and z^*, we have

$$p^{*1} = p^{*1}(W^1, W^2, X^1, X^2, \beta, \phi, r, k_i, m_i)$$
$$p^{*2} = p^{*2}(W^1, W^2, X^1, X^2, \beta, \phi, r, k_i, m_i)$$
$$z^* = z^*(W^1, W^2, X^1, X^2, \beta, \phi, r, k_i, m_i).$$

These can be useful for static comparative analysis. When there is a change in a parameter, it is accompanied by a change in price and the water quality. They are also used to simulate some scenarios, given the initial prices and the water quality.
Given the initial prices and the water quality and the dynamic system of differential equations, we can draw optimal time-paths of prices and water quality.

2.6 Time Paths

To get the time paths of p^1 and p^2, we solve the system of differential equations in the linear case, we have optimal time paths as follows

$$p_t^1 = -(\rho\beta / m_2)K_1 e^{b_2 t} + p^{1*}$$

$$p_t^2 = \left(\frac{r+B}{2} - \phi\right) K_2 e^{b_2 t} + p^{2*}$$

$$z_t = \frac{1}{\rho}\left(A - (\frac{r+B}{2} - \phi) K_2 e^{b_2 t} + p^{2*} \right)$$

where $K_1 = \left(p_0^1 - p^{1*}\right) / -(\rho\beta / m_2)$ and $K_2 = \left(p_0^2 - p^{2*}\right) / (A - (\frac{r+B}{2} - \phi))$.

If $K_1 > 0$, then the rice price will go down on the time path to steady state equilibrium asymptotically. If $\phi > \frac{r+B}{2}$ and $K_2 > 0$, then the time path of fish price, $p^2{}_t$, declines over time on the path to steady state equilibrium asymptotically. These cases are expected in the final results of the simulation. If both prices will go down over time, then the social surplus will be higher than in other cases. Fish price cannot go up due to better environmental quality resulting from internalizing the cost of environmental use (external cost) to rice production. With the values of parameter assumed above, the time paths can be drawn in Figures 2.2 and 2.3.

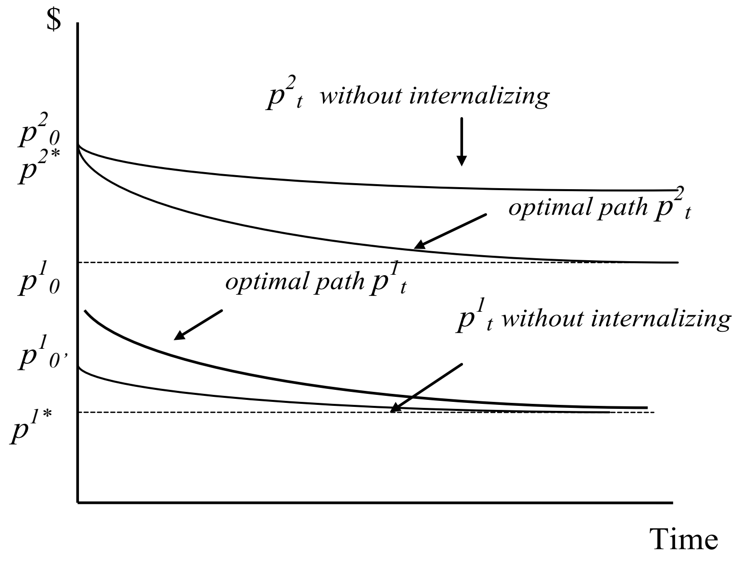


Figure 2.2 Time Paths of Fish and Rice Price

Note that the paths without internalizing are based on real prices and the path of z is based on the relationship between p^2 and z, $p^2 = -\rho z + A$ and $p^2{}_t$.

The decrease in prices over time can be explained by rapid technological changes as well as governmental funding. Incentive for government to fund stems from the concern for enhanced environmental quality and increased revenues from increased outputs. Moreover, the decline in prices can be explained by changes in the values of parameters of the model from different policies as in Section 5.

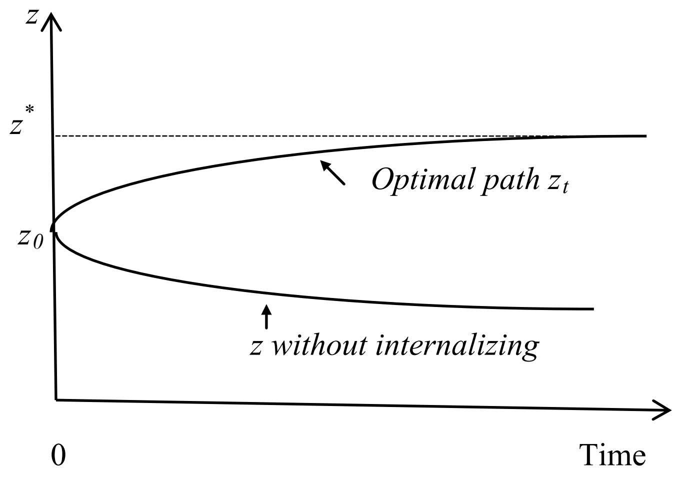


Figure 2.3. Time Path of Water Quality

Initial value of water quality, z_0, is in already polluted state (see Figure 2.3). Without internalizing external cost, water quality declines over time due to increase in pesticide use. After internalizing by using policies such as, tax on pesticide, ban of some types of very toxic pesticides or aquaculture development (due to competition in land use between aquaculture and rice production, if fish culture area goes up, then rice area goes down leading to less pesticide use), pesticide discharge declines, thus water quality increases along the optimal path.

In the case of nonlinear functional forms, the time path is computed the same as above.

2.7 Phase Diagram

The phase diagram is a very important tool for optimal management. It shows how to reach the steady state equilibrium. It consists of three components: loci (*isoclines*) of the curves $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$ and $\dot{z}_t = 0$; stable arm (also called *policy function*) that shows which initial values of p_0^1, p_0^2 and z_0 will converge to steady state; and trajectories (called *streamlines*) that show the directions of motion of the different time paths.

Loci of $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$ and $\dot{z}_t = 0$,

$$z_t = -\frac{\beta}{m_1\phi} p_t^1 + \frac{\beta k_1}{m_1\phi}$$

$$p_t^1 = -\frac{\beta\rho}{(r-\phi)m_2} p_t^2 + \frac{\beta\rho k_2}{(r-\phi)m_2} + c^1$$

$$p_t^2 = \frac{\beta\rho}{\phi m_1} p_t^1 - \frac{\beta\rho k_1}{\phi m_1} + A$$

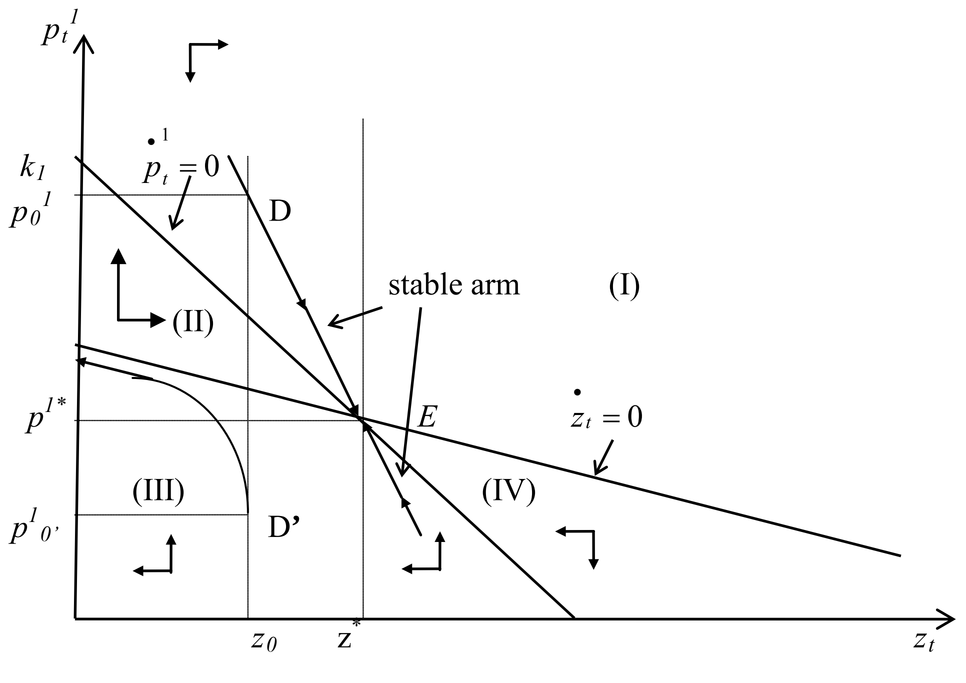


Figure 2.4. Phase Diagram in Space (p^1, z_t)

In Figure 2.4, two loci divide the space into 4 regions. Arrows in each region show the direction of the motion of time paths. Directions of arrow are determined by

$$\frac{\partial \dot{p}^1}{\partial p^1} = r - \phi < 0$$

thus, the sign of $\dot{p}^1$ in regions (II) and (III) is positive, in regions (I) and (IV) is negative,

$$\frac{\partial \dot{z}}{\partial z} = \phi > 0$$

thus, the sign of $\dot{z}$ in region (I) and (II) is positive, in regions (III) and (IV) is negative. The trajectory from point D**'** shows that with the initial value at D' = ($p^1_{0'}$, z_0), the rice price will increase and the water quality will go down and approach zero. The trajectory from point D shows that, the rice price lies on the stable arm and will converge to steady state at point E.

If the initial value lies on the stable arm, then the social planner does nothing except to lower $|b_2|$ to raise social welfare as mentioned above. If it does not lie on the stable arm, then the social planner makes the policy to change the initial value of state variable, *z,* such that it lies on the stable arm. Policies affecting the changes can be tax, subsidy, or regulation, among others.

The phase diagram for space (p^2_t, z_t) is similar to this, only a little change in slope of $\dot{p}^2_t = 0$, steeper than that of $\dot{p}^1_t = 0$.

In the case of the nonlinear, the phase diagram is identified by the same procedure above after applying the Taylor's expansion approximation method.

2.8 Speed of convergence

Whether the speed of convergence for these prices asymptotically approaching steady state equilibrium is fast or slow, the total time for approaching is infinite. However, this doesn't mean that the speed of convergence does not impact on the discounted social surplus. An analysis of the speed of convergence shows an interesting result as follows:

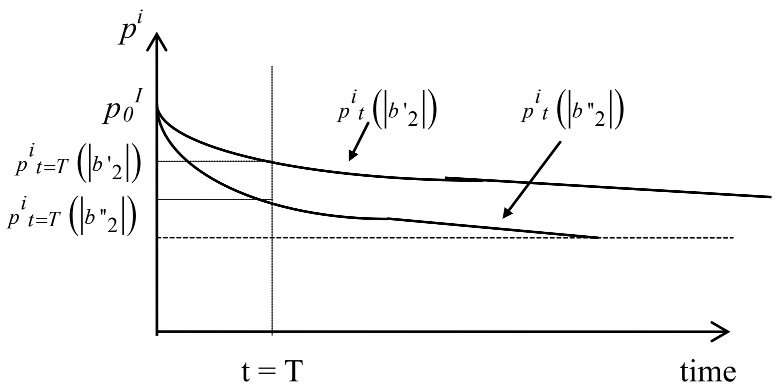


Figure 2.5 Impact of Change in Value of $|b_2|$

The speed of convergence is determined by the absolute value of b_2 , $|b_2|$ (from solving eigen values in differential equations); the greater the value of $|b_2|$ is, the slower the speed of convergence is (the slope of the path is flatter as in Figure 2.5).

Figure 2.5 shows two time paths of p^i_t with two different values of $|b_2|$, where

$|b'_2| > |b''_2|$. At time $t = T$, we have
$p^1_{t=T}(|b'_2|) > p^1_{t=T}(|b''_2|)$.

Denote the discounted social surplus in Objective Function, W, if the price declines, then the social surplus increases:
$W'_{t=T}(|b''_2|) > W'_{t=T}(|b'_2|)$.

Thus, as the value of $|b_2|$ is lowered, then the discounted social surplus of the generation of time $t = 0$ to $t = T$ will be raised. As shown in Figure 2.5, it does not make future generation from $t = T$ to infinite worse off.

How can the social planner make value of $|b_2|$ lower to raise social welfare?

$|b_2|$ is an increasing function of ϕ, r, β, ρ and a decreasing function of m_1 and m_2. Therefore an increase in m_1 and m_2 or a decrease in any r, β, ρ and ϕ makes $|b_2|$ lower.

Decrease in parameters of interest rate r, ratio of discharge β and damage cost ρ

β, ρ can be reduced by some policies such as tax on pesticide, and guidelines for proper use of pesticide. Vo (1996) shows that pesticide application almost exceeds the necessary levels to protect the rice plant against insect attack in the Mekong Delta, because farmers still apply pesticide when there are no signals of insect attack.

Increase in the slopes of the demand curves m_1, and m_2

m_1, and m_2 can be changed by governmental policy in international trade, quota, import, export, subsidy and so on which impact on the demand for fish and rice.

In general, the model maximizing social surplus is very useful for optimal management of resources as well as production. The social planner can interpret the variations and the changes in prices, outputs, and water quality over time via differential equations, time paths and phase diagrams. As a result, effective policies are set up to get maximum social welfare.

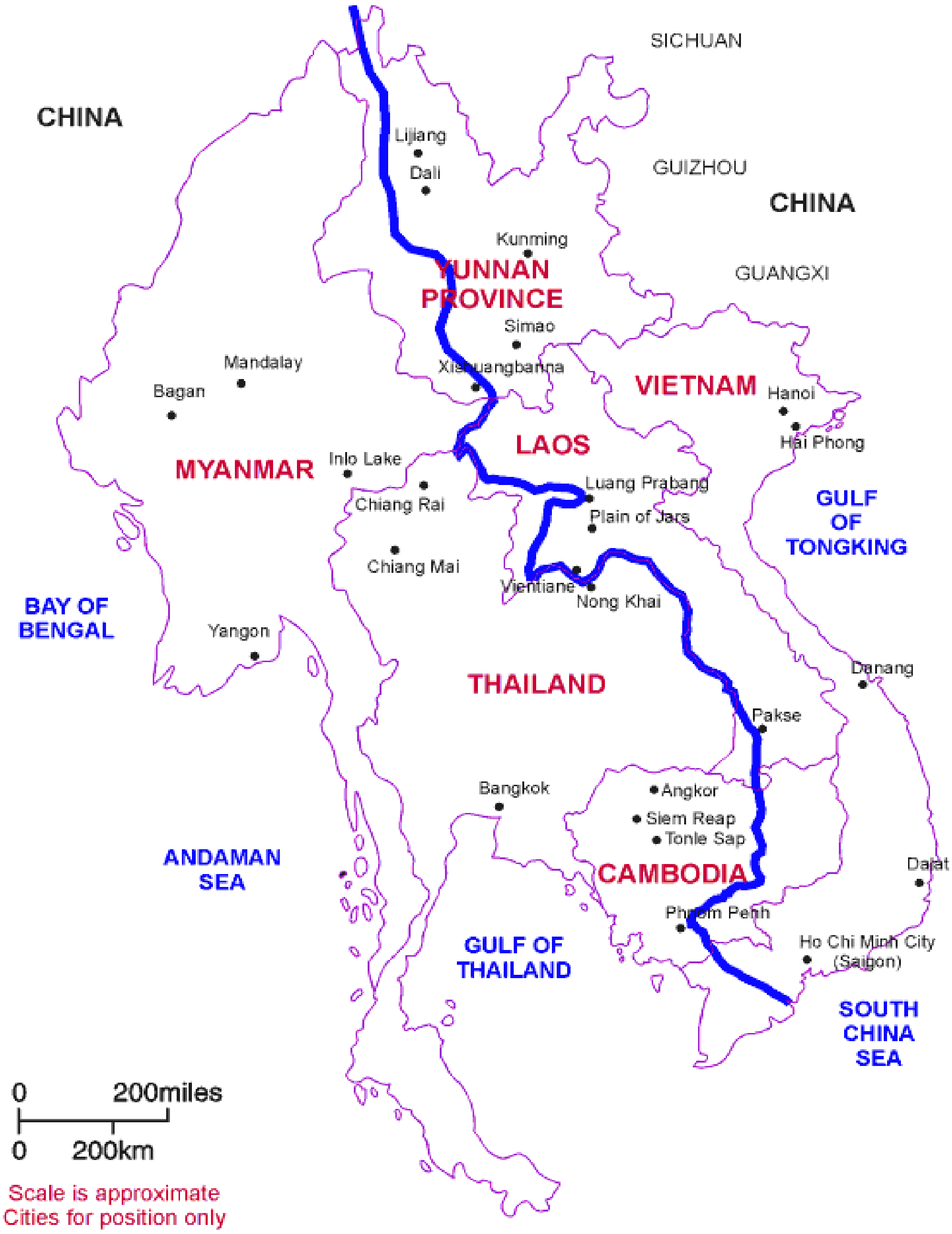
3.0 DATA AND ECONOMETRIC WORK

3.1 Overview of the Mekong Delta

The Mekong is the largest river in Southeast Asia and it ranks 12th in the world in terms of length (4,800 km) and 8th in terms of run off (475 billion m^3/ year). It originates from the Tibetian Plateau of China and crosses six countries namely, China, Myanmar, Thailand, Laos, Cambodia and Vietnam. The river ends in the Mekong Delta with an area of 49,520 km^2, including 39,000 km^2 (80%) located in Vietnam and often called Cuu Long Delta. The Mekong Delta has two sides bordering the sea so that a diversified coastal biological zone is formed which has the potential for aquaculture and mangrove forests.

The Mekong Delta is a very fertile land for agricultural development: it occupies only 12% of the total cultivated area, but its annual food production accounts for nearly

50% of total national food production, since it is the dominant supplier of rice export in Vietnam. During the last two decades, agricultural production has registered an obvious advance- the cultivated area has been widening and the rice-cultivated area and production have been increasing due to cropping intensity and diversity.



Note: the dark (blue) line is the Mekong River; the end of it in Vietnam is the Mekong Delta, study area.

Figure 3.1. Map of Vietnam and Mekong River

In 1976, the area in rice cultivation occupied only 2.05 million hectares, but in 1997 that increased to 3.47 million hectares. At the same time, the average yield has increased from 2.2 to 4.2 tons/crop/hectare. Accordingly, the rice output has increased from 4.7 million tons in 1976 to 16 million tons in 1997 (Statistical Yearbook of Vietnam, 1998), as many as 3.4 times. The Mekong Delta is also a large source of fruit production, with 360,000 hectares of perennial trees, most of which are well-known fruits, such as mangoes, king oranges, longans, durians, rambutans, coconut, etc. As a result of abundant water sources, aquaculture has rapidly developed, bringing about hundreds of millions of dollars from its export products. Fresh fish output has increased from 628,000 tons in 1986 to 1,860,230 tons in 2000.

Water resource development is extremely important to the development of the Mekong Delta. The extension and development of canals help strengthen the capacity of irrigation water supply, improve the water logging condition, flush acid soils and take away the pesticide residual to the East Sea (also called the South China Sea or Indo-China Sea). During the last decade, the irrigation systems have effectively influenced in increasing the production of rice and fish culturing, protecting the environment and improving the living conditions of the residents.

Table 3.1 Basic Production in the Mekong Delta

	Vietnam	Mekong	Percent (%)
Population (million)	76.33	16.13	21.14
Food cultivating area (million hectares)	8.87	4.03	45.39
Rice cultivating area (million hectares)	7.65	3.99	52.12
Rice output (million tonnes)	29.14	15.32	52.57
Aquaculture culturing area (thousand hectares)	535.00	350.90	65.59
Fresh water fish output (thousand tonnes)	305.72	177.24	58.11
Fresh water shrimp output (thousand tonnes)	59.00	44.31	74.64

Source: *Statistical Yearbook of Vietnam, 2000.*

The population and food cultivating area of the Mekong occupy only a small part of Vietnam, about 21% and 45%, respectively, but rice, fresh water fish and shrimp outputs contribute about 52%, 58% and 75% of total national production, respectively. This shows that the Mekong Delta agricultural economy consists mainly of fish culture and rice production.

3.1 Demand Functions

3.2.1 Data

Before 1986, the price of goods was decided by the Governmental Pricing Committee because of the centrally-planned economy. Therefore, this price is not suitable for this study which assumes a competitive market economy. As a result, the data used for estimation is from 1986 to 2000.

The secondary data on rice output, fish output, population, gross national product (GDP), and consumer price index (CPI) come from the Statistical Yearbooks of Vietnam for 1986, 1990, 1995 and 2000. The data on rice price and fish price were collected and computed from the daily price bulletins of the Governmental Pricing Committee, Representative Office in South Vietnam, Ho Chi Minh City (see Table 3.2).

Denotation in Table 3.2: POP = population, Y1 = rice output, Y2 = fish output, CPI89 = CPI (consumer price index) with base year 1989, P1 = constant rice price, P2 = constant fish price. GDP (gross domestic product) and POP are for entire Vietnam. Rice produced in the Mekong Delta is consumed in all of Vietnam, so GDP and POP of entire Vietnam would affect the demand and the supply of rice production.

Table 3.2 Population, GDP, Rice and Fish Production in the Mekong Delta

YEAR	GDP (VN$ Billion)	POP (Million People)	Y1 (Million Tonnes)	P1 (VN$ 1,000)	CPI89	Y2 (Million Tonnes)	P2 (VN$ 1,000)
1986	0.6	61.11	7.08	0.54	0.037	0.63	3.24
1987	2.9	62.45	6.45	0.46	0.12	0.65	3.17
1988	15.4	63.73	7.61	0.49	0.57	0.75	3.28
1989	28.09	64.77	8.88	0.49	1.00	0.74	3.01
1990	41.96	66.23	9.48	0.43	1.42	0.69	3.23
1991	76.71	67.77	10.35	0.43	2.45	0.76	3.05
1992	110.54	69.41	10.95	0.45	3.25	0.76	3.12
1993	136.57	71.03	11.07	0.39	3.71	0.82	3.26
1994	170.26	72.51	12.12	0.36	4.26	0.99	3.12
1995	228.89	73.96	12.83	0.41	4.78	1.19	3.26
1996	272.03	75.36	13.82	0.37	5.42	1.55	2.99
1997	313.62	76.71	13.85	0.33	5.62	1.65	2.98
1998	361.47	78.06	15.32	0.36	6.14	1.64	2.69
1999	402.50	79.25	16.28	0.36	6.15	1.77	2.87
2000	429.87	80.18	16.56	0.30	6.13	1.86	2.80

Fresh fish cultured in the Mekong Delta consists of many families and species, each of which has a different price. Therefore P2, the average fish price, is calculated from the three most popular and dominant species of carp fish in the Mekong Delta.

3.2.2 Functional Forms

Inverse demand is often viewed as a function of output y, income per capita I, complementary or supplementary goods price p^j, and the trend variable t,

$p = p(y, I, p^j, t)$.

According to the law of demand, the more the output y is, the lower the price p is, meaning they have an inverse relationship. If people have a higher income, they are more willing to accept a higher price, so these variables have the same signs. In Vietnam, rice and fish are the staple food necessary for every meal, and therefore the complementary or the supplementary goods price p^j *is* ignored in this study. The trend variable is considered as a representative of technology advances; the longer the time is, the more the new technologies apply; and the lower the price is, the relationship between the trend and the price is inverse.

Functional forms of inverse demand often used in empirical work are linear, Cobb-Douglas and log. In linear form, it is specified as

$p^1 = k_1 + l_1 I - m_1 y^1 - n_1 t,$ and

$p^2 = k_2 + l_2 I - m_2 y^2 - n_2 t,$

where 1 and 2 are rice and fish, respectively, coefficients $m_{1,2}$,$n_{1,2}$,$l_{1,2}$ and $n_{1,2}$ >0.

In the Cobb-Douglass form, it is specified as

$p^1 = k_1 y^{-m1} I^{l1} t^{-n1}$ and

$p^2 = k_1 y^{-m2} I^{l2} t^{-n2}$.

These functional forms are similar to those in Chapter 2.

3.2.3 Estimation

To estimate the inverse demand, the nominal prices and GDP must be converted to real ones by the consumer price index, CPI89, and rescaling for price and GDP variables.

Applying the functional forms in both linear and nonlinear equations with the data from Table 3.2, the results show that the R-squared is very high, about 0.87, but almost all the coefficients are insignificantly different from zero at many levels and their signs are unexpected even after applying different functional forms. Some tests, such as the functional form and specification (reset and recur option in command diagnos in Shazam software) autocorrelation (Chow test and Durbin-Watson test) and heteroskedasticity (command HET in) show no such problems. However, the test for multicollinearity, by detecting the correlation among the variables, shows in Table 3.3 below:

Table 3.3 Correlation among Variables

	T	y^1	y^2	p^1	p^2	GDP
T	1.0000					
y^1	0.98327	1.0000				
y^2	0.91202	0.87588	1.0000			
p^1	-0.92603	-0.88574	-0.84797	1.0000		
p^2	-0.84028	-0.83358	-0.86151	0.81467	1.0000	
GDP	0.98395	0.95752	0.96122	-0.91532	-0.86345	1.0000

In Table 3.3, variables trend, *T* (or technology progress), and *GDP* are almost perfectly correlated with the others. This means that there is a severe multicollinearity of the independent variable, *T* , with the independent others, y^1, y^2 , and *GDP*, and so is the *GDP* variable. The problems of multicollinearity are embodied as follows: Small changes in the data produce wide swings in the parameter estimates. The coefficients may have very high standard errors and low significance levels even though they are jointly significant and the R-squared for the regression is quite high. The coefficients may have the "wrong signs" and implausible magnitudes (Green, 1999, p.256). Thus, the multicollinearity of the trend and income variables included in the functions leads to wrong results of regression. Therefore it is necessary to remedy this problem.

Remedy

Several strategies have been proposed for coping with multicollinearity. The best way is to have more data, but this is impossible because of the limited range of data. Several other approaches that have been of little practical use are ridge regression and principle components (Green, 1999, p.258). However, after applying these in this case, they do not give good results in any functional form. The obvious practical remedy, the most frequently used, is to drop the variables suspected of causing multicollinearity, although it causes the problem of missing variables in the specified model. Table 3.3 shows that the trend and income variables are causing the multicollinearity to the model and, therefore, they are dropped. Applying this approach, the results of estimation by using the Shazam software are as follows:

Rice inverse demand

Linear Form:

$$p^1 = 0.71424 - 0.01963\, y^1$$
$$(15.372) \quad (-6.8799)$$

The t-ratio is in parenthesis, and the R-square and R- square adjusted are 0.7845 and 0.7680, respectively.

The Durbin-Watson ratio is 2.4505, so we do not reject the null hypothesis, $\rho = 0$. The heteroskedasticity test, by using the command HET in Shazam, shows the do-not-reject hypothesis of homoskedasticity.

Cobb-Douglas Form:

$$p^1 = 3.1\, y^{-0.74947}$$
$$(9.7043) \quad (-5.8439)$$

The t-ratios are in parenthesis, which are significant at any level. The R-square and R- square adjusted are 0.7243 and 0.7031, respectively.

The Durbin-Watson ratio is 2.2269, so we do not reject null hypothesis, $\rho = 0$. Heteroskedasticity test shows the do-not-reject hypothesis of homoskedasticity.

The test for the functional forms in linear and in nonlinear by using option “recur and reset” in command diagnos shows that both of the above functional forms are acceptable

Fish inverse demand

Linear Form

$$p^2 = 4.1098 - 0.46046\, y^2$$
$$(11.124) \quad (-2.8355)$$

The t-ratios are in parenthesis, meaning they are significantly different from zero at any level. The R-square, and R- square adjusted are 0.3775 and 0.296, respectively. Other tests have the same procedure and results as the above; however, the test for autocorrelation, the Durbin-Watson, is equal to 1.244, which rejects the null hypothesis. Therefore, the command “auto” in Shazam is used to correct and give the results as above.

Cobb-Douglas Form

$$p^2 = 3.4615\, y^{-0.3284}$$
$$(28.420) \quad (-3.5903)$$

The t-ratios are in parenthesis, meaning they are significantly different from zero at any level. The R-square and R- square adjusted are 0.4841 and 0.4445, respectively.

The heteroskedasticity test shows the do-not-reject hypothesis of homoskedasticity. Durbin-Watson ratio is 1.3793, which rejects the null hypothesis, $\rho = 0$. Therefore, the command "auto" in Shazam is used to correct and give the results as above.

The test for the functional forms in linear and in nonlinear by using option "recur and reset" in command diagnos shows that both of the above functional forms are acceptable.

3.2.4 An Analysis in Two Inverse Demands

The signs of all coefficients of the two inverse demands are as expected in part 3.3.1. Their magnitudes are plausible by checking and interpreting their elasticities as follows:

Table 3.4 Demand Elasticities of Rice and Fish

	Rice	Fish
Elasticity at Mean (Linear Form)	-0.78386	-0.31965
Constant Elasticity (Cobb-Douglas Form)	-0.74947	-0.32837

All absolute values of elasticities in Table 3.4 are smaller than one, which means that rice and fish are inelastic, as almost all other agricultural goods. All elasticities (own-price elasticity) in the Table are negative and thus suitable with the law of demand for normal goods e.g., a 1-percent increase in rice price reduces 0.75% of the quantity of rice demanded. The difference in the elasticity magnitudes between the two functional forms for rice (-0.78386 and –0.74947) is negligible. Similarly, the difference for fish (-0.31965 and –0.32837) is negligible too. This implies that the specified functional form and estimation procedure are credible. However, the rice elasticity is three times as much as the fish elasticity in absolute value.

3.3 Fish Cost Functions

3.3.1 Data

Data are primary, collected from a face-to-face interview. The questionnaire includes 11 main questions (with 38 additional questions, see questionnaire in Appendix) relating to cost of culturing, yield of fish, and pesticide residue in water bodies. The respondent or his wife is the owner of the fishpond. The 16 locations for the interview are from regions of both rice production and fish culture. Eight samples of fish cost were included in the interview and 4 water samples were collected in each location. One water sample collected from a water body shared by two respondents with their adjacent fishponds is used for both interviewed samples from these two respondents. So total face-to-face interview samples are 128 and total water samples are 64. The fishpond area in each sample is at least 500 m^2, and the species of fish must be *cyprinus carp* or *oreochronus carp* or *osphromemus carp*, three prevalent species of fresh water fish in the Mekong Delta. Time point of the interview is in the third or fourth month of the crop. The yield of fish is predicted by the respondent.

One hundred thirty one samples were interviewed. After checking, two samples were ruled out because of excessively high cost and low yield (outlier). Data from the 129 interviewed samples are processed into table in Appendix A2. Data on pesticide residue are analyzed from 64 water samples. More than 30 types of pesticide are applied in rice production in the Mekong Delta and cost for analyzing pesticide residues in water sample is very high. Thus, it is reasonable to select a few widely-used types of pesticides to analyze the residues. Based on Vo Mai's empirical work (see Table 5.3), three widely-used types of pesticides, Methamidophos, Lindan and M.Parathion were selected for this research. Each water sample was analyzed to get the residues and the magnitudes of residue were summed up after transforming into a type according to scale: 20 μg pesticide of group II is equivalent to 1 μg pesticide of group I (Hoang, 2000) (ranking group is based on toxicity of the pesticide); Lindan and Methamidophos are group II and M.Parathion is group I. The pesticide residue magnitude, *s*, of each water sample is the sum of that of Lindan, Methamidophos and M.Parathion timed by 20. The range of pesticide residue in this collection is from 0.35 to 4.12 μg/ liter, this range is lower than that of the survey by the University of Cantho, from 0.9 to 5.2 μg/ liter (Le and Lam, 2000). This difference can be explained by the residue of each sample of this research including only three popular types of pesticide, but the residue of each sample from the survey of the University of Cantho including all types of pesticides. The residue is then converted into a water quality variable by defining (see Figure 2.1)

Water Quality, z = u – Pesticide Residue, s.

u is set as the upper bound of water quality. To avoid a negative magnitude of water quality variable, u must be greater than the maximum pesticide residue, which is 4.12 μg/ liter. Thus, u equaling 5 is reasonable. For example, the best water quality in the survey region is 4.65 (5 – 0.35) and the worst is 0.88 (5 – 4.12). So, the upper bound of the water quality variable z is 5 (the best quality without pesticide residue). The water quality measure is simply an index with u chosen to be 5 simply to get a scale that does not go negative. It has no meaning in anything but a scaler sense.

3.3.2 Functional Forms

Average fish cost is equal to the total cost divided by yield. It depends on many factors such as environmental conditions, government subsidy, and capacity of the owner, who also serves as manager and technician. Three key factors considered in the recent Mekong Delta situation are years of experience, education level of the owner, and pesticide residue in fishpond or in water source. The technique of raising fish is much more complex and advanced than that of raising chicken, pig, or planting rice, vegetable or fruit because raising fish is more risk, uncertainty and not easy to know the growth or diseases of fish or shrimp living in water bodies (Le and Lam, 2000). Therefore, the producer has a high level of education or many years of experience, the average cost is lower (Department of Aquaculture, University of Nong Lam, 1997). So the sign of this relationship is negative. If the residue is high in fishpond, in other words, if the water quality is low, then the average cost is high due to low yield. So the sign of relationship between average cost and water quality is negative. These relationships are embodied in the function,

Average fish cost = f(water quality, education level, years of experience).

The water quality variable is defined as above. Education level includes 1, 2, 3 and 4. Entering grade 1 to 5 (primary school) is 1, entering grade 6 to 9 is 2, entering grade 10 to 12 is 3, entering university is 4. Years of experience are 1, 2, 3, 4, … of year.

Functional form is specified as linear

$$c^2 = C^2 - \rho z - \gamma_1 e - \gamma_2 ye$$

where C^2 is a constant, *z* is water quality, *e* is education level, *ye* is years of experience and ρ, γ_1, γ_2 are parameters, and as nonlinear, assumes the Cobb-Douglas form,
$c^2 = C^2 z^{-\rho} e^{-\gamma_1} ye^{-\gamma_2}$.

3.3.3 Estimation

Data for average fish cost estimation is from Table A.2 of Appendix A2. Statistics for variables *z* and c^2 is in Table 3.5 as follows:

Table 3.5. Statistics for Variables *z* and c^2

Name	N	Mean	St. Dev	Variance	Minimum	Maximum
$c^2(z)$	129	2.4491	0.18732	0.03508	2.116	2.788
z	129	2.7800	0.96878	0.93853	0.880	4.650

Result of regression for the above linear form is
$c^2 = 3.0076 - 0.04382z - 0.11779e - 0.03316ye$
(75.231) (-3.784) (-7.1509) (-4.9943)

The t-ratios are in parenthesis, which are significant at any level. The R-square and R- square adjusted are 0.6350 and 0.6263, respectively.

The Durbin-Watson ratio is 2.037, so we do not reject the null hypothesis, $\rho = 0$. The heteroskedasticity test shows do- not- reject hypothesis of homoskedasticity in Arch Test, Harvey Test, and Glejser Test, but Koenker and BPG (White) Tests reject the null hypothesis. This case is multiplicative heteroskedasticity, which commonly takes the form
$\sigma_i^2 = \sigma^2 Z_i^\delta$.
If the parameter, δ, measures the strength of heteroskedasticity, when $\delta = 0$, then the model is homoskedasticity. Z_i is an independent variable relating to σ_i . To remedy multiplicative heteroskedasticity, firstly, commonly found in applied work, arises when $Z_I = X_i$, where X_i is an independent variable (*z, e* and *ye* of this model) and the value of δ is set equal to 2 (Kmenta, 1997, p. 283) i.e., when
$\sigma_i^2 = \sigma^2 X_i^2$, then the regression equation can be made homoskedastic by dividing both sides by X_i to give
$\frac{Y_i}{X_i} = \alpha\left(\frac{1}{X_i}\right) + \beta + \frac{\varepsilon_i}{X_i}$, where Y_i is a dependent variable.

Applying this to correct multiplicative heteroskedasticity by weighted OLS for every independent variable *z, e,* and *ey*, the results are the same as before i.e., Koenker and BPG (White) tests still reject the null hypothesis.

Another way to correct is to apply Harvey's (1976) model,
$\sigma_i^2 = \sigma^2 \exp\left(\delta' Z_i\right)$,
and by the full generalized least square (FGLS) (see Green, 1999, pp. 518-520). Results of this remedy are
$c^2 = 3.0246 - 0.05087z - 0.11575e - 0.03375ye$
(89.865) (-4.4573) (-7.4215) (-5.0593)

The t-ratios are in parenthesis, which are significant at any level. The R-square and R- square adjusted are 0.6849 and 0.6774, respectively.

The Durbin-Watson ratio is 2.0370, so we do not reject the null hypothesis, $\rho =$ 0.

This result is a little different from before, the parameters of education and the years of experience are a little higher, while that of water quality is a little lower. Estimation is a little better as indicated by the higher R-square and R- square adjusted, 0.6849> 0.635 and 0.6774> 0.6263, respectively.

Similarly, the Cobb-Douglas form is estimated and has the same problem and remedy as the linear form. Its results are

$$c^2 = 2.9683 z^{-0.04677} e^{-0.08676} ye^{-0.05413}$$

(73.929)(-3.9027) (-6.8993) (-4.5247)

The t-ratios are in parenthesis, which are significant at any level. The R-square and R-square adjusted are 0.6371 and 0.6283, respectively. The Durbin-Watson ratio is 1.99, so do not reject null hypothesis, $\rho = 0$. The test for linear vs. nonlinear shows both functional forms are acceptable.

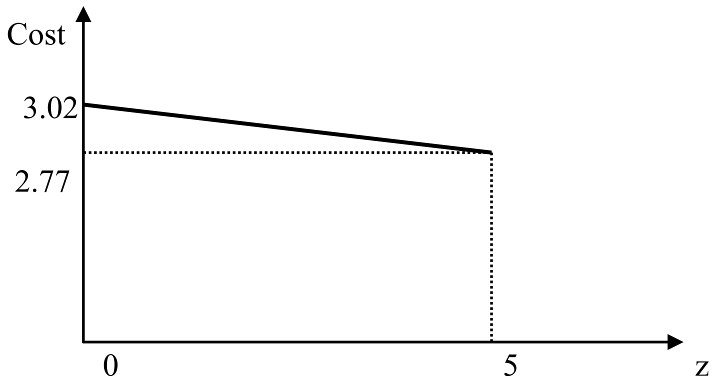


Figure 3.2 Linear Fish Cost Function with Water Quality Variable

If the cost function is associated with pollutant stock variable, s, then we have $c^2(s) = 3.0246 - 0.05087(5 - s) = 2.77 + 0.05087s$ and its graphic is as Figure 3.3

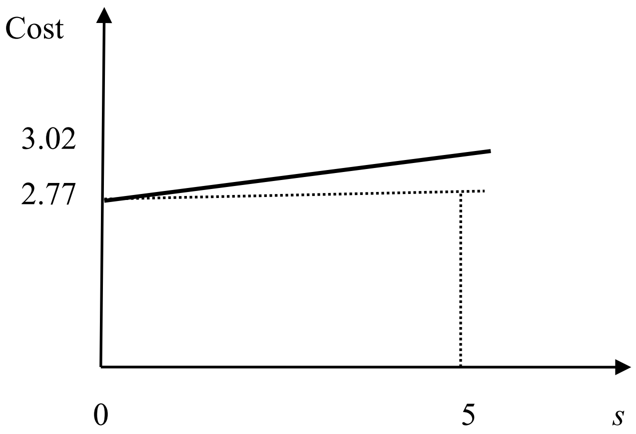


Figure 3.3 Linear Fish Cost Function with Pollutant Stock Variable

Different point between Figure 3.2 and Figure 3.3 is the opposite signs of the slopes, although they have the same absolute value, |0.05087|. This different point makes the shadow price, λ, positive in the Hamiltonian problem if water quality variable, z, is used.

In the nonlinear case, the graphics are similar to linear ones.

3.4 Assimilative Capacity Function

3.4.1 Data

Data for the estimation was obtained from analyzing 64 water samples collected from 16 locations in four different points of time (different from 64 water samples associated with the face-to-face interview). There are two rice crops per year. This collection was done during one crop.

After starting the rice crop, rice farmers spray pesticide 2 to 4 times for 40 days to protect against insect attacks. So, a lot of pesticide discharges into the water bodies. The residue in samples collected at the end of this time is labeled time 1 (see Table 3.5). After 40 days of starting the rice crop, most rice farmers don't spray the pesticide any more, if there are no signs of insect attack, therefore, since the 40th day of the crop, the residue has decreased (water quality has increased) due to assimilative capacity of the water environment as well as run-off. To determine the decrease in the residue, water samples were collected before starting crop, labeled time 0; by the 40th day, labeled time 1; by the 80th day, labeled time 2; and by the 120th day, labeled time 3 (see Figure 3.4).

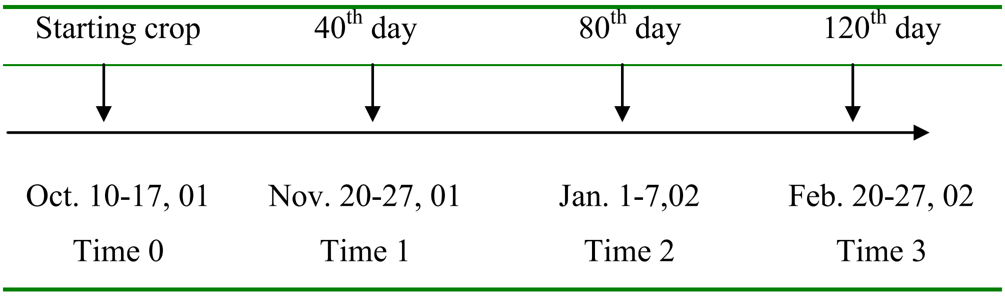


Figure 3.4. Timing for Water Sample Collection

Residues from 16 locations and 4 points of time, a total of 64 samples (different from the 64 samples in the above fish cost estimation), are shown in Table 3.6. The rice area in the collecting location, which is the source of pesticide pollution, is in the last column. It is used to estimate parameter of pesticide discharge, β, later.

The residue in the previous time (from time 1) is always higher than in the succeeding time in Table 3.6. This confirms the assimilative capacity of water environment.

Table 3.6. Pesticide Residue in 64 Samples for Water Quality Estimation (μg/l)

Location	Time 0	Time 1	Time 2	Time 3	Rice Area ($1000m^2$)
1	0.15	2.32	1.67	0.98	12.62
2	0.82	3.24	2.82	2.14	34.62
3	1.03	4.26	3.31	2.21	47.22
4	0.52	3.81	2.86	1.73	27.30
5	0.51	3.45	2.55	1.55	28.57
6	1.14	4.37	3.36	2.26	49.86
7	0.87	4.86	3.46	2.31	46.93
8	0.67	3.64	2.75	1.71	27.24
9	0.85	4.13	3.11	2.04	52.31
10	0.62	3.18	2.39	1.34	30.24
11	0.86	4.59	3.57	2.23	47.38
12	0.38	2.61	1.72	0.87	24.13
13	0.44	3.14	2.45	1.38	34.31
14	0.21	2.49	1.77	1.02	19.37
15	0.85	4.68	3.62	2.49	40.15
16	0.37	2.88	2.05	1.21	21.23
Total	10.29	57.65	43.46	27.47	543.48

Pesticide residue stock variable, *s*, in Table 3.6 is converted into water quality variable, *z,* in Table 3.7 as follows:
Z1 = 5 – Time 1; Z2 = 5 – Time 2; Z3 = 5 - Time 3. Assimilative capacity is computed by the difference in water quality between two consecutive times, i.e., A1 = Z2 - Z1; A2 = Z3 – Z2.

Table 3.7 Water Quality and Assimilative Capacity

Location	Z1	Z2	Z3	A1	A2
1	2.68	3.33	4.02	0.65	0.69
2	1.76	2.18	2.86	0.42	0.68
3	0.74	1.69	2.79	0.95	1.10
4	1.19	2.14	3.27	0.95	1.13
5	1.55	2.45	3.45	0.90	1.00
6	0.63	1.64	2.74	1.01	1.10
7	0.14	1.54	2.69	1.40	1.15
8	1.36	2.25	3.29	0.89	1.04
9	0.87	1.89	2.96	1.02	1.07
10	1.82	2.61	3.66	0.79	1.05
11	0.41	1.43	2.77	1.02	1.34
12	2.39	3.28	4.13	0.89	0.85
13	1.86	2.55	3.62	0.69	1.07
14	2.51	3.23	3.98	0.72	0.75
15	0.32	1.38	2.51	1.06	1.13
16	2.12	2.95	3.79	0.83	0.84
Total	22.35	36.54	52.53		

3.4.2 Functional Form

The assimilative capacity function for water quality is also specified in linear $a(z) = \phi z$, and nonlinear
$a(z) = z^{\phi}$.

Constants are suppressed. If the water quality is high, then the assimilative capacity is high, which means that ϕ is positive.

3.4.3 Estimation for Assimilative Capacity Function

Estimation of the assimilative capacity function is based on the data in Table 3.7. The assimilative capacity is the function of the water quality variable, *z*. This means that A1 regresses on Z1, and A2 does regress on Z2. Thus, this is pooling regression with 64 samples, 16 cross-sections, and 2 time- periods. *The cross- sectionally heteroskedastic and timewise autoregressive model*, which removes heteroskedasticity and autocorrelation (Kmenta, 1997, pp. 616-620), is applied in this case. Using the "pool" command with additional option "noconstant" for linear form and "same" to the same ρ for each cross-sectional element (see Shazam, 1997, pp. 270, 273). Results run by Shazam software for linear form are

$a(z) = 0.78156\, z$

(24.967)

The t-ratio is in parenthesis, which is significant at any level. The Buse raw-moment R-square (meaningful in pooling regression, see Shazam, 1997, pp.214, 271) is 0.9526.

The procedure of regression for the nonlinear form is the same as for the linear form, but results are not satisfied as follows:

$a(z) = z^{0.4021}$

(5.2159)

The t-ratio shows significance at any confidence level, however, Buse raw-moment R-square is low, 0.42318, and the Buse R-square is -2.6105. According to Shazam Manual (p. 214, 1997), if Buse R-square is negative, user must reconsider the functional form. Therefore, the nonlinear form for assimilative capacity function is ruled out.

3.4.4 Estimation for β

According to the model, discharge that pollutes water bodies by applying pesticide for rice production is βy^1. This discharge, *d,* must be equal to residue "time 1" in Table 3.6 less the residue "time 0" available before the crop. The functional form is specified
d (= time 1 – time 0) = βy^1 in linear, and
$d = (y^1)^{\beta}$ in nonlinear.

Constant is suppressed. y^1 in this case is rice output in water sample collecting region, i.e., rice area (1000m^2) in the last column of Table 3.6 times yield per hectare (4.2 tons/ ha).

The results of regression after correcting for heteroskedasticity by command "het" are

$d = 0.11137\, y^1$

(46.887)

The t-ratio is in parenthesis, significant at any confidence level. The R-square and R- square adjusted are 0.7608 and 0.7608, respectively. The Durbin-Watson ratio is 2.0492, so do not reject the null hypothesis, $\rho = 0$, and in nonlinear form

$d = (y^1)^{0.32456}$

(32.676)

The t-ratio is in parenthesis, significant at any confidence level. The R-square and R- square adjusted are 0.5462 and 0.5462, respectively. The Durbin-Watson ratio is 1.9820, so do not reject the null hypothesis. The elasticity at mean is 1.0089, which is elastic. So, an increase (decrease) in the percentage of rice production affects a bigger decrease (increase) in that of water quality.

In general, the data from secondary as well as primary sources give the relatively good regression results. Problems in heteroskedasticiy, autocorrelation, multicollinearity, and outlier are corrected. The test for linear vs. nonlinear shows both functional forms acceptable. These results in this section are important sources for the model simulation in the next parts.

4.0 SIMULATION OF THE MODEL

4.1 Values of Model Parameters and Shadow Price

4.1.1 Values of Model Parameters

The simulation is for two cases: 1) all functions are linear, 2) two demand functions are nonlinear and the others are linear. The values of parameters to simulate the model are adapted from Section 3 into Table 4.1.

Table 4.1. Values of the Model Parameters

Parameter	Linear	Nonlinear
m_1	0.01963	0.753
m_2	0.65944	0.372
k_1	0.71424	1.1407
k_2	4.1098	1.2420
r	0.1000	0.1000
β	0.11137	0.11137
ϕ	0.78156	0.78156
A	3.0014	3.0014
C^2	3.0246	3.0246
ρ	0.05087	0.05087
z_0	2.7800	2.7800
c^1_0	0.25847	0.25847
c^2_0	2.4491	2.4491
p^1_0	0.2696	0.2696
p^2_0	2.8600	2.8600

Note: The nonlinear column is only for the two demand functions. Parameters of the other functions are linear, so they are the same in both columns.

The discount rate, r, is 10%. Initial value of the water quality variable, z_0, is the average of 64 samples in the fish cost collection (see Table 3.5). c^1_0 is the real average rice cost of the crop year 2001-02, from the survey of the Governmental Pricing Committee, Representative Office in Ho Chi Minh City. c^2_0 (initial value) is the real

average fish cost in the 129 collected samples (see Table 3.5). p^1_0 and p^2_0 are the real price of rice and fish, respectively in the year 2001 adjusted external cost given below. The value of A is computed as
$A = (p_0^2 + \rho z_0)$ = (2.86 +0.05087*2.78) = 3.001419. The remaining parameters are from the econometric results in Chapter 3.

4.1.2 Shadow Price

The average fish cost depends on water quality as well as two other factors as in Equation,
$c^2 = 3.0246 - 0.05087z - 0.11575e - 0.03375ye.$

The term -0.05087z is used for identifying the shadow price, λ_0. If there was no discharging of pesticide into the water bodies, then $z = 5$, which implies no external cost to fish culture. In the year 2001, the base year for the simulation, $z_0 = 2.78$ (see Table 3.5), so external cost per kg of fish is identified as
$(5 - z_0)* \rho = (5 - 2.78)* 0.05087 = 0.11293$ (e.g., 112.93 \$VN per kg).
So, the total external cost for the total fish output, y^2_0 = 195,410 tons in 2001, is
0.11293*195410 = 22,067.65 thousand $VN
(e.g., 22.068 billion $VN in 1989 or 135.05 billion $VN in 2001, or 9.003 million $US in 2001, with exchange rate at 15100 $VN = 1 $US in 2001).

This amount of the external cost is resulted from rice production with output y^1_0 = 1.64 million tons. So each kg of rice causing an external cost is
22,067.65/ 1,642,000 = 0.01344 (e.g., 13.44 $VN per kg).

This amount is $\beta\lambda_0$ in the model. Therefore,

(4.1) $\lambda_0 = 0.01344/ 0.11137$
$= 0.120679.$

Initial price applied for the model simulation must internalize the external cost, $\beta\lambda_0$ (which is often called the social cost),
Price = Private Cost + Social Cost

Thus, the initial price of rice, $p^1_{0,}$ must be
$p^1_0 = 0.25616 + 0.1344$
$= 0.2696.$

Similarly,
Average Cost = Private Average Cost + Social Average Cost
$c^1_0 = 0.24503 + 0.01344 = 2.5847.$

These numbers are given in Table 4.1 above.

4.2 Simulation for the Linear Case

4.2.1 Time Paths

Solving for eigenvalues in (2.34) and (2.35)

$$B = \sqrt{(r-2\phi)^2 - 4\rho^2\beta^2 / m_1 m_2}$$
$$= \sqrt{(0.1-2*0.78156)^2 - 4*(0.05087)^2(0.11137)^2 / 0.01963*0.6594}$$
$$= 0.6742448, \text{ and}$$

(4.1) $b_2 = -0.6798633$
$b_1 = 0.7798633.$

b_1 being positive is ignored by ruling out divergent path. Setting Equation (2.25) equal to zero and substituting the values of parameters to get the values of steady-state prices,

$$\begin{bmatrix} -0.68156 & 0.085912 \\ -0.28861 & 0.78156 \end{bmatrix} \begin{bmatrix} p^{1*} \\ p^{2*} \end{bmatrix} + \begin{bmatrix} -0.14085 \\ -2.139653 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

(4.2) $$\begin{bmatrix} p^{1*} \\ p^{2*} \end{bmatrix} = \begin{bmatrix} 0.2423 \\ 2.8271 \end{bmatrix}.$$

Similarly, optimal value of water quality, z^*, is computed as

$$z^* = (\beta / \phi)\left[k_1 / m_1 - p^{1*} / m_1\right]$$
$$= 3.425868.$$

Thus, we have all the initial and steady-state values, then have time paths of prices and water quality in Equation (2.36) and shadow price,

(4.3)
$$p_t^1 = 0.0273e^{-0.67986t} + 0.2423$$
$$p_t^2 = 0.03285e^{-0.67986t} + 2.8272$$
$$z_t = -0.64587e^{-0.67986t} + 3.4259$$

The steady-state prices of rice and fish are less than their initial values and, therefore, the time paths go down over time and approach optimal values asymptotically (see Figures 4.1 and 4.2). On the other hand, the time path of water quality goes up over time (see Figure 4.3.).

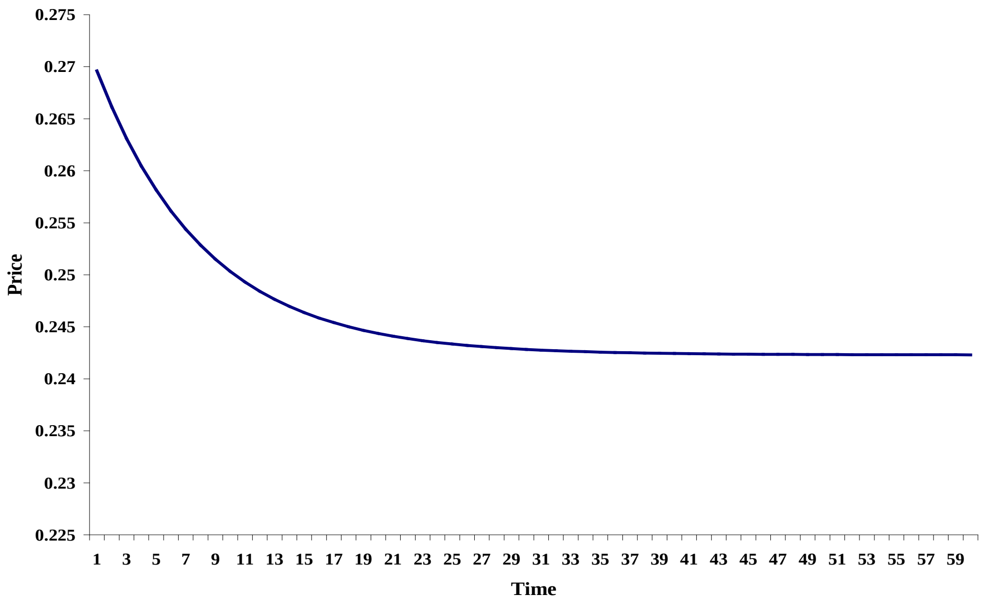


Figure 4.1 Time Path of Rice Price in Linear Case

The price path of rice falls over time in the socially optimal framework. This is because the technology progress is applied and there is no land constraint. The assumption of no land constraint is a reasonable given the real circumstances along the Mekong as shown in Table 3.2, fish and rice outputs increasing over time by expanding areas from new lands and shifting from other crops. However, the rate of decrease in rice price is smaller than before due to external cost. Note that if land was constrained it would expect the price path of rice to rise over time as output would be falling.

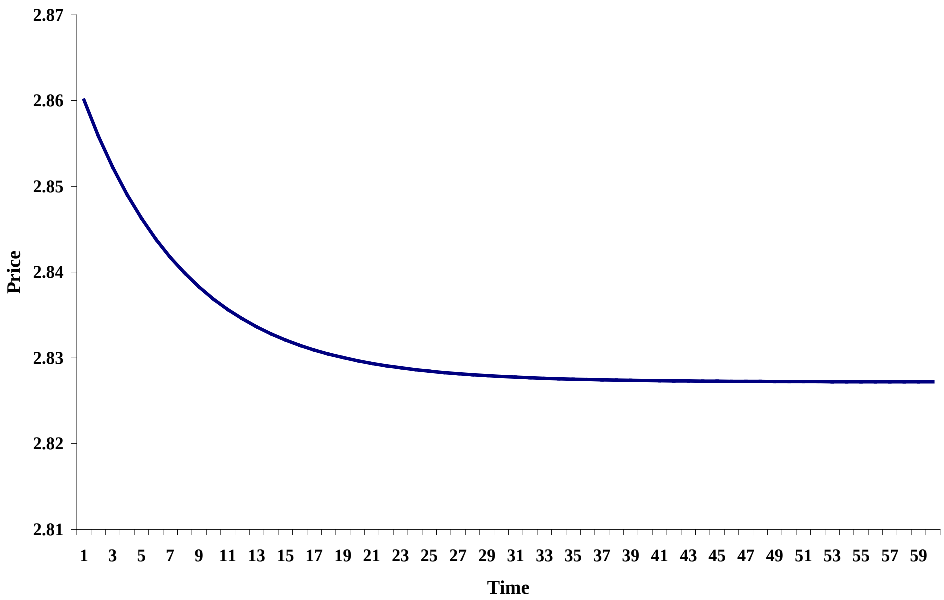


Figure 4.2 Time Path of Fish Price in Linear Case

The price path of fish falls over time in the socially optimal framework. This is because the technology progress is applied, its areas are expanded as well as better water quality due to external cost to rice production.

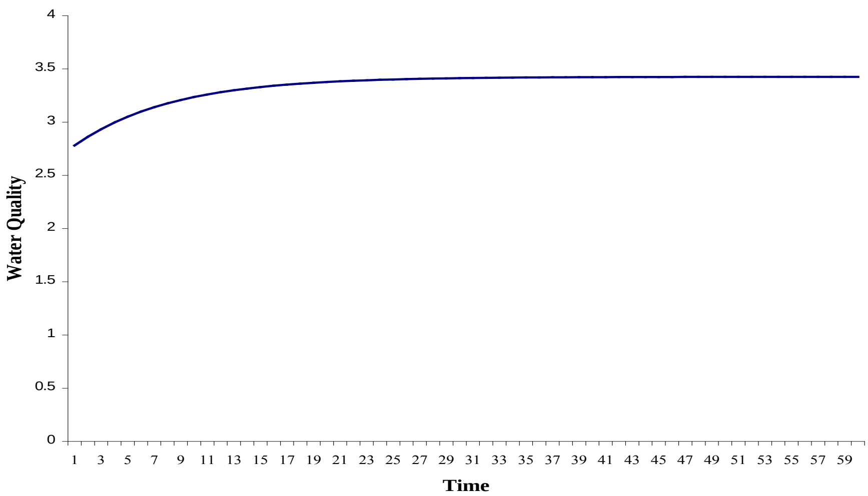


Figure 4.3 Time Path of Water Quality in Linear Case

Table 4.2 Variable Values in Scenario of Linear Case

	p^1	p^2	y^1	y^2	z
t = 0 (2001)	0.2696	2.860	22.651	2.7141	2.780
t = 5 (2006)	0.2582	2.846	23.235	2.7441	3.051
t = 10 (2011)	0.2503	2.837	23.633	2.7645	3.236
t = 15 (2016)	0.2464	2.832	23.835	2.7748	3.330
t = ∞ (Steady state)	0.2423	2.827	24.041	2.7855	3.426

Values of p^1, p^2 and z in Table 4.2 are from their time paths. Values of outputs, y^1 and y^2, are derived from the inverse demands by plugging values of p^1 and p^2, respectively. Both of prices decline over time leading to higher consumers' surplus. Both outputs go up over time leading to benefits for producers, at the same time, water quality is improved considerably due to rice production internalyzing the external cost.

The speeds of convergence of the prices and water quality are very fast as shown in Table 4.2. In the 5th year, the rice price declines from 0.2696 to 0.2582 and the 15th year to 0.2464, this almost reaches steady state price, 0.2423. The fish price and water quality are similar to. After about six years (t= 7) the prices as well as water quality almost reach a half of path to steady state values. Thus, the social planner is not much concerned about raising the speed of convergence to get higher social welfare.

4.2.2 Phase Diagrams

Plugging in the values of the parameters in Table 4.1 into Equation (2.9'), (2.10') and (2.11) yields the differential equation system of motion for the case of the Mekong Delta,

(4.4) $$\dot{z} = 0.78156z + 5.6735p^1 - 4.0522$$

(4.5) $$\dot{p}^1 = -0.68156p^1 + 0.00859p^2 + 0.14085$$

(4.6) $$\dot{p}^2 = -0.039758z - 0.28861p^1 + 0.20614\,.$$

(4.7) $$\dot{\lambda} = -0.68156\lambda + 0.07714p^2 - 0.31705$$

Loci of $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$ and $\dot{z}_t = 0$ is determined as follows:

As $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$, $\dot{z}_t = 0$ and from (4.4), (4.5) and (4.6), we have

(4.8) $z_t = -7.2592p_t^1 + 5.1846$

(4.9) $p_t^1 = 0.0126p_t^2 + 0.20666$

(4.10) $p_t^2 = 0.3693p_t^1 + 2.7376\,.$

Substituting $p^2 = A - \rho z$ into (4.9) gives

(4.11) $p_t^1 = -0.000641z + 0.24447\,.$

Equations (4.8) and (4.11) are loci of $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$ and $\dot{z}_t = 0$ in the space ($p^1{}_t$, z_t).

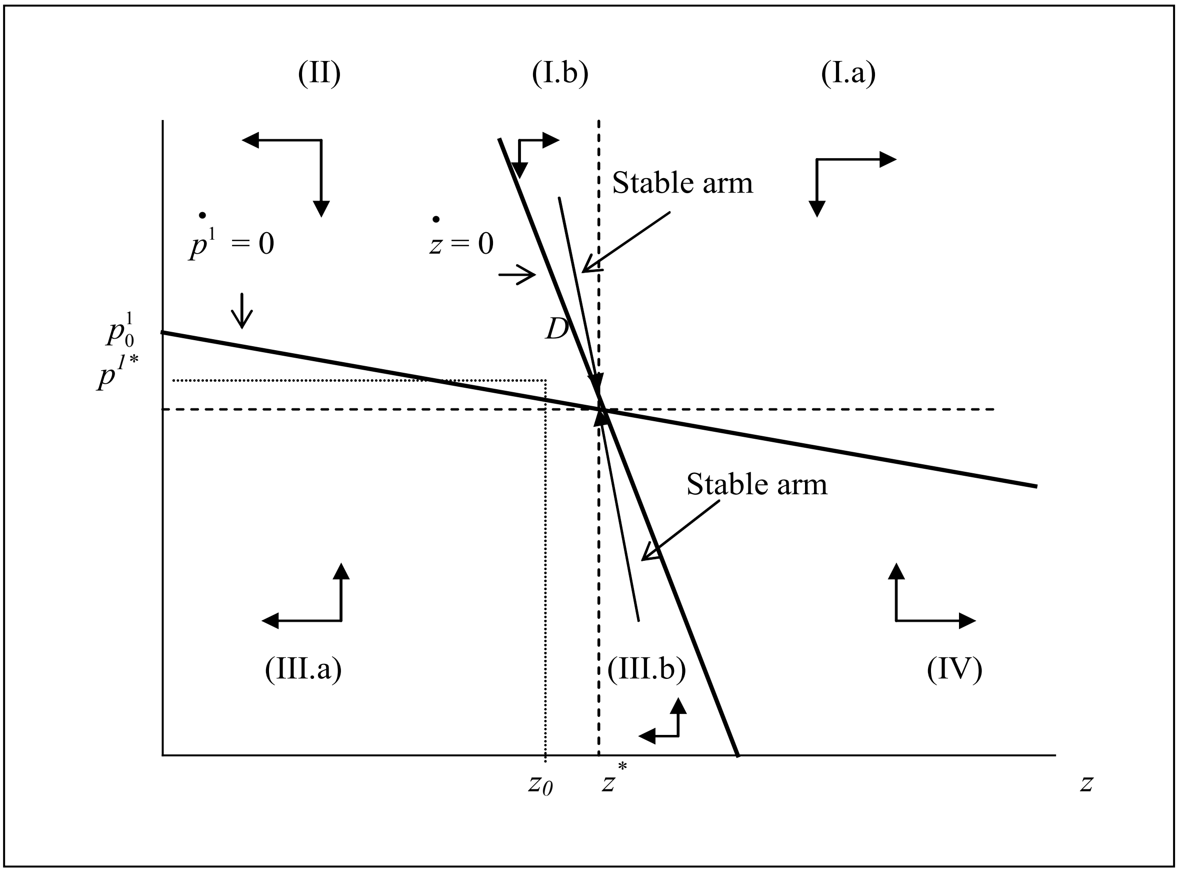


Figure 4.4 Phase Diagram for the Linear Case

In Figure 4.4, two loci divide the space into 4 regions labeled (I), (II), (III) and (IV). Arrows in each region show the direction of the motion of time paths. Directions of arrow are determined by taking the derivative Equation (4.5) with respect to p^1 (see Chiang, 1987, pp. 629-633),

$$\frac{\partial \dot{p}^1}{\partial p^1} = r - \phi = -0.68156 < 0 \ ,$$

which implies that, as we move continually from south to north (as p^1 increases), $\dot{p}^1$ steadily decreases, so that the sign of $\dot{p}^1$ must pass through three stages, in the order +, 0, -. Thus, the sign of $\dot{p}^1$ in region (III) and (IV) is positive, and in region (I) and (II) is negative.

Similarly, the sign of $\dot{z}^1$ in Equation (4.4) is

$$\frac{\partial \dot{z}}{\partial z} = \phi = 0.78156 > 0,$$

which implies that, as we move continually from west to east (as z increases), $\dot{z}$ steadily increases, so that the sign of $\dot{z}$ must pass through three stages, in the order -, 0, +. Thus, the sign of $\dot{z}$ in region (I) and (IV) is positive, and in region (II) and (III) is negative. Regions (I) and (III) are divided into subregions (I.a), (I.b), and (III.a), (III.b), respectively, by the vertical dashed-line crossing the steady state point. Arrows in subregions (I.a) and (I.b) have the same direction, but any initial value (p_0^1, z_0) lying in (I.b) leads to convergence and lying in (I.a) leads to divergence. Similarly, any initial value (p_0^1, z_0) lying in (III.b) leads to convergence and lying in (III.a) leads to divergence. (p_0^1, z_0) lying in the remaining regions leads to divergence.

The initial value (p_0^1, z_0) lying on (I.b) and (III.b) is determined by Equations (4.7) and (4.10) and $(p_0^1, z_0) = (0.2669, 2.78)$ as follows:
Rewriting the inverse equation of (4.8),
$p^1(z) = -0.13776\, z + 0.71421,$
If $z_0 \in (0, z^*)$ and $p^1(z_0) < p^1{}_0$, then these values (p_0^1, z_0) lie in subregion (I.b).
If $z_0 > z^*$ and $p^1(z_0) > p^1{}_0$, then these values (p_0^1, z_0) lie in subregion (III.b).
Otherwise, they lie in divergent regions.

Thus, the initial value in the case of Mekong Delta, point $D(p_0^1, z_0) = (0.2669, 2.78)$, *does not* lie in the subregions (I.b) and (III.b). It lies in region (II), which is divergent (see Figure 4.4). The rice price goes down over time and water quality does, too. Thus, we *do not* have an optimal solution, even though the environmental cost is internalized. In order $D(p_0^1, z_0)$ lie in subregion (I.b), z_0 should not be less than 3.05378. How to raise z_0 to get optimal solution will be discussed in next section.

4.3 Simulation for the Nonlinear Case

4.3.1 Time Paths

The functional form of the assimilative capacity of water environment is only linear as shown by the econometric work as in Section 3. Therefore, we simulate the model with functional forms of two *nonlinear* demands, a *linear* assimilative capacity and a *linear* fish cost.

Plugging the parameter value in Table 4.1 into Equations (2.18), (2.19) and (2.20) gives us the system of the differential equation,

$$(4.12) \qquad \dot{z} = 0.78156z - 0.5039\left(p^1\right)^{\frac{-1}{0.7495}}$$

$$(4.13) \qquad \dot{p}^1 = -0.68156p^1 - 0.43627\left(p^2\right)^{-\frac{1}{0.32537}} + 0.17616$$

$$(4.14) \qquad \dot{p}^2 = -0.039758z + 0.02563\left(p^1\right)^{\frac{-1}{0.7495}}$$

In steady state, $\dot{z} = \dot{p}^1 = \dot{p}^2 = 0$, so set Equations (4.12), (4.13) and (4.14) equal to zero and then solve this system for steady-state values. Using command NL (nonlinear) in Shazam to solve Equation (2.22), we have
$p^{2*} = 2.783937$
$p^{1*} = 0.242267$
$z^* = 4.274452.$

Plugging these above values into Equation (2.25) linearized gives us

$$(4.15)\quad \begin{bmatrix} \dot{p}^1 \\ \dot{p}^2 \end{bmatrix} = \begin{bmatrix} -0.68156 & 0.04229 \\ -2.9007 & 0.78156 \end{bmatrix} \begin{bmatrix} p^1 \\ p^2 \end{bmatrix} + \begin{bmatrix} 0.04737 \\ -1.473 \end{bmatrix}.$$

Solving the parameter matrix of Equation (4.15) to get eigenvalues, b_1, b_2 for setting up time paths, we have

$b_1 = 0.6925118$

$b_2 = -0.5925118$.

b_1 being positive is not used by ruling out divergent path. Eigenvectors of negative eigenvalue are $v_1 = 1$ and $v_2 = 0.4749$.

By similar procedure in the linear part, the time paths are determined as

$$(4.16)\quad p_t^1 = 0.0273e^{-0.59251t} + 0.2423$$

$$(4.17)\quad p_t^2 = 0.07606e^{-0.59251t} + 2.78394$$

$$(4.18)\quad z_t = 4.27445 - 1.49445e^{-0.59251t}.$$

These equations are drawn as Figures 4.5, 4.6, and 4.7.

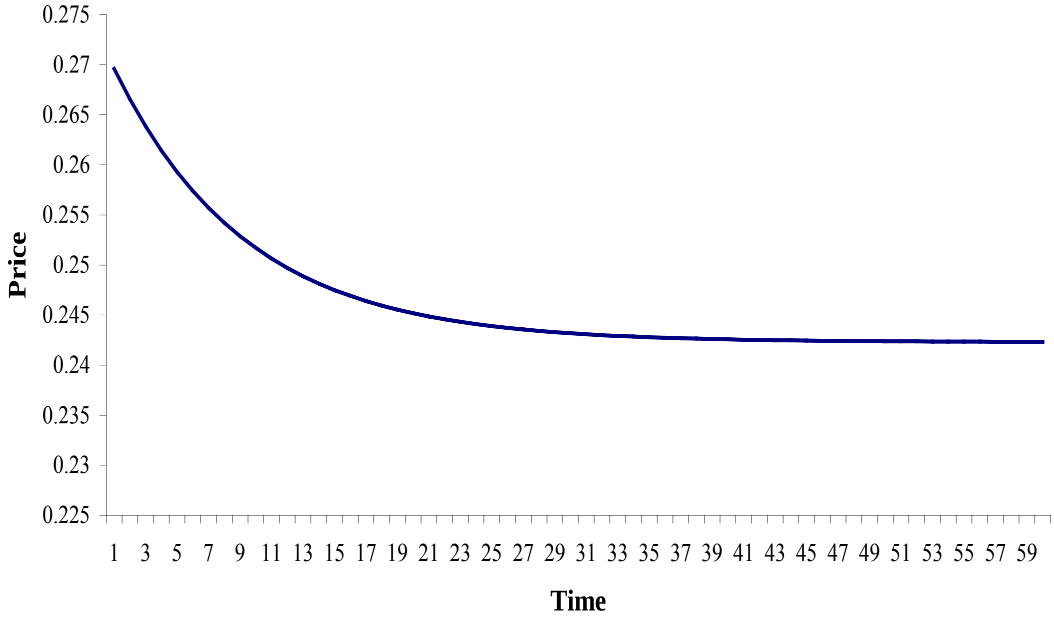


Figure 4.5 Time Path for Rice Price in Nonlinear Case

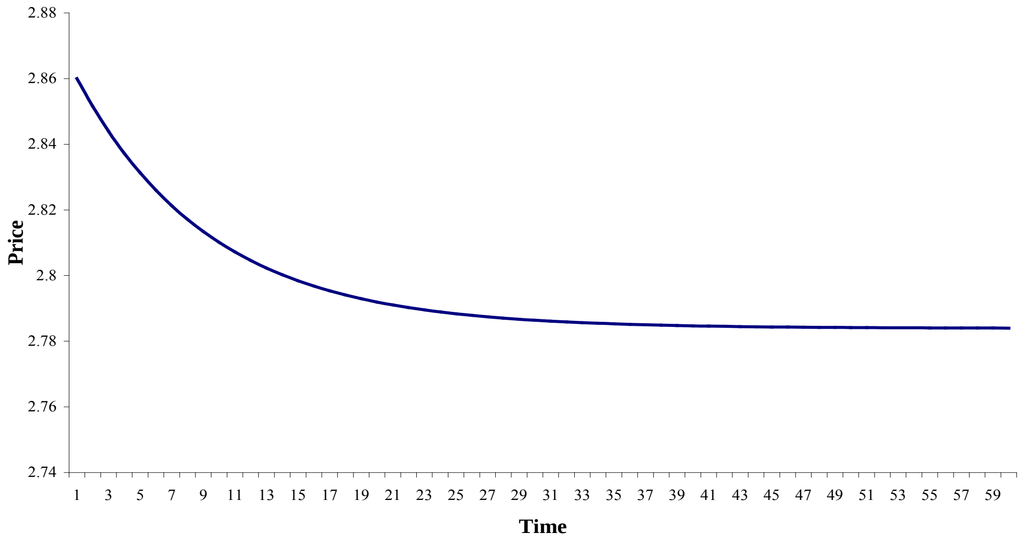


Figure 4.6 Time Path of Fish Price in Nonlinear Case

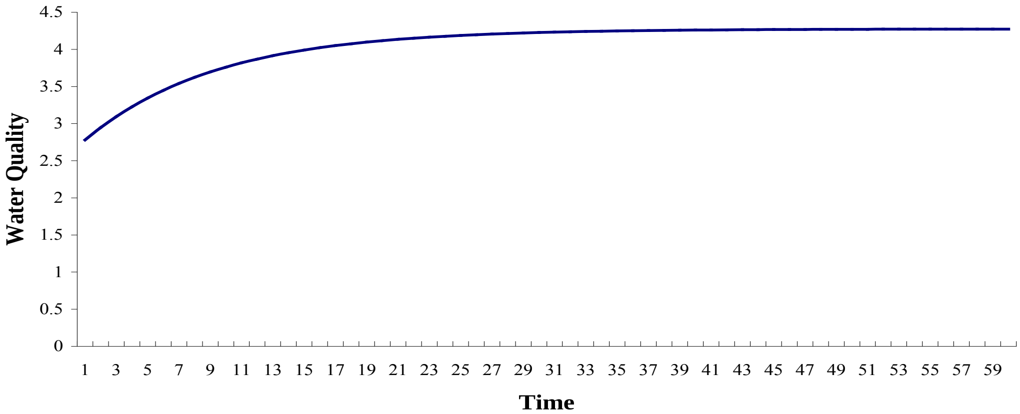


Figure 4.7 Time Path of Water Quality in Nonlinear Case

4.3.2 Phase Diagrams for the Nonlinear Case

Loci of $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$ and $\dot{z}_t = 0$ is determined as follows:

As $\dot{p}_t^1 = 0, \dot{p}_t^2 = 0$, $\dot{z}_t = 0$ and from (4.12), (4.13) and (4.14), we have

(4.20) $z = 0.64473\left(p^1\right)^{-1.3342}$

$p^1 = -0.6401\left(p^2\right)^{-3.0734} + 0.25847$.

Substituting $A- \rho z$ for p^2, then

(4.21) $p^1 = 0.6401\left(3.001419 - 0.05087z\right)^{-3.0734} + 0.25847$.

Equations (4.20) and (4.21) give two loci of $\dot{p}^1_t = 0$ and $\dot{z}_t = 0$ in space (p^1, z). Signs as well as directions of the motion are determined by taking the derivative of (4.12) and (4.13) with respect to z and p^1, respectively,

$$\frac{\partial \dot{p}^1}{\partial p^1} = r - \phi = -0.68156 < 0,$$

thus, the sign of $\dot{p}^1$ in region (III) and (IV) is positive, in regions (I) and (II) is negative.

Similarly, the sign of $\dot{z}^1$ in Equation (4.13) is

$$\frac{\partial \dot{z}}{\partial z} = \phi = 0.78156 > 0,$$

thus, the sign of $\dot{z}$ in regions (I) and (IV) is positive, in region (II) and (III) is negative. Regions (I) and (III) are divided into subregions (I.a), (I.b) and (III.a), (III.b), respectively, by the vertical dashed-line crossing steady state point. The arrows in subregions (I.a) and (I.b) have the same direction, but any initial value (p_0^1, z_0) lying in (I.b) leads to convergence and lying in (I.a) leads to divergence. Similarly, any initial value (p_0^1, z_0) lying in (III.b) leads to convergence and lying in (III.a) leads to divergence. (p_0^1, z_0) lying in the remaining regions leads to divergence.

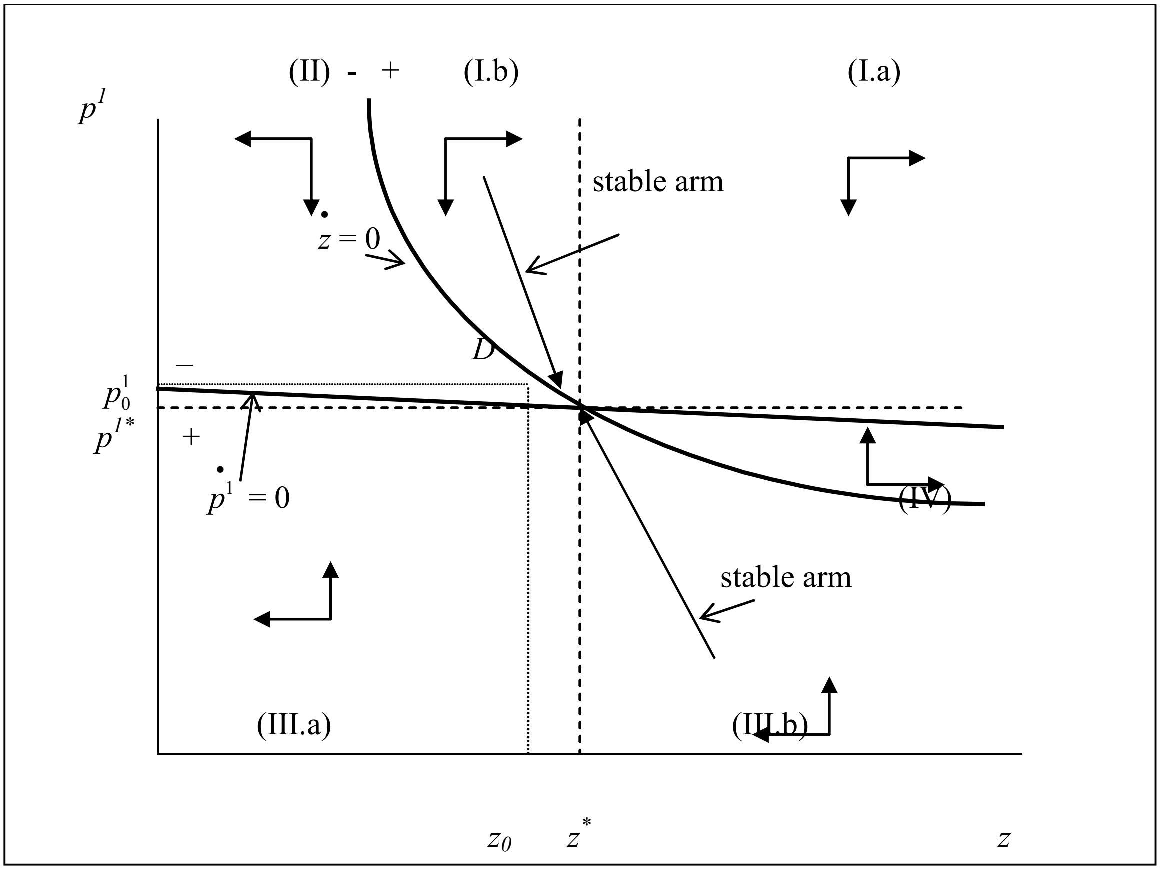


Figure 4.8. Phase Diagram for the Nonlinear Case

As a result, the initial value in the case of the Mekong Delta, point D, (p_0^1, z_0) = (0.2669, 2.78) *does not* lie in the subregions (I.b) and (III.b). It lies in region (II), which is divergent (see Figure 4.8). In this case, the rice price goes down over time and so does the water quality. Thus, we *do not* have an optimal solution for the scenario, even though the environmental cost is internalized. How to solve this problem will be discussed in Section 5.

4.4 Comparison between the Two Cases: Linear and Nonlinear

Results of two cases are summarized in Table 4.3

Table 4.3. Comparison between the Two Cases: Linear and Nonlinear

Result	Linear	Nonlinear
p^{1*}	0.24230	0.24227
p^{2*}	2.82715	2.78394
z^{*}	3.42587	4.27445

p^{1*} in both cases is almost the same. p^{2*} is a little different (2.82715- 2.78394 = 0.04321). This difference leads to the value of z^* in nonlinear to be higher than that in the linear due to the lower fish price. This difference may result from the autocorrelation problem in the fish demand function, although it is corrected. In general, the difference does not affect the time paths' direction and the qualitative result of the phase diagram.

4.5 Tests for the Second Order Condition

According to Mangasarian Theorem for the optimal control problem (see Chiang, 1992, pp. 214-217), the necessary conditions of the maximum principle are also sufficient for the global maximization of *W* (social surplus), if (1) both the objective, *F*, and the state, *f*, functions are differentiable and concave in the variables (p^1, p^2, z) jointly, and (2) in the optimal solution it is true that $\lambda(t) \geq 0$ (if *f* is linear in these variables, then $\lambda(t)$ needs no sign restriction).

Let the Hamiltonian problem

$H = F(y^1, y^2, z) + \lambda f(y^1, z)$.

Testing Concavity of F

$$\frac{dF}{dy^1} = F_{y^1} = p^1 - c_1 = 3.1(y^1)^{-0.75}, \quad \frac{d^2F}{d(y^1)^2} = F_{y^1y^1} = -2.225(y^1)^{-1.75} < 0$$

$$\frac{d^2F}{dy^1dy^2} = 0, \quad \frac{d^2F}{dy^1dz} = 0.$$

$$\frac{dF}{dy^2} = F_{y^2} = p^2 - c_2 = 3.46(y^2)^{-0.75}, \quad \frac{d^2F}{d(y^2)^2} = F_{y^2y^2} = -1.135(y^2)^{-1.328} < 0,$$

$$\frac{d^2F}{dy^2dz} = 0.04328z^{-1.047} > 0.$$

The Hessian matrix is

$$|F_1| = \left|F_{y^1y^1}\right| = \left|(-0.75)(3.1)(y^1)^{-1.75}\right| < 0$$

$$|F_2| = \begin{vmatrix} (-0.75)(3.1)(y^1)^{-1.75} & 0 \\ 0 & (-0.33)(3.46)(y^2)^{-1.33} \end{vmatrix} > 0$$

$$\left|F_3\right| = (-0.75)(3.1)(y^1)^{-1.75}\begin{vmatrix}(-0.33)(3.46)(y^2)^{-1.33} & -0.04z^{-1.047} \\ -0.04z^{-1.047} & (-1.04)(0.04)z^{-2.04}\end{vmatrix} < 0$$

Thus the Objective Function is concave.

Testing concavity of the State Equation for nonlinear case (linear itself is concave):

$$f(y^1, z) = \dot{z} = a(z) - \beta y^1 = z^{0.4} - 0.11y^1$$

$$\left|f\right| = \begin{vmatrix}0 & 0.4z^{-0.6} \\ 0.4z^{-0.6} & -0.24z^{-1.6}\end{vmatrix} < 0.$$

Thus *f* is concave.

Testing for nonnegative shadow price, λ:

From Equation (2.5), $p_t^1 - c^1 = \beta\lambda_t$, p^1 should be greater or equal to c^1. The parameter of pollutant discharge, *β*, should be nonnegative. This implies that the shadow price, *λ*, should be nonnegative.

Thus, the second-order condition of the Hamiltonian problem, *H*, is satisfied i.e., *H* is maximized.

4.6 Discussion

In general, the dynamic model simulation for the case of water resource in the Mekong Delta shows some important points for managing its resources better as well as for increasing in its social welfare. The time paths show future prices and water quality under initial (the year 2001) conditions. Both prices will go down and approach the steady state asymptotically. A decrease in prices benefits the consumer, especially, the poor in Vietnam, a developing country, where the poor making up a big proportion of society, spend about 50% of their income on rice and fish consumption. Moreover, producer's surplus also goes up due to an increase in outputs. The time paths benefit the social or production managers in their decision-making or policy formulation. The time path of water quality points to an increase in the quality in the future. This increase benefits not only the fish consumer due to a decrease in the fish price but also society due to improvements in biodiversity, drinking water and water-based recreational activity. These benefits will be reached when social planner sets up and implements the policies mentioned in the next section.

The Phase Diagrams show a qualitative analysis of the initial positions leading to convergence to steady state (optimal equilibrium). As shown in Figures 4.4 and 4.8, the initial value of rice price and water quality leads to a divergent path, which is not optimal. As a result, the social manager should look for a policy that affects the state variable, *z*, to change the initial point to a convergent path. The results of applying both the linear and nonlinear form are the same except for different magnitudes of corresponding values.

5.0 POLICY SUGGESTIONS

5.1 Comparative Analysis for Policy Suggestions

If dynamic equilibrium prices go down, then consumer's surplus goes up and as outputs going up leads to an increase in producer's surplus, i.e., an increase in social surplus. Thus, a comparative analysis for steady state prices is necessary for setting up a policy that decreases the price and increase in output.

5.1.1 Comparative Analysis of Steady State Rice Prices for Sensitivities

Optimal rice price depends on parameters as in Equation

$$p^{1*} = \frac{(m_1/\phi)\left[\rho\beta(r-\phi)c^1\right] - \rho^2\beta^2 k_2/\phi}{\rho^2\beta^2 + (r-\phi)m_1 m_2}.$$

Terms $\beta^2\rho^2$ and $\beta^2\rho^2 k_2/\phi$ are very small compared with other terms in above Equation; therefore, for simplicity, they are neglected. If so,

$$p^{1*} = \frac{\beta\rho c^1}{\phi m_2}.$$

Taking derivative p^{1*} with respect to $\phi, \beta,$ and ρ gives us sensitivities:

(0.1) $\dfrac{dp^{1*}}{d\phi} = \dfrac{-\beta\rho c^1 m_2}{\phi^2} < 0$ (= - 0.002397),

(0.2) $\dfrac{dp^{1*}}{d\beta} = \dfrac{\rho c^1}{m_2} > 0$ (= 0.01987),

(0.3) $\dfrac{dp^{1*}}{d\rho} = \dfrac{\beta c^1}{m_2} > 0$ (= 0.04365),

(0.4) $\dfrac{dp^{1*}}{dm_1} = \dfrac{-\beta\rho c^1}{m_2^2} < 0$ $(= -0.0022)$

Thus, an increase in the value of the parameter of the assimilative capacity, ϕ, or a decrease in the value of parameter of pollutant discharge, β, or damage cost, ρ, leads to a decline in rice price. The slope of fish demand, m_2, is steeper, implying a decrease in rice price. As a result, social welfare will increase. The social manager or policy maker must look for ways to change these values of the parameters to raise social welfare.

5.1.2 Comparative Analysis for Steady State Fish Prices

Similarly, steady state fish price in Equation is

$$p^{2*} = \frac{\rho m_2(r-\phi)\left(c+^1 \beta k_1/\phi - m_1 A/\rho\right) + \beta\rho^2 k_2}{\rho^2\beta^2 + (r-\phi)m_1 m_2}.$$

Terms $\beta^2\rho^2$ and $\beta^2\rho^2 k_2$ are very small compared with other terms in Equation (2.33), so, for simplicity, they are neglected; then

$$p^{2*} = \frac{\rho}{m_1}\left(c^1 + \frac{\beta k_1}{\phi} - \frac{A m_1}{\rho}\right).$$

Taking derivative p^{1*} with respect to ϕ, β, and ρ gives us the sensitivities:

(0.5) $\dfrac{dp^{2*}}{d\phi} = \dfrac{-\beta\rho k_1}{m_1\phi^2} < 0$

(0.6) $\dfrac{dp^{2*}}{d\beta} = \dfrac{\rho k_1}{m_1\phi} > 0$

(0.7) $\dfrac{dp^{2*}}{d\rho} = \dfrac{c^1}{m_1} + \dfrac{\beta k_1}{\phi m_1} > 0$

(0.8) $$\frac{dp^{2*}}{dm_1} = \frac{-\rho}{m_1^2}\left(c^1 + \frac{\beta k_1}{\phi}\right) < 0 .$$

Thus, an increase in the assimilative capacity, ϕ, or a decrease in pollutant discharge, β, or damage cost, ρ, leads to a reduction of the rice price. The slope of rice demand, m_1, is steeper and, as a result, the fish price goes down.

5.1.3 Comparative Analysis for Speed of Convergence

As absolute value of eigenvector, $| b_2 |$, is lower, the speed of convergence (a decrease in prices or an increase in water quality) is faster and this leads to higher welfare for current generation. In the linear case,

$$b_2 = \frac{r - \sqrt{(r-2\phi)^2 - 4\rho^2\beta^2 / m_1 m_2}}{2} .$$

Term $-4\rho^2\beta^2 / m_1 m_2$ is very small compared with $(r-2\phi)^2$. For simplicity, it is ignored, so

$b_2 = -\phi$, then

(0.9) $$\frac{d\,|b_2|}{d\phi} = 1 > 0 .$$

Thus, an increase in the assimilative capacity, ϕ, leads to a decrease in social welfare. This case is opposite to the ones in *5.1.1* and *5.1.2*.

The comparative analysis in these parts is summarized in Table 5.1.

Table 5.1 Comparative Analysis of the Model

	p^{1*}	p^{2*}	$\| b_2 \|$
ϕ	–	–	+
β	+	+	
ρ	+	+	
m_1		–	
m_2	–		

If we rule out the case of the slope of convergence, b_2, then an increase in the assimilative capacity, ϕ, or a decrease in pollutant discharge, β or damage cost, ρ leads to higher social welfare. What policies to change these parameters to raise the initial value of water quality, z_0, to convergent region as well as to increase the social welfare will be suggested below.

5.2 Policy Suggestions to Change Parameters and Raise Water Quality, *z*

Water quality depends on the amount of pesticide discharges and the assimilative capacity of the environment. In turn, the amount of discharge depends on the price of pesticide and the price of its substitute products, the level of insect attack, the farmer's use of pesticide, as well as pesticide regulations. The policy suggested here to reduce the discharge involves:

- Raising the pesticide price by levying a tax on pesticide (discussed below).
- Training farmers how to use pesticide effectively and efficiently. There are some empirical studies that document over-application as well as arbitrary use of pesticides based on farmer's feeling rather than on technical guidance for pesticide

use. According to Vo Mai's research (1996), the number of times the pesticide sprayed on one rice crop ranges from zero to seven. The most frequency is 3 times. More than 7 times is about 9.6% (see Table 5.2).

Table 5.2 Number of Times of Pesticide Spray on One Rice Crop in the Mekong Delta, 1994

Time	Dong Thap (%)	Song Hau (%)	Long Xuyen (%)	Ca Mau (%)	Total (%)
0	1.4	0.7	1.9	5.3	2.4
1	1.8	8.4	5.9	10.6	6.2
2	7.8	25.2	13.1	20.6	15.6
3	20.6	18.2	16.9	29.3	21.2
4	21.1	20.9	13.7	19.3	18.9
5	15.6	11.2	16.9	12.0	14.1
6	7.3	7.7	11.8	1.3	7.1
7	5.5	2.8	9.8	0.6	4.8
>7	18.8	4.9	9.8	0.6	9.6
Total	100	100	100	100	100

Source: Vo Mai, 1996

Furthermore, 80% of the pesticide dose used in one crop is sprayed during the first 40 days of growth, even though there are no signs of insect attacks. This high concentration of spraying is dangerous to the environment since high densities of toxic substances are difficult to assimilate in a short period of time. The reasons for over-application and arbitrary use of pesticides are that 1) pesticides are relatively cheap and their costs account for a small share of the total rice production cost (about 5-8%); 2) Farmers do not have a comprehensive knowledge of how to protect rice production efficiently and effectively, lack of knowledge about IPM. The importance of this is that a tax on pesticide may not be enough to change behavior; would need education programs as well.

- Promoting integrated pest management (IPM) program by the government using state funds. In the past, it was funded by the government, foreign countries, and NGOs.
- Funding and subsidizing of research and applications of substitute products for pesticide. Currently, the National Institute of Biology, Hanoi has succeeded in finding new products made from herbage and micro-organisms to substitute for existing chemical pesticides. Both new products do not damage the environment.
- Enforcing and renewing the list of pesticides banned. Chlorinate hydrocarbon group needs to be banned completely because of its long persistent existence in the environment, e.g., Lindan is 6.6 years, and Aldrin is 3 years (Le, Lam, 2000, p.266). A survey was done in 1994 to identify types and stock of pesticide residues in ponds raising fresh-water shrimp (Vo Mai, 1996). The locations of ponds are far out in the rice fields, about 500m-1000m (see Table 5.3). Table 5.3 shows that most water samples contained pesticide residues. Some pesticides such as *DDT, Lindan, Metamidophos, Methyl Parathion, Aldrin, Heptachlor,* and *Dieldrin* are banned from production and trading, but their residues still exist in water samples.

Table 5.3. Pesticide Residues of 19 Water Samples in Shrimp Pond in the Mekong Delta, 1994

	Pesticide name	Residue in the sample (μg/l)	Number of samples containing residue
01	Lindan	0.015 -41.2	17
02	Heptachlor	0.003 - 0.01	2
03	Aldrin	0.001 - 0.02	5
04	Dieldrin	0.006- 0.07	4
05	DDT	0.0017 - 0.16	10
06	Endosulfan	0.0008 - 0.3	5
07	Methamidophos	1.8 - 13	19
08	Diazinon	0.6 - 1.26	2
09	M. Parathion	0.18 - 0.76	7
10	Dimethoate	0.28 - 1.12	5
11	Malathion	0.06 - 0.16	2
12	Fenitrothion	0.2	1

Source: Vo Mai, 1996

It is easy to find or buy a bottle of banned pesticide in chemical or fertilizer and pesticide stores in Vietnam.

Enforcement of these policies would lead to an increase in water quality, while at the same time making the parameter of pesticide discharge, β, lower, and in turn, lower the two steady-state prices as shown in the comparative analysis.

The assimilative capacity of the environment, $a(z)$, depends on three key factors: 1) Environment destroys the chemical structure of the pesticide, but this occurrence is not known fully, making human intervention difficult; 2) Pesticide degrades itself over time; thus the pesticide, whose residue persistently exists, must be banned from production and application as noted above. Pesticide, whose residue exists one to two years, must be taxed to restrict its use; 3) Water currents of rivers bring the residue from rice-flooded-fields to the East-Sea (also called South China Sea or Indo-China Sea) due to the tidal regime of the East-Sea. So, if the river system is improved speed up the run-off, then the residue will be reduced. These policies make the assimilative capacity of the environment higher (for raising initial value of water quality, z_0) at the same time, making value of parameter of assimilative capacity, ϕ, higher and damage cost, ρ, lower, which, in turn, lower two steady state prices.

3.3 Tax on Pesticide

There are some policy instruments that can be used to internalize the environmental cost of rice production, such as tax on rice output, tax on residue discharge, and tax on pesticide input. A tax on rice output will raise the rice price, but it provides no incentive to reduce the pesticide use. A tax on discharge cannot be implemented because it is difficult and costly to measure the residues to enforce the tax. A tax on pesticide input is more reasonable, because it is easier to implement, and it provides an incentive to use cheaper substitute products of pesticides that do not damage the environment. The farmer will, therefore, limit its dose and frequency of use.

Before 1996, there was no tax on pesticide and it was one of the items of high priority import items. Since 1996, tax rates in the range of 1%- 5% have been levied on pesticide import or domestic production. When compared with other imported goods with high tax rates such as 100-150% for motor-cycle, or 150-200% for car and so on, the tax rate on pesticide is negligible or almost zero. Thus, the tax has no effect in reducing pesticide use. Therefore, a higher tax must be levied in order to reduce the quantity for the protection of environment and human health.

It is not easy to determine an optimal tax on pesticide. This is because we cannot measure all the damages of pesticide residues to human beings, the environment as well as the economy, such as losses in biodiversity, death of humans, and external costs to some industries in the economy. Thus, a tax on pesticide suggested in this study is designed to internalize the external cost to fish culture e.g., a minimum tax on pesticide, which is computed as follows:

The external cost caused by producing one kilogram of rice is 13.44 $VN (real price, 1989) as mentioned in Section 4.

The cost of pesticide input is 280,000 $VN (nominal price in 2001) in one crop, with yield of 4,200 kg per hectare.

Total external cost per crop is
13.44 * 4,200*6.12 = 345,462 $VN (6.12 is producer price index, base year 1989).

The total pesticide input cost after internalizing is
280,000 + 345,462 = 625,462 $VN.

The tax rate on pesticide will be
(345,462/ 280,000)* 100% = 123.38 % of initial price.

For example, the price of one bottle of M.Parathion on the market is 15,000 $VN, a tax on it is
15,000* 1.2338 = 18,506
The price after tax is
15,000 + 18,506 = 33,506 $VN.

This tax rate will be levied on pesticide importers and domestic pesticide producers. On the policy side, the government would be able to double pesticide prices by the tax. In other words, is this magnitude of tax practically feasible.

5.4 Expanding the Rice-Fish/ Shrimp Production Pattern

The rice-fish/ shrimp production pattern has been used by farmers in some regions in the Mekong Delta. In this pattern, a small levee built around the rice field is used to stabilize the water volume and hold the fish/ shrimp inside the rice field. As a result, the farmer can plant rice with a higher yield and raise fish/ shrimp at the same time. Because of raising fish, the farmers have to limit the minimum dose of pesticide use so that survival and growth of fish are not compromised. Thus, this pattern of production reduces pesticide pollution in the water system. The results of cost-benefit analysis show that economic efficiency of the pattern is high. Farmers' income increases as much 1.5- 2.5 times, and the amount of pesticides decreases by 64 -77%, compared with the rice-only production pattern. Data in Table 5.4 are from the survey of Department of Aquaculture, Nong Lam University, Ho Chi Minh City, Vietnam, 1997.

In Table 5.4., farmers decrease 64% pesticide use in the rice-fish pattern and 77.5% in the rice-shrimp pattern as compared to the rice only. Also, the chemical fertilizer volume is decreased by 55%. The yield of rice in the rice-shrimp/ fish pattern is less than that of rice only pattern, because a small area of the rice field is used to dig dikes inside and build a small levee surrounding the field.

Table 5.4. Input and Output in 3 Patterns: Rice-fish, Rice-shrimp, Rice only (1 ha/ crop)

	Pattern		
	Rice-shrimp	Rice-fish	Rice only
Input			
- Chemical fertilizer (kg)	85	78	190
- Pesticide (kg)	0.7	1	3.1
Total (kg)	85.7	79	193.1
Output			
-Rice (kg)	2,470	2,459	3,225
-Fish (kg)	-	276	-
-Shrimp (kg)	190	-	-

Source: Department of Aquaculture, Nong Lam University, Hochiminh City, Vietnam, 1997.

Table 5.5. Results of Production of 3 Patterns (for 1 ha/ year)

	Pattern (million $VN)		
	Rice- shrimp	Rice- fish	Rice only
Fixed cost	6.094	6.094	-
Variable cost	4.238	4.156	2.030
Total income	21.036	15.802	8.062
Net income	16.798	10.646	6.032

Source: Department of Aquaculture, Nong Lam University, Hochiminh City, Vietnam, 1997.

In Table 5.5, net income in the rice-only pattern is very low. Net income in the rice-shrimp pattern is the highest (nominal price in 1997), next to the rice-fish pattern. At the same time, volumes of pesticide used for them are smaller. This means that, the rice-fish/ shrimp pattern gives the farmer high efficiency and benefits the water environment. The net income from the shrimp-rice and the fish-rice production patterns is very attractive; however, these patterns are not easy to develop due to two important conditions: 1) Water sources for the rice field must be fully stabilized during crop; rice plant can survive more than 3 weeks without water, but fish cannot survive after 10 minutes without water; 2) Farmers of adjacent rice fields do not apply pesticide, e.g. there is no pesticide externality. The policies needed to overcome the biggest barriers to joint production: too low a price of pesticides, the externality problem (implies pesticide tax), lack of technical knowledge of how to fish farm (implies education and training), capital costs of establishing fish farms (implies some form of reducing those capital costs - e.g., loans, etc.).

This analysis suggests a policy to expand this pattern of production further by its high efficient in production and reduction of environmental deterioration. It is more effective than the tax policy. However, the tax policy will support the expansion of the pattern due to the reduction in pesticide use causing the negative externality to fish farm production. This policy is similar to a 'win-win' solution.

5.5 Developmental Policy for Aquaculture

According to Food and Agriculture Organization (FAO), "aquaculture is considered a friend of the environment (except for coastal fish culture which negatively impacts on ecosystem)" (FAO, 1997). "Vietnamese fish culture is still not developed to its full potential viewed in light of advantages of natural conditions available". "The growth rate of fish consumption of the world is about 16% per year" (FAO, 1997), which is a big opportunity for developing countries having natural conditions suitable for aquacultural development. These views are important bases to set up developmental policy for aquaculture in the Mekong Delta. Particularly, the benefits of aquaculture's expansion policy include the following:

- Both water and land environments become less polluted due to a decrease in pesticide use. Pesticide is considered as the key pollutant in rural water bodies. If one hectare of rice is converted into fishpond, then the water body is freed from 3 kg of discharged pesticide per year into water bodies (3 kg stick on rice leaf, 3 kg fall down the water surface) (Hoang, 2000).
- One hectare of fishpond needs at least 10 laborers to work; on the other hand, one hectare of rice needs only 4 laborers. Thus, if converted, each hectare would need 6 more laborers leading to a reduction in the rate of unemployment. According to the Statistical Yearbook, 1998, the rate of unemployment in rural areas is 7%, the equivalent of 560,000 laborers (out of 8 million people from 16 to 55 years old) in the Mekong Delta. Thus, if 93.33 thousand hectares of rice (4.7% of the total rice area) are converted into fishponds, then the 7% unemployment rate in the Mekong Delta is reduced to zero. Moreover, deforestation and illegal work resulting from this unemployment rate will be reduced and socio-economic welfare will improve considerably due to the reduction in unemployment.
- From an economic perspective, profit from fishponds is more than three times that of rice (2.4 and 7.3 million VN$, respectively, nominal price in the year 1999), and foreign currency from export is more than four times from the same area (1200 and 4900 $US per ha, respectively) (Governmental Pricing Committee, 1999). These benefits are summarized in Table 5.6 below.

Table 5.6 Benefits of Converting Rice Field into Fish Pond per Hectare

	Fish (1)	Rice (2)	Benefit (3) = (1) – (2)
Pesticide discharge (kg)	0	3	-3
Labor input (person)	10	4	6
Net income (million $VN)	7.3	2.4	4.9
Revenue from export ($US)	4,900	1,200	3,700

Sources: Governmental Pricing Committee, 1999.
Hoang, 2000.
Statistical Yearbook, 1998.

Why don't many rice producers now convert to fish farms if the value of the output and profits are so much higher with joint production of rice and fish? Some factors that they face are: tradition and culture, need for home consumption of rice, fixed costs of introducing aquaculture, problems of flooding needing capital to ensure fish don't get washed away, need to develop different skills (have already invested in rice related human capital, would need to learn how to raise fish). Some suggested policies must be directed to address it as follows:

- Workers, technicians and managers raising fish should have a high level of skills. According to the report of Ministry of Aquaculture in the workshop for the aquaculture development (Soc Trang, Vietnam 25-26 Aug, 2002), technicians for current aquacultural development have been supplied only 35% of demand. Thus, it is necessary to have training programs on the technique of fish culture as well as the programs that transfer technology from institutes and universities, and projects that establish a well-funded aquacultural extension agency.
- The priority of aquaculture in governmental policy for socio-economic development is low; as a result, government spending for research, application of new technology, and other programs for aquaculture development is limited. It is necessary to reset this priority.
- Raising fish requires a lot of capital, but many farmers are poor; at the same time, banks don't want to lend to the poor and the procedures for obtaining loans from state banks are complex. Thus, low-interest rate loans, subsidy programs, and easy loan procedures are necessary conditions to develop aquaculture.
- The education and training programs for farmers to learn how to farm fish is necessary to increase fish production. This may be as important as reducing the financial barriers to fish farming.

Another important aspect of the policy relevance is that joint production of two food sources will be much easier to accomplish that convincing farmers to shift to a non-food 'export' good. This is because home consumption of fish is possible and the time needed to raise a fish crop is approximately equal to the time needed to raise rice crop, therefore there are no intertemporal tradeoffs between rice only production and rice/ fish production (e.g., unlike convincing farmers to switch to tree crops that take a long time to mature).

In general, the comparative analysis shows the direction as well as the magnitude of parameters affecting the steady-state prices. An increase in the value of parameter of assimilative capacity, ϕ, or a decrease in the value of parameter of pollutant discharge, β, and the value of parameter of damage cost, ρ, leads to raising the initial value of water quality, z_0, and at the same time lowering the steady-state price. Some key ideas and measures are suggested to set up policies to raise or lower these values of the parameters. An aquacultural development policy will affect not only the change in parameters but also bring about improvements in the unemployment situation, environment, and other socio-economic issues.

6.0 SUMMARY, CONCLUSIONS AND FURTHER STUDIES

6.1 Summary of Study Contributions

A dynamic model for the socially optimal management of renewable resource is set up. A water quality variable, z, is conceptually used for the model. The first order conditions give the useful interpretation in the optimal management. Data are collected and used in estimations of demand functions of rice and fish, the assimilative capacity of water quality, fish cost function of producers, and the parameter of pesticide discharge. The simulation of the model shows useful results for the social managers to establish policies that maximize social surplus. Policy suggestions for improving water quality, expansion of aquaculture and transfer of technology for fish and rice producers are provided.

6.2 Conclusions

Originating from an analysis of increasing pesticide pollution in rice production in the Mekong Delta, a model for maximizing the social surplus is developed for optimal management of resources as well as production. Its first-order conditions give us some important quantitative formulae that explain the dynamic relationships among prices, water quality, and shadow price. It also gives us some qualitative interpretation, such as an additional increase in rice price during this period optimally equals an increase in foregone resource rent in the next period plus the damage cost of fish in the next period by using water resources in this period (Equation (2.10)). The model also reconfirms the fundamental formula: price is equal to cost of production plus cost of using the environment (Equation (2.5')).

The time paths and phase diagrams resulting from the first-order conditions show the variations and the changes in prices, outputs, and water quality over time, the initial position in regions leading to divergence or convergence. As a result, effective policies are set up to maximize social welfare.

Data from secondary and primary sources have well served the estimation of the parameters of the model. Functions for the two demands, the average fish cost, the assimilative capacity and the parameter of discharge (β) are identified by econometric work. The computed shadow price and the fish cost function are used to identify the total loss of fish culture by pesticide use, about 9 billion $US in the year 2001. Relatively good results of regression are used for model simulation. Two cases of linear and nonlinear forms are applied with scenarios of initial values for the year 2001. The simulation shows optimistic results with prices going down and water quality going up over time, meaning the social surplus will rise, and the water environment will be better. However, the phase diagram shows that we do not have an optimal solution, because the initial value of water quality in the year 2001, $z_0 = 2.78$, is lower than what is required by the model, $z_0 = 3.05$. Fortunately, the difference between these two values is small, and it is not difficult to raise z_0 from 2.78 to 3.05 via policies suggested in Section 5.

A comparative analysis of the model shows the directions of change in parameters and their sensitivities leading to a change in the steady state values, an increase in the value of parameter of assimilative capacity, ϕ, or a decrease in the ratio of discharge, β, or the value of parameter of damage to fish, ρ, leading to lower optimal prices and better environment. How to change the parameter values is analyzed and the analysis suggests different policies such as a tax on pesticide input, change in priority in industry development, improvement to achieve a faster speed of water currents in river systems, changes in pesticide regulations, training and transfer of technology to the farmer, and policies for aquacultural development. These policies will result in considerable benefits to the environment, the economy, and the farmers.

6.3 Limitations of the Study

This study has the following limitations:

- Aquaculture in the Mekong Delta is diversified such as raising fish in brackish water, in fresh water, in cage, and in rice field. However, this study focuses on fishpond and in three popular species only.
- The model ignores the pollution from fish culture.
- Negative impacts of pesticide to land environment, biodiversity and human health are ignored.
- The policy suggestions are only key points and are not discussed in details.

- The simulation does not show a particular increase in the social surplus, because the cost of raising water quality is not measured.

6.4 Further Studies

Some further studies are suggested as follows:

- Relaxing the assumption that fish culture does not pollute the water environment. For the time being, in the Mekong Delta, pollution from fish culture is negligible; however, in the future, when the economy is more developed, then fish may be raised by intensive-culture regimes that discharge a lot of surplus feed into the water environment causing eutrophication or the "algae bloom" phenomenon of pollution.
- Applying the model for other industries besides fish and rice.
- Further in-depth studies of each particular policy suggested in Section 5.

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APPENDIX: QUESTIONNARE

For Cost of Culturing Farm in Mekong Delta

Farm code number ---------------------

Province ---------------------------------

District ----------------------------------

Interviewer ------------------------------

Village ----------------------------------

Date of interview …/…./ 200…

Checked by superviser ----------------

Respondent: 1.Owner____2. Wife of owner ____

01. Farm type: 1.1. Pond-extensive____ 1.2.Pond semi-int____1.3. Others___(……..…)

02. Number of Labor: 2.1 Household_____ 2.2 Hired_____

03. Was this site used for aquaculture previously

	TYPE	CHECK
3.1	Rice farming	□
3.2	Wetland/swamp	□
3.3	Public water body	□
3.4	Low-yield/unsuitable agricultural land	□
3.5	Coconut	□
3.6	Others (…………………………………….)	□

04. Area of Farm

	Type	Area (1000 m^2)
4.1	Total farm area	
4.2	Growing fish Pond	
4.3	Nursing/fingerlings Pond	
4.4	Rice field	

05. Water Exchange

1.By pump ____2.By tide _____3.By well

06. Species of fish

1. Cyprinus carp____ 2. Oreochronus carp____3. Osphromemus carp

07. Cost

	TYPES	AMOUNT
7.1	Labor cost	
7.2	Fertilizers	
7.3	Feed	
7.4	Seed, fingerlings	
7.5	Depreciation	
7.6	Vehicle operation (repairs, fuel, power, registration, etc,)	
7.7	Interest	
7.8	Overhead costs (phone, tax)	
7.9	Cleaning and harvesting	
	Total	

08. Total Yield_______Kg/crop

8.1.Common______kg, 8.2. Silver_______kg, 8.3. Grass_______

09. Education of owner _______(1-4)

10. Year of culturing experience______ years

11. Do you think that pesticide residue affects to fish productivity

a. yes ____ 2. no_____

If yes, what is the level of the affect?

1. Very serious____ 2. Serious____3. Little serious____

Thank you for your cooperating and answering

Closing