Optimal Control of Property Right of Resources When Two Externalities (Environmental Property Right Distortion and Production Pollution Distortion) Co-Exist: The Small Economy Case

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WP 03-18

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December 8, 2003

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The Small Open Economy Case*

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Abstract

Few studies investigate how environmental property right and production pollution distortions influence the economy when these two externalities co-exist. This case falls into a standard "second best theory". That is, it is important that pollution control policy should be coordinated with the reduction of environmental distortions. Given the non-linearity of production pollution distortion, the optimal property right may not be perfect. To guarantee the achievement of optimal total income via optimal property right, the monitoring agency should take into account the whole system and enforce different monitoring mechanisms in diversified situations. Empirical analysis is proposed on the reef fishery of Pacific island economies and the world.

Keywords: Trade and environment, pollution control policy comparison
JEL Classification: F18, Q20

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*This research is a part of my Ph.D. dissertation at the Department of Agricultural and Resource Economics, University of Maryland. I would like to thank my advisor Dr. Ramon Lopez for his tremendous support, encouragement and feedback during the course of this research. Thanks are also given to Dr. Douglas Lipton, Dr. Richard Just, Dr. Lars Olson and Mr. Garth Parry for their valuable comments. This draft still remains to be revised.

I. Introduction

This paper studies how environmental property right and production pollution distortions influence the economy when these two externalities co-exist. The optimal property right may not be perfect because of the non-linearity of a production pollution distortion. Two different monitoring mechanisms (static system and dynamic system) are analyzed and compared. Preliminary empirical results from the Chesapeake Bay blue crab fishing industry demonstrate the existence of those two externalities and confirm the basic economic intuition in our theoretical model.

Most countries, especially the less developed (LDCs) are affected by three types of distortions in their economies: trade policy, environmental property right and production pollution distortions. Trade policy distortions mainly involve the deadweight loss and inefficient resource allocation due to import tariffs and/or quantitative restrictions (Krueger, Valdes, and Schiff, 1988). Environmental property right distortions mainly relate to the open access problem in the resource sector. That is, the property right is not well defined in the resource sector and the full social value of natural resource use is not internalized due to inadequate institutions and difficulties of implementing and enforcing the relevant policies (Lopez 1997). Production pollutions refer to industrial pollution that may damage the natural resource stock thus negatively affecting the production using the natural resources (Copeland and Taylor 1999).

Much research has been done on the influence of environmental property right distortions on an economy open to trade. When other conditions are the same, differences in property rights can create a motive for trade and/or decide the welfare outcome. Chichilinsky (1994) demonstrated that the “South” (a region with ill defined property rights) can experience a welfare loss in trade with the “North” (a region with well defined property rights). Brander and Taylor (1997) investigated the case of a small open economy with open access renewable resources. Their result is somewhat counter-intuitive: “for a resource abundant country that cannot specialize in the resource good, the steady state utility levels fall monotonically with ‘improvements’ in this country’s terms of trade”. Brander and Taylor (1998) further investigated the case of a large country and confirmed this result: “a diversified resource exporting country necessarily suffers a decline in steady state utility resulting from trade, and may lose along the entire transition path".

Conversely, the international trade model will also affect the resource stock via the property system. Lopez (2000) studied the case of Cote d'Ivoire and pointed out that when the agricultural output composition effect dominates the agricultural expansion effect, total trade liberalization could be a win-win type of policy. The agricultural output composition effect refers to the increase of the production of land-saving agricultural goods and the agricultural expansion effect indicates the rise of the production of the land-intensive agricultural goods. In the case of partial trade which only reduces protection to non-agricultural goods, it can cause deterioration of the biomass resources thus diminishes welfare.

When both trade policy and environmental property right distortions co-exist, the scenario falls into the category of a standard "second best" solution. That is, eliminating only one of the two distortions does not necessarily improve welfare. Rather, it is important that trade policy be coordinated with the reduction of domestic environmental distortions. Zhao (2000) studied the relationship between reducing trade tariffs and improving property rights to environmental resources. He found that if the reform always sets one distortion optimally given the other, then in the long run which one is reduced first does not matter, as the reform will converge to a point where both are removed. But if the reform reduces distortions in an arbitrary way, the coordination becomes important when one of the distortions is much more significant than the other, or when the reduction is not gradual.

Research has also been done on the welfare effect of international trade in presence of pollution-created intersectoral production externalities. Under these conditions, trade can play an important role in spatially separating incompatible industries. Copeland and Taylor (1999) have found that if pollution does not affect utility directly, then free trade always enhances welfare for an unregulated small open economy. Two identical, unregulated countries will gain from trade if the share of world income spent on the dirty good is high. However, when the share of world income spent on the dirty good is low, trade can lead to a negatively reinforcing process of environmental degradation and real income loss for the exporter of the dirty good. In their model, it is assumed that there is no distortion of the property right condition in the resource sector.

In all, there is a rich literature on each of those three distortions separately. There is also research on combination of the first two distortions (i.e. trade and property right distortions). Few studies consider the case when the last two distortions (environmental property right and production pollution distortions) co-exist. McConnell and Strand (1989) addressed this issue from the perspective of demand and supply of commercial fisheries. They found that when "fish stocks are efficiently allocated (under perfect property right), improving water quality enhances the return to the fishery. But with open access, benefits from improving water quality are less obvious..….Fisheries management should be 'decompartmentalized' and be seen in a larger framework, one in which water quality and fisheries decisions are joint decisions. Viewed in this manner, the marginal gains to fisheries management and water quality improvement may both be enhanced." McConnell and Strand (1989) did not explicitly depict the ill-defined property right conditions. Using the production function adopted in Zhao (2000), we are able to explicitly represent the ill-defined property right conditions and derive similar results. That is, it is important that pollution control policy should be coordinated with the reduction of property right distortions. Specifically, there are two monitoring systems for policy makers to choose: static system or dynamic system. In the static system, individual firms in the resource industry are assigned short-term property rights and the government considers the total shadow value of the resource stock; while in the dynamic system, individual firms in the resource industry have the long-term property rights and will consider its own share of the shadow value of the resource stock. Which system is a better choice will depend on the varying conditions.

We study the case of two existing distortions (imperfect property right and pollution) by setting up a two stage monitoring system enforced by the government and firms in the resource sector. In the first stage, firms maximize their profits given the number of firms in the resource sector; in the second stage, given the decisions made by firms, government maximizes total welfare by choosing the number of firms or monitoring the labor input used by firms. The maximizations in these two stages are actually two aspects of the same decision process and should take place at the same time. They are divided into two stages for convenience of modeling only. The monitoring system can be static or dynamic, depending on different conditions.

By assuming a non-linear production pollution function and adopting a specific production form in the resource sector, which is also used by Zhao (2000), we find that the perfect property right condition may not produce desirable results in the presence of a pollution externality. When governments make policies concerning two related externalities, it may be better to take into account the whole system, rather than focusing on controlling only one externality. An appropriate monitoring system should be chosen to achieve the optimal result depending on varying conditions.

This prospectus is organized as follows. Section II builds the basic theoretical model. Section III discusses the static monitoring system. Section IV overviews the dynamic monitoring mechanism. Section V applies the dynamic monitoring system when the optimal property right is perfect or below perfect. Section VI discusses the monitoring system when the optimal property right is above perfect. Section VII applies the empirical analysis on Pacific Island Economies and reef fishery in the world. Section VIII discusses the results and concludes the prospectus.

II. THE BASIC THEORETICAL MODEL

We consider an economy of two goods, the manufactured good *M* and resource good *H*. There are two primary input factors: labor (L) and the stock of environmental capital (K). There is also a monitoring agency (government), which employs labor L_A. The monitoring mechanism used by government may vary according to the optimal property right condition. This will be addressed in more detail in Section V and VI.

Borrowing from Copeland and Taylor (1999), we assume that when there is neither production in the resource sector nor pollution in the industry sector, the capital of natural resource *K* evolves according to

$$dK/dt = g(\overline{K} - K) \tag{1}$$

where $\overline{K}$ is the "natural" level of environmental capital, and $g > 0$ measures the natural recovery rate of the environment. Industry *M* is a dirty industry that uses labor as an input and emits pollution as a joint product of output. We assume that *M* is produced with a constant return to scale technology given by

$$M = L_M \tag{2}$$

Good *M* is the numeraire with price 1. Thus the wage rate is $w = 1$ if *M* is produced in the economy.

Pollution is generated by

$$z = \beta(L_M) \tag{3}$$

where $\beta(\cdot)$ is a convex function, and $\beta'(\cdot) > 0, \beta''(\cdot) > 0$. This means that pollution is generated at an increasing rate when more of the industrial good is produced.

The other industry produces resource good *H* with a technology given by

$$H = aK^{1/2}{L_H}^{1/2} = K^{1/2}{L_H}^{1/2} \tag{4}$$

where a is a scale factor (assuming $a = 1$ for simplicity), K is the resource stock and L_H is the labor employed in the *H* sector and $L_H + L_M + L_A = L_T$, where L_T is the total labor force in the economy.

Thus, when there is production in the resource sector and pollution generated by the dirty industry, the environmental capital stock evolves by $dK/dt = g(z)(\overline{K} - K) - H$. For simplicity, we assume $g(z)(\overline{K} - K) = g(\overline{K} - K) - z$. Then, the evolvement function of the environmental capital is

$$dK/dt = g(\overline{K} - K) - z - H = g(\overline{K} - K) - \beta(L_M) - K^{1/2}{L_H}^{1/2} \tag{1$'$}$$

Let p represent the price of *H*. Following Zhao (2000), we assume that there are *n* identical extractors (firms) in the resource sector, and the output of each is the portion of the total output equal to its share of the total labor input. Let L_i be the labor input of firm i ; this firm's output of *H* is then given by

$$K^{1/2}{L_H}^{1/2}\frac{L_i}{L_H} \tag{5}$$

where $L_H = \sum_{j=1}^{n} L_j$.

The profit function of each firm in the resource sector is given by

$$\pi = pK^{1/2}{L_H}^{1/2}\frac{L_i}{L_H} - wL_i = pK^{1/2}{L_H}^{1/2}\frac{L_i}{L_H} - L_i$$

where $w = 1$ when *M* is produced.

III.AN OVERVIEW OF THE STATIC MONITORING SYSTEM

We will first consider the static monitoring system in this model for a small open economy. In the static design, the government will assign the firms temporary property right to the resource. Thus, firms will first statically maximize their own profits by choosing the amount of labor and taking the stock size K as given; then in the second stage, the government will maximize the total income by considering the shadow value of the stock evolvement.

In the first stage, for each extractor in the *H* sector, the firm *i* solves

$$MAX_{L_i}\pi = pK^{1/2}\frac{(\sum_n L_j)^{1/2}L_i}{\sum_n L_j} - wL_i = pK^{1/2}\frac{(\sum_n L_j)^{1/2}L_i}{\sum_n L_j} - L_i$$

($w=1$, when *M* is produced)

Thus, solving the first-order conditions yields

$$d\pi/dL_i = pK^{1/2}(\sum_{j=1}^{n} L_j)^{1/2}/(\sum_{j=1}^{n} L_j) - 1/2\,pK^{1/2}L_i/(\sum_{j=1}^{n} L_j)\times(\sum_{j=1}^{n} L_j)^{-1/2} - 1$$

$$= \quad pK^{1/2}(\sum_{j=1}^{n} L_j)^{-1/2} - 1/(2n)pK^{1/2}(\sum_{j=1}^{n} L_j)^{-1/2} - 1$$

$$= \quad pK^{1/2}(\sum_{j=1}^{n} L_j)^{-1/2}(1-1/(2n)) - 1 = 0$$

which implies $(\sum_{j=1}^{n} L_j)^{1/2} = pK^{1/2}(1-1/(2n))$

$$\Rightarrow L_i = [p^2K(1-1/(2n))^2]/n$$

For convenience, we will generate a variable $\delta \equiv 1-\frac{1}{2n}$, which is used to measure the property right condition of the resource. Notice that δ ranges from $1/2$ to 1, with $1/2$ being perfect property right and 1 being null. Thus, the individual firm's labor employment will be

$L_i = 2(1-\delta)\delta^2p^2K$ and the total labor employment in the resource industry will be

$$L_H = p^2K\delta^2 \tag{6}$$

Then, the total output of *H* is $H = L_H^{1/2}K^{1/2} = pK\delta$

In the second stage, given the above conditions, the government wants to maximize total income:

$$Max I = \int_{-\infty}^{+\infty}\left[pH + (L_T - L_H - L_A)\right] e^{-\lambda t}dt = \int_{-\infty}^{+\infty}\left[p^2K\delta + (L_T - L_A - p^2K\delta^2)\right] e^{-\lambda t}dt$$

$$s.t. \dot{K} = g(\overline{K} - K) - \beta(L_T - L_A - L_H) - H = g(\overline{K} - K) - \beta\left(L_T - L_A - p^2K\delta^2\right) - pK\delta$$

$$where. \beta'(\cdot) > 0, \beta''(\cdot) > 0$$

The current-value Hamiltonian can be written as

$$\xi = \quad p^2K\delta + (L_T - L_A - p^2K\delta^2) + \lambda[g(\overline{K} - K) - \beta\left(L_T - L_A - p^2K\delta^2\right) - pK\delta]$$

F.O.C.

$$\frac{d\xi}{d\delta} = p^2K - 2p^2K\delta + \lambda\left[-\beta'(L_T - L_A - p^2K\delta^2)(-2p^2K\delta) - pK\right]$$

$$= pK\left\{p - 2p\delta + \lambda\left[2p\delta\beta'(L_T - L_A - p^2K\delta^2) - 1\right]\right\} = 0$$

$$\Rightarrow p(1 - 2\delta) = \lambda\left[1 - 2p\delta\beta'(L_T - L_A - p^2K\delta^2)\right] \text{..}(7)$$

$$\dot{K} = g(\overline{K} - K) - \beta(L_T - L_A - L_H) - H = g(\overline{K} - K) - \beta(L_T - L_A - p^2K\delta^2) - pK\delta = 0 \text{......}(8)$$

$$\dot{\lambda} = -\frac{\partial\xi}{\partial K} + r\lambda = -(p^2\delta - p^2\delta^2) + \lambda\left[r + g + p\delta - \beta'(L_T - L_A - p^2K\delta^2)p^2\delta^2\right] = 0$$

$$\Rightarrow \lambda = \frac{p^2\delta(1 - \delta)}{g + p\delta + r - p^2\delta^2\beta'(L_T - L_A - p^2K\delta^2)} \text{..}(9)$$

$(K, L_H, \delta, \lambda)$ satisfying conditions (6),(7),(8),(9) will be the solution for the static design. For simplicity, we can assume $L_A = 0$. Later, we might make $L_A > 0$ when we want to directly monitor labor used in each firm if the optimal number of firms is not an integer.

1. A short analysis of marginal effect of δ :

From (7), we know that there are two contradictory effects associated with the change of property right δ :

(1) Current marginal income effect of δ : $p(1-2\delta)$. For every unit increase of δ, the income will change by $p(1-2\delta)$. The intuition is that the perfect property right condition is $\delta = 1/2$, when

$\delta > 1/2$, the property right condition gets worse. This in turn will reduce the total income because of the over-exploitation of the resource.

(2) Marginal Effect on resource capital K : the increase of δ will have two simultaneous effects on K. One is the harvesting: λ. The increase of δ will lead to more extraction of resource K. This in turn will decrease the shadow value of resource K by λ. The other is the pollution: $2\lambda\delta p\beta'(L_T - L_A - p^2 K\delta^2)$. With the increase of δ, more labor will flow from the pollution industry to the resource industry, reducing pollution and preserving resource K. In addition, the shadow value of resource K will be improved by $2\lambda\delta p\beta'(L_T - L_A - p^2 K\delta^2)$. Overall, the marginal effect on resource K is $\lambda[1 - 2p\delta\beta'(L_T - L_A - p^2 K\delta^2)]$.

At the optimal steady state, $p(1-2\delta) = \lambda[1 - 2p\delta\beta'(L_T - L_A - p^2 K\delta^2)]$. That is, the marginal effect on the current total income should be equal to the marginal effect on the shadow value of the resource stock.

2. Conditions for different optimal δ :

Notice that the smallest possible δ is $1/2$, because the smallest possible n is 1. But, in fact, when there is only one firm in the resource sector, we can reduce the labor used by this firm (L_H) below its own myopic optimal level. This is equivalent to reducing δ. Recall the condition (6) $L_H = p^2 K\delta^2$. When $\delta = 1/2, L_H = \dfrac{p^2 K}{4}$. If we reduce L_H under this level, then we will achieve the same effect as if we reduce δ. For example, if we choose $L_H = \dfrac{p^2 K}{16}$, then this is equivalent to setting $\delta = \dfrac{1}{4}$. This can happen when the pollution effect is very weak compared with the direct resource extraction effect of the unique firm. Thus, under static system, even a perfect property right will not fully protect the shadow value of the resource. Rather, a labor use restriction needs to be imposed on the unique firm to fully take into account the social value of the resource stock. Later after we discuss the dynamic system, we will find that this is the special case where dynamic system is surely better than the static system.

Depending on different conditions, the optimal property right can be $0 \le \delta < \frac{1}{2}, \delta = \frac{1}{2}, \frac{1}{2} < \delta \le 1$.

These can be derived from (7) also.

From (7), we know that

$$\frac{d\xi}{d\delta} = p^2K - 2p^2K\delta + \lambda\left[-\beta'(L_T - L_A - p^2K\delta^2)(-2p^2K\delta) - pK\right]$$
$$= pK\left\{p - 2p\delta + \lambda\left[2p\delta\beta'(L_T - L_A - p^2K\delta^2) - 1\right]\right\}$$

If at $\delta = \frac{1}{2}$, $p\beta'(L_T - L_A - \frac{1}{4}p^2K) - 1 = 0$, the optimal δ will be $\frac{1}{2}$.

If at $\delta = \frac{1}{2}$, $p\beta'(L_T - L_A - \frac{1}{4}p^2K) - 1 > 0$, the optimal δ will be greater than $\frac{1}{2}$.

If at $\delta = \frac{1}{2}$, $p\beta'(L_T - L_A - \frac{1}{4}p^2K) - 1 < 0$, the optimal δ will be less than $\frac{1}{2}$.

3. The effect of change of δ on the resource stock K:

Also from (8), we can derive the change of δ on the resource stock K. Totally differentiating (8), we will have

$$[-\beta'(L_T - L_A - p^2K\delta^2)(-2p^2K\delta) - pK]d\delta + \left[-g - \beta'(L_T - L_A - p^2K\delta^2)(-p^2\delta^2) - p\delta\right]dK = 0$$
$$\frac{dK}{d\delta} = -\frac{2p^2K\delta\beta'(L_T - L_A - p^2K\delta^2) - pK}{p^2\delta^2\beta'(L_T - L_A - p^2K\delta^2) - p\delta - g} = ?$$

If $\frac{1}{2p\delta} < \beta'(L_T - L_A - p^2K\delta^2) < \frac{1}{p\delta} + \frac{g}{p^2\delta^2}$, then the numerator becomes

$$2p^2K\delta\beta'(L_T - L_A - p^2K\delta^2) - pK = 2p^2K\delta\left(\beta'(L_T - L_A - p^2K\delta^2) - \frac{1}{2p\delta}\right) > 0$$

and the denominator becomes

$$p^2\delta^2\beta'(L_T - L_A - p^2K\delta^2) - p\delta - g = p^2\delta^2\left(\beta'(L_T - L_A - p^2K\delta^2) - \frac{1}{p\delta} - \frac{g}{p^2\delta^2}\right) < 0,$$

then $\frac{dK}{d\delta} > 0$, which means that increase of δ will also increase K.

The intuition is that when the pollution effect is larger than the direct extraction effect, but not large enough to dominate the growth of resource K, having more firms (thus more labor) working in the resource sector will actually preserve the resource stock. This is because the pollution generated by the labor will reduce more resource stock than the direct extraction by the same amount of labor.

If $\beta'(L_T - L_A - p^2 K\delta^2) < \frac{1}{2p\delta}$, then the numerator becomes

$$2p^2 K\delta\beta'(L_T - L_A - p^2 K\delta^2) - pK = 2p^2 K\delta\left(\beta'(L_T - L_A - p^2 K\delta^2) - \frac{1}{2p\delta}\right) < 0$$

and the denominator becomes

$$p^2\delta^2\beta'(L_T - L_A - p^2 K\delta^2) - p\delta - g = p^2\delta^2\left(\beta'(L_T - L_A - p^2 K\delta^2) - \frac{1}{p\delta} - \frac{g}{p^2\delta^2}\right) < 0,$$

then $\frac{dK}{d\delta} < 0$, which means that increase of δ will reduce K.

This can happen when the pollution effect is not significant compared with direct extraction effect. Thus, with more firms (labor) working in the resource sector, more resource stock will be extracted and the total stock level will fall.

If $\beta'(L_T - L_A - p^2 K\delta^2) > \frac{1}{p\delta} + \frac{g}{p^2\delta^2}$, then both the numerator and denominator will become positive and $\frac{dK}{d\delta} < 0$. The intuition is that both the pollution effect and extraction effect will become so large that they even dominate the growth of resource K. Thus, no matter how the labor is allocated across these two sectors, the resource stock level will always be worse when production in either sector happens. In the end, this can deplete all the natural resources and equation (8) will not hold as a steady state condition any more.

IV. AN OVERVIEW OF THE DYNAMIC MONITORING SYSTEM

In the dynamic design, firms will be assigned long-term property right resources. Thus, in the first stage, when they maximize their profits, they will consider the shadow value of the resource stock. In the second stage, the government will maximize the total income based on the decisions made by firms in the first stage.

In the first stage of the dynamic design, for each extractor in the H sector, the firm tries to solve

$$MAX_{L_i}\pi = \int_{-\infty}^{+\infty}\left[pK^{1/2}\frac{(\sum_n L_j)^{1/2}L_i}{\sum_n L_j} - wL_i \right] e^{-\lambda t}dt = \int_{-\infty}^{+\infty}\left[pK^{1/2}\frac{(\sum_n L_j)^{1/2}L_i}{\sum_n L_j} - L_i \right] e^{-\lambda t}dt$$

$$s.t.\dot{K} = g(\overline{K}-K) - \beta(L_T - L_A - \sum_n L_j) - pK^{1/2}(\sum_n L_j)^{1/2}.where.\beta'(\cdot) > 0, \beta''(\cdot) > 0$$

The current-value Hamiltonian can be written as

$$\xi = pK^{1/2}\frac{(\sum_n L_j)^{1/2}L_i}{\sum_n L_j} - L_i + \lambda\left(g(\overline{K}-K) - \beta(L_T - L_A - \sum_n L_j) - pK^{1/2}(\sum_n L_j)^{1/2} \right)$$

$F.O.C.$

$$\frac{d\xi}{dL_i} = pK^{1/2}(\sum_n L_j)^{-1/2}\left(1 - \frac{1}{2n} - \frac{n\lambda}{2}\right) - 1 + n\lambda\beta'\left(L_T - L_A - \sum_n L_j \right)$$

$$= pK^{1/2}(L_H)^{-1/2}\left(1 - \frac{1}{2n} - \frac{n\lambda}{2}\right) - 1 + n\lambda\beta'(L_T - L_A - L_H)$$

$$= pK^{1/2}(L_H)^{-1/2}\left(\delta - \frac{\lambda}{4(1-\delta)}\right) - 1 + \frac{\lambda}{2(1-\delta)}\beta'(L_T - L_A - L_H) = 0 \qquad (7)'$$

$$\dot{K} = \frac{\partial\xi}{\partial\lambda} = g(\overline{K}-K) - \beta(L_T - L_A - \sum_n L_j) - pK^{1/2}(\sum_n L_j)^{1/2}$$

$$= g(\overline{K}-K) - \beta(L_T - L_A - L_H) - pK^{1/2}(L_H)^{1/2} = 0 \qquad (8)'$$

$$\dot{\lambda} = -\frac{\partial\xi}{\partial K} + r\lambda = \left(\frac{1}{2n} - \frac{\lambda}{2}\right)pK^{-1/2}{L_H}^{1/2} - \lambda g + r\lambda$$

$$= \left(1 - \delta - \frac{\lambda}{2}\right)pK^{-1/2}{L_H}^{1/2} + \lambda(r-g) = 0 \qquad (9)'$$

From $(7)'$, we can represent L_H as a function of δ, that is, $L_H(\delta)$. In the second stage, given the above conditions, the government wants to maximize total income by

$$Max_{\delta} I = pH + (L_T - L_H - L_A) = pK^{1/2} L_H(\delta)^{1/2} + [L_T - L_A - L_H(\delta)]$$

$F.O.C.$

$$\frac{dI}{d\delta} = pK^{1/2} \frac{1}{2} L_H(\delta)^{-1/2} L_H{}'(\delta) - L_H{}'(\delta) = 0 \quad (10)$$

$\left(K', L_H{}', \delta', \lambda'\right)$ satisfying conditions $(7)', (8)', (9)', (10)$ will be the solutions for dynamic design.

1. A short analysis of marginal effect of L_H :

From $(7)'$, we know that there are two contradictory effects associated with the change of labor used in the resource sector L_H :

(1) Current marginal income effect of L_H : $pK^{1/2}(L_H)^{-1/2}\delta - 1$. For every unit of labor, the profit of the firm in the resource sector will change by $pK^{1/2}(L_H)^{-1/2}\delta - 1$, where $pK^{1/2}(L_H)^{-1/2}\delta$ is the change of product value in the resource sector and 1 is the labor cost. Correspondently the current income will also change by this amount.

(2) Marginal effect on resource capital K : the increase of L_H will have two simultaneous effects on K. One is the harvesting: $-\frac{\lambda}{4(1-\delta)} pK^{1/2}(L_H)^{-1/2}$. The increase of L_H will lead to more extraction of resource K, thus reducing its shadow value. The other is the pollution: $\frac{\lambda}{2(1-\delta)} \beta'(L_T - L_A - L_H)$. With the increase of L_H, more labor will move from the pollution industry to the resource industry, reducing pollution and preserving resources K. This in turn will raise the shadow value of resource. Overall, the marginal effect on resource K is $\frac{\lambda}{2(1-\delta)}\left[\beta'(L_T - L_A - L_H) - \frac{1}{2} pK^{1/2}(L_H)^{-1/2}\right]$

At the optimal steady state,

$pK^{1/2}(L_H)^{-1/2}\delta - 1 + \frac{\lambda}{2(1-\delta)}\left[\beta'(L_T - L_A - L_H) - \frac{1}{2}pK^{1/2}(L_H)^{-1/2}\right] = 0$. That is, the two effects will match up with each other.

2. Conditions for different optimal δ:

Depending on different conditions, the optimal property right can be $0 \le \delta < \frac{1}{2}, \delta = \frac{1}{2}, \frac{1}{2} < \delta \le 1$. These can be derived from (10).

From (10), we know that

$$\frac{dI}{d\delta} = pK^{1/2}\frac{1}{2}L_H(\delta)^{-1/2}L_H{}'(\delta) - L_H{}'(\delta) = L_H{}'(\delta)\left[\frac{1}{2}pK^{1/2}L_H(\delta)^{-1/2} - 1\right]$$

If at $\delta = \frac{1}{2}$, $L_H{}'(\delta)\left[\frac{1}{2}pK^{1/2}L_H(\delta)^{-1/2} - 1\right] = 0$, the optimal δ will be $\frac{1}{2}$.

If at $\delta = \frac{1}{2}$, $L_H{}'(\delta)\left[\frac{1}{2}pK^{1/2}L_H(\delta)^{-1/2} - 1\right] > 0$, the optimal δ will be greater than $\frac{1}{2}$.

If at $\delta = \frac{1}{2}$, $L_H{}'(\delta)\left[\frac{1}{2}pK^{1/2}L_H(\delta)^{-1/2} - 1\right] < 0$, the optimal δ will be less than $\frac{1}{2}$.

3. A short comparison of the static and dynamic designs:

In the static design, the production of firms in the resource sector is myopic, which will leads to over-exploitation, but the government considers the overall shadow value of the resource in the second stage, which will properly protect the resource.

On the contrary, in the dynamic design, the production of firms in the resource sector will take into account the shadow value of the resource stock, but each firm will only consider her own share of the long-term resource stock. The overall social value of resources is still not fully internalized when the optimal number of firms is bigger than 1.

Thus, which design is more efficient remains ambiguous. We need now to discuss the conditions to determine which one is better.

V. OPTIMAL CONTROL OF PROPERTY RIGHT WHEN $0 \le \delta \le 1/2$

When the optimal property right is perfect or below perfect, the optimal number of firms in the resource sector is 1. In this case, it is more efficient to apply the dynamic monitoring system. When the monitoring agency assigns the long-term instead of the short-term property right to the unique firm in the resource sector, this firm will consider the shadow value of the resource stock when she makes production decisions. Since the firm is unique in the resource sector, she will consider all the shadow value of the resource. Furthermore, when the unique firm maximizes her profit, the total income is also maximized, because the total income is the sum of the profit of the unique firm and the wage income of the total labor. The correspondent first order conditions will be exactly the same as $(7)', (8)', (9)', (10)$ except that we know $\delta' = 1/2$.

VI. OPTIMAL CONTROL OF PROPERTY RIGHT WHEN $1/2 < \delta \le 1$

1. The optimal number of firms in the resource sector is an integer.

We will first discuss the condition when the optimal number of firms in the resource sector is an integer. In this case, we can safely assume the labor used in the monitoring agency L_A is zero. Because as long as the monitoring agency does not have to monitor the labor L_H directly, it can be costless to control the number of firms by means of issuing licenses, etc.

After we derive the solutions, $(K, L_H, \delta, \lambda)$ for the static system and $(K', L_H', \delta', \lambda')$ for the dynamic system, three criteria should be applied before we decide which monitoring system to be used:

(1)A higher total Hamiltonian value should be generated by the monitoring system. That is, if $I\left(K', L_H{}', \delta', \lambda'\right) \geq I(K, L_H, \delta, \lambda)$, then the dynamic monitoring system is better, and vice versa.

(2)More shadow value of the resource stock should be preserved at the steady state. That is, if $\lambda' K' \geq \lambda K$, then the dynamic monitoring system should be chosen, and vice versa.

(3)Incentive constraint of the firms in the resource sector: the monitoring system should generate more profit for the firms in the resource sector. That is, if $\pi\left(K', L_H{}', \delta', \lambda'\right) \geq \pi(K, L_H, \delta, \lambda)$, then the dynamic monitoring system should be preferred, and vice versa.

Note, however, the above three criteria may not be satisfied at the same time for a certain monitoring system. In this case, which monitoring system should be used will depend on which criterion is the most important. If the policy objective is to generate the maximum total income, then criterion (1) should be applied; if the policy objective is to protect the resource stock, then criterion (2) should be adopted; if the policy objective is to guarantee the most profit for the firms in the resource sector, then criterion (3) should be used.

2. The optimal number of firms in the resource sector is not an integer.

When the optimal number of firms in the resource sector is not an integer, then the solutions $(K', L_H{}', \delta', \lambda')$ or $(K, L_H, \delta, \lambda)$ can not be directly applied because it is difficult to allow in only a half or quarter of the firm. In this case, we need to use the monitoring agency to control both the number of firms and the labor used (L_H) to approximate the optimal solutions.

First, we should allow in m number of firms in the resource sector, where m should be the smallest integer no less than the optimal n .

Second, the monitoring system should be used to guarantee the achievement of the optimal labor used in the resource sector. Since now the number of firms in the resource sector is larger than optimal, more labor than optimal will be used in the resource sector if no monitoring is enforced. However, to monitor the labor used in the resource sector, extra labor should be employed in the monitoring agency, thus L_A is not zero any more.

For generic purpose, we can assume the monitoring system follows a pattern, which can be represented by a function

$$L_H^A = L_H^A\left(L_H^B, L_A\right) \tag{11}$$

where L_H^A represents the labor used in the resource sector after monitoring, L_H^B represents the labor used in the resource sector before monitoring, L_A represents the labor used in the monitoring sector. Note that L_H^B is equal to mL_i, where L_i should satisfy (6) in static design or $(7)'$ in dynamic design. Thus, L_H^B should be treated as a known factor in the whole system.

Now, $\left(K, L_H^A, \delta, \lambda, L_A\right)$ satisfying conditions (6),(7),(8),(9),(11) will be the solutions for the static design, and $\left(K', L_H^{A'}, \delta', \lambda', L_A{}'\right)$ satisfying conditions $(7)', (8)', (9)', (10)$,(11) will be the solutions for the dynamic design.

Similarly, when we decide which monitoring system should be used, three criteria should be applied:

(1) A higher total Hamiltonian value should be generated by the monitoring system. That is, if $I\left(K', L_H^{A'}, \delta', \lambda', L_A{}'\right) \geq I\left(K, L_H^A, \delta, \lambda, L_A\right)$, then the dynamic monitoring system is better, and vice versa.

(2) Shadow value of the resource stock should be preserved in a more cost effective way at the optimal state. That is, if $\lambda' K' - wL_A{}' \geq \lambda K - wL_A$, then the dynamic monitoring system should be preferred, and vice versa.

(3)Incentive constraint of the firms in the resource sector: the monitoring system should generate more profit for the firms in the resource sector. That is, if $\pi\left(K', L_H^{A'}, \delta', \lambda', L_A{}'\right) \geq \pi\left(K, L_H^A, \delta, \lambda, L_A\right)$, then the dynamic monitoring system should be chosen, and vice versa.

Again, when not all criteria can be satisfied at the same time, which criterion will be used depends on the policy objective.

VII. EMPIRICAL APPLICATIONS OF TWO EXTERNALITY THEORETICAL MODEL

Some of the best examples of two sector economies with a polluting sector that impacts a common-property resource sector are small island economies. Although there may be other production sectors, there are typically large agricultural and large fishery sectors that may account for a large share of the gross domestic product. On small islands, particularly mountainous ones, agriculture is limited to areas near the coast or on relatively steep hillsides. The result is that there is a close connection between agricultural runoff and water quality. Many of the fisheries for these economies are artisanal, and thus near shore where the water quality is most impaired. Islands in tropical or sub-tropical climates often have fringing coral reefs that serve as habitat for fish, and are particularly sensitive to declining water quality. For my analysis I will test the theoretical model in two settings. The first application is to the relatively homogenous Pacific Island economies, and the second is to the more diverse worldwide coral reef fisheries. The approaches will vary in the two settings due to the availability of data.

1. The Pacific Island Economies: Coastal Fishing Industry

The Pacific Island Economies include American Samoa, Cook Islands, Com. Northern Mariana Islands, Fiji Islands, Federated States of Micronesia, French Polynesia, Guam, Kiribati, Marshall Islands, New Caledonia, Nauru, Niue, Papua New Guinea, Palau, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis & Futuna. The map of them can be viewed in Figure 1.

A common characteristic of these island economies is that agriculture and fishing are dominant sectors in their economies. For example, agriculture, forestry and fishing activities accounted for over 17% of GDP in 2000 for American Samoa. Its tuna canning industry (manufacturing, but fishing-related) supplied 70% of the USA market for canned tuna and employed 5000 people, around 8% of its total population. For Palau, fishing activities alone account for over 25% of its total GDP. Actually, agriculture and fishing in combination account for over 20% of GDP in many Pacific island economies.

Another common characteristic in this area is that almost all the rural labor is “informal”. They change their jobs frequently and quickly. This indicates that the transaction cost is rather low in the labor market. This conforms to the market situation in our model.

A third common characteristic is that the coastal areas of these islands contain a large proportion of the world’s coral reefs. Corals are tiny plant-like animals that depend on clean, clear waters and sunlight to survive. The reef is the elaborate structure which is made from the coral skeleton gradually built up for thousands of years. According to the United Nations Environment Program, coral reefs are important indicators of the health of regional sea areas, integrating the cumulative impacts of different regional pressures, and recording the consequences of land-based sources of pollution. As a fragile ecosystem, these coral reefs can be endangered by over-fishing, on-land pollution and natural hazards. As “rain forests of the sea”, the reef structure is home to many coastal inhabitants, including many commercial reef fishes. As the health of coral reef declines, fish stock falls correspondently.

The above three outstanding characteristics make it reasonable to test our theoretical model on those economies. Fishery production, especially coral reef fishery, is generally open access, and fish stocks are affected by both fishing activity and pollution from farming on land. Therefore, two externalities co-exist: imperfect property right and production pollution distortion. As noted by Mark D. et. al (2001), “Overfishing has become so widespread that there are few, if any, reefs in the world which are not threatened. ……Often remote from reefs, deforestation, urban development and intensive agriculture are now producing vast quantities of sediments and pollutants which are pouring into the sea and rapidly degrading coral reefs in close proximity to many shores.”

For those two externalities, imperfect property rights can be represented by the number of fishers in the fishing industry. Production pollution distortion can be represented by the number of farmers, assuming a constant return to scale technology adopted in agriculture.

The linkage of these two externalities can be revealed by the labor market equilibrium. When a fisherman carries out production, his/her activity will directly reduce the fish stock. If he/she takes a job as a farmer, then his/her economic activity generally will contribute to pollution on land, which will then negatively affect the fish stock indirectly. Thus, estimating the effect on fishery production and fish stock from the labor market will provide an empirical analysis of our theoretical model.

2. Empirical Model

We start our empirical analysis by estimating the revenue function of an individual fisher. Revenue functions were estimated in a nonhomothetic generalized Leontief functional form by Kirkley and Strand (1988) and Squires and Kirkley (1996). We decide to estimate the revenue function in a quadratic functional form because it has the advantage of providing a second-order approximation to any functional form. Thus, we represent the individual revenue function, R_j, as

$$R_j = b_0 + b_1 w + b_2 K_j + b_3 p \;\; + 1/2 b_{11} w^2 + 1/2 b_{22} K_j^{\;2} + 1/2 b_{33} p^2 + b_{12} w K_j + b_{13} wp \;\; + b_{23} K_j p \quad .(12)$$

where R_j is the net revenue of fishers in the jth island economy,

w is the wage rate for a fisher in the jth island economy,

K_j is the fish stock size in the jth island economy for a given year,

p is the price of fish in a given year,

From (12), using Hotelling's lemma, we can derive the correspondent input demand and output supply equations as

$$Q^j = A_{10} + A_{11} w + A_{12} K_j + A_{13} p \qquad (13)$$

$$x^j = A_{20} + A_{21} w + A_{22} K_j + A_{23} p \qquad (14)$$

where Q^j is the total catch of fish by fishers in the jth island economy. In Pacific Island economies, it could be sea cucumber or parrotfish or the sum of them. The reason why those two fishes are chosen is explained in the following data section.

x^j is the total number of fishers in the jth island economy.

And the relationship between these coefficients should be

$$A_{10} = b_3, A_{11} = b_{13}, A_{12} = b_{23}, A_{13} = b_{33}, A_{20} = b_1, A_{21} = b_{11}, A_{22} = b_{12}, A_{23} = b_{13}.$$

We also add a linear equation to address the evolvement of fish stock.

$$K_j = A_{30} + A_{31} x^j + A_{32} y^j + A_{33} K_{j-1} \qquad (15)$$

where y^j is the total number of farmers in the jth island economy,

K_{j-1} is the lagged fish stock size in the jth island economy by one year.

The equations (13), (14) and (15) form a system and can be estimated by a maximum likelihood procedure.

3. The Data

All the data come from the Food and Agriculture Organization (FAO) of the United Nations, the Pacific Regional Information System (PRISM) of Secretariat of Pacific Community (SPC), "World Atlas of Coral Reefs" and the Reef Check program at Institute of the Environment in University of California at Los Angeles (UCLA). The FAO datasets include annual catch data of different kinds of coastal fishes in those Pacific island economies. The PRISM of SPC provides information on national income and labor indicators (wage rate, employment number, etc.) in those Pacific island economies. The book "World Atlas of Coral Reefs" provides the basic general information on the coral reefs in this region. The Reef Check program data include the reef survey data in some of these Pacific Island economies: Fiji, Guam, New Caledonia, Palau, Federated States Of Micronesia, Papua New Guinea, French Polynesia, Com. Northern Mariana Islands and American Samoa.

The annual fish catch data from FAO include the commercial fish catch in the world from 1970-2000. From those, we find the sea cucumber data from Fiji Islands, Kiribati, New Caledonia, Palau, Papua New Guinea, Solomon Islands, Tonga and Vanuatu. We also find the parrotfish harvesting data from American Samoa, Guam, Northern Mariana Island and Palau. These fish catch data will be used in our empirical analysis to determine the dual effects of stock and pollution externalities. The reason for us to choose these two fishes is that sea cucumber and parrotfish are so called "indo-pacific indicators" and they are included in the reef check survey.

The fish stock data can be derived from the "World Atlas of Coral Reefs" and the reef check survey carried by Reef Check, Institute of the Environment, UCLA. The summary statistics of the coral reefs data in the Pacific Island Economies are listed in Table 1.

The reef check survey was done over 1100 reefs in 31 countries and territories by Reef Check, Institute of the Environment, UCLA during 1997-2001. For those Pacific island economies involved in the Reef

Check program (Fiji, Guam, New Caledonia, Palau, Federated States Of Micronesia, Papua New Guinea, French Polynesia, Com. Northern Mariana Islands and American Samoa), not all of them are surveyed every year during 1997-2001. The summary of numbers of sites involved in those Pacific island economies are listed in Table 3. Based on the reef stock survey data, combined with the FAO annual catch data, we will have an incomplete panel data set for those Pacific Island economies involved from 1997-2001.

In the survey, a set of biological indicators was chosen to serve individually as indicators of specific types of anthropogenic impacts and collectively as a proxy for ecosystem health. The organisms were chosen both for ecological and economic value and together were meant to provide an ecoholistic representation of key coral reef fish, invertebrates and plants. (Hodgson, G and J. Liebeler 2002). To match the fish catch data obtained from FAO, we only choose sea cucumber and parrotfish as estimation of the stock from a list of indicators. The summary statistics of these two fish stocks are listed in Table 2.

According to G. Hodgson (1999), the protocol used in the reef check survey included collection of four types of data: a site description; a fish survey, an invertebrate survey and a substrate survey.

The site description included 37 questions about the biophysical aspects of each reef, as well as socioeconomic descriptors of human activities in the area, and space for anecdotal and historical background information. The reef sampling design was based on surveys of two depth contours, 3 and 10m. At each depth, one or more survey lines (transects) were placed among the reef contour to obtain a total length of 100m.

The fish survey was carried out first. Fish indicator taxa were recorded along four 20m long, 5 m wide belt transects (separated by 5 m gaps) for a survey area of 400m^2 at each depth (3 and 10m). After the transects were deployed, the fish survey was delayed for 15 min to allow the fish to recover from any disturbance by divers. Fish were recorded within the belt transect for a period of 3 min at 5 m intervals. In some locations, coral reef was only found at one of the two depths—so only one contour was surveyed.

The same belt transect was then used for the invertebrate survey. Following the invertebrate survey, the four 20m long segments were point-sampled at 0.5m intervals and substrate type was recorded using a list of 10 possible choices: live hard coral, dead coral, soft coral, fleshy seaweed, sponge, rock, rubble, sand, silt/clay and other. The definition for dead coral was targeted at coral killed within the past one year while the definition for fleshy seaweed excluded coralline algae. (G. Hoggson 1999).

Because the number of fishes is observed in a total area of $400m^2$ or $800m^2$ in the survey, we can approximate the total fish stock in a country by multiplying the total coral reef area and the amount of fish observed in the survey. These estimated values are also listed in Table 2. We need to mention that these estimated total stock values are tentative and subject to adjustment. The reason is that Reef Check survey were intentionally biased towards reefs in relatively good condition (G. Hodgson 1999), our result may overestimate the fish stock in a country. Another reason is that, the available reef check data provide valuable information when interpreted on regional and global scales and over multi-year periods, but are insufficient to provide a reliable indication of reef health on an individual country or reef scale for any given year because of the sample sizes. (G. Hodgson and J. Liebeler 2002). To overcome this problem, we will make adjustment according to the different factors influencing coral reef ecosystem: populatioin, land area, GDP, water temperature, shading, current flow, oxygen depletion and weather. Among those variables, the water temperature is very important, especially prolonged temperature exposure is the key component in causing reef bleach. It can directly affect the dissolved oxygen (DO) in the water and biological oxygen demand (BOD), as well as the survival of some aquatic species. The time series data on sea surface temperature from the satellite can be obtained from National Oceanographic Data Center/American National Oceanic and Atmospheric Administration (NODC/NOAA). A standard product is WOCE(World Ocean Circulation Experiment) Global Data, Version 2, July 2000 (CD-ROM). We hope this product will give us sea surface temperature needed.

The labor market data and price data can be obtained from the statistics yearbook or annual economic review or fact book of those island economies. For example, we can collect 1996-2001statistical yearbook of Com. Northern Mariana Islands. In its statistical yearbook, we can have sessions such as employment, price, agriculture and fishing. These sessions will provide us such variables as number of farmers, number of fishers, and prices on different fish species. As to the wage data, it can be retrieved from the stipulation of minimum wage rate. This can help us to get a flavor of the comparative labor cost across the whole region on average, although it might not be exactly the real wage the workers receive in the region.

4. Proposed Policy Implication

Although these Pacific islands vary in population, size, natural resources and policies, they face a common constraint: the fragile environment, especially the vulnerable coral reef ecosystem. These coral reef ecosystem can be endangered by over-fishing, on-land pollution and natural hazards. Thus, the proper protection of coral reef ecosystem requires an integrated management of fishing, agricultural production and other civil development. Our empirical analysis will generate some concrete advice towards this direction.

5. The Commercial Reef Fisheries In the World

As "rain forests of the sea", coral reefs provide humans with living resources and services worth many billions a year, a staggering amount for an ecosystem covering less than one percent of the Earth's surface. (NOAA Magazine Online 2003)

Yet, the world's coral reefs are in crisis. This is particularly true since most coral reefs occur in shallow water near shore where human impacts are the greatest. According to NOAA, the following threats are particularly severe:

Pollution from poor land use, chemical loading, marine debris, and invasive alien species;

Over-fishing and related harm to habitats by fishing gear and marine debris;

Destructive fishing practices (such as cyanide and dynamite fishing) that destroy large sections of reef and kill many species not yet harvested;

Dredging and shoreline modification in connection with coastal navigation or development;

Vessel groundings and anchoring that directly destroy corals and reef framework;

Disease outbreaks that are increasingly prevalent in reef ecosystems;

Global climate change and associated impacts such as coral bleaching, more frequent storms and rise in sea level.

In the above list, the first two most severe threats are related with production pollution and imperfect fishing property rights, which are the major focus of our theoretical model.

Starting from 1997, the reef check survey is done over 1100 reefs in 31 countries and territories. These countries and territories are: American Samoa, Australia, Bahamas, Bahrain, Barbados, Belize, Bonaire, Brunei, BVI, Cambodia, China, China-Hong Kong, China-Taiwan, CNMI, Colombia, Cuba, Egypt, Eritrea, Fiji, French Polynesia, FSM, Grand Cayman Island, Honduras, India, Indonesia, Iran, Israel, Jamaica, Japan, Madagascar, Malaysia, Maldives, Mauritius, Mexico, Mozambique, Myanmar, Netherlands Antilles, New Caledonia, Palau, Panama, Philippines, PNG, Saudi Arabia, Seychelles, South Africa, St. Lucia, Tanzania, Thailand, USA-Florida, USA-Hawaii, USA-Guam, Vietnam and Yemen. Most of these countries and territories are either developing economies or island economies. Thus most of them share the similar characteristics with the Pacific Island Economies.

For this reason, we think it also reasonable to extend our empirical analysis on coral fishing industry in these economies.

6. Empirical Model

We will apply the similar empirical model as in Pacific Island Economies.

It is important to notice that these 31 countries and territories belong to different regions. Thus regional differences between Atlantic, Pacific and Red Sea must be taken into account. It is possible that we will pick one fish specie at one region and another fish specie at the other region from the survey. The possible fishes for us to choose are so-called "Global Indicators" in the Reef Check survey. They include Banded coral shrimp (Stenopus hispidus), Butterfly fish (Chaetodon spp.), Crown of thorns starfish (Acanthaster planci), Fleshy algae, Grouper (>30cm) (Serranidae), Hard coral, Lobster, Long-spined black sea urchins (Diadema spp.), Moray eel (Muraenidae), Parrotfish (>20cm) (Scaridae), Pencil urchin, Recently killed coral, Snapper (Lutjanidae), Sponge, Sweetlips (Haemulidae), Triton (Charonia spp.). (G. Hodgson and J. Liebeler 2002)

It is also possible that we would pick another commercial fish as harvesting specie and use the survey data as a composite index for reef health and fish stock. These possibilities exist when we do the empirical analysis for the whole coral fishing industry of the world in the future research.

7. The Data

The two major data source will come from the annual commercial fish catch data of FAO and the reef check survey by the Reef Check program at Institute of the Environment in University of California at Los Angeles (UCLA). A short summary statistics on the number of sites involved in countries and years in the coral reef survey is listed in Table 3. A summary of the general reef characteristics in these countries and territories is listed in Table 4.

According to 2001 World Atlas of Coral Reefs, the global coral reef area is 284,300 km2, spread among 101 countries. While this is only 0.09 percent of the total area of the world's oceans, the reefs are widely dispersed, presenting a challenge to any monitoring design. To gain an appreciation of the magnitude of the problem, one only has to look at the Bahamas, with 700 islands, the Philippines with 7,000 or Indonesia with 30,000-most ringed with coral reefs. The costs and number of trained personnel necessary to monitor even one transect line on one reef of each island in these countries would be astronomical. Thus, it would be desirable to take a random sample from representative reef areas. However, to obtain sufficient data on a given reef say 1km long, three to five complete Reef Check surveys would be required on a quarterly basis (i.e. 12 to 20 per year). For rare organisms such as humphead wrasse, additional surveys would be needed. Should this level of detail be required on a national level, the task would be impossible – several million individual surveys. Thus far, the sample sizes available from most Reef Check countries are insufficient to provide a reliable indication of reef health on an individual country or reef scale for any given year. The available results provide valuable information when interpreted on regional and global scales and over multi-year periods (G. Hodgson and J. Liebeler 2002). Thus, we need to overcome this problem in our future research. A possible option would be to make adjustment by each individual country's geographic, climatic and tidal conditions.

8. Proposed Policy Implication

Similar to the policy advice given in the Pacific Island Economies, the policy suggestions on how to protect the coral reefs will be proposed. Since this analysis is across several regions, the regional comparison would also be included in policy suggestions.

VIII. CONCLUSION

This prospectus addresses the issue of optimal property rights of resources in the existence of environmental property right and production pollution distortions, which constructs a two-stage monitoring system enforced by the government and firms in the resource sector: in the first stage, firms maximize their profits given the number of firms in the resource sector by choosing labor hired in the firm; in the second stage, given the decision made by firms, government maximizes the total welfare by choosing the number of firms. Using a specified production function as used in Zhao (2000), this prospectus studies and compares two different monitoring systems for a small open economy: the static monitoring system and the dynamic monitoring mechanism.

The non-linearity of the industrial pollution function indicates that the optimal property right condition in the resource sector may not be perfect. When the optimal property right is perfect or below perfect, the government should apply the dynamic monitoring system to achieve the most desirable result. When the optimal property right is above perfect, the government should compare these two different monitoring systems and choose the appropriate one based on different criteria and policy objectives.

The empirical analysis will be applied on reef fishing industry of Pacific Island Economies and in Reef Fisheries of the world.

Related policy advices on protection of coral reefs and integrated management of agriculture and fishery are expected to be proposed.

Table 1. The Summary Characteristics Of Coral Reef In Pacific Island Economies

Countries	Reef Area(km2)	Coral Diversity	Population(thousands)	GDP(million US$)
Papua New Guinea	13840	378/517	4927	4730
Solomon Islands	5750	101/398	466	224
New Caledonia	5980	151/359	202	2987
Vanuatu	4110	296/379	190	191
Fiji Islands	10020	177/398	832	1602
Com. Northern Mariana Islands	<50	na/na	72	664
Guam	220	140/220	155	3066
Palau	1150	154/384	19	92
Kiribati	2940	110/365	92	43
Nauru	<50	na/na	12	267
Tuvalu	710	na/364	11	14
Wallis and Futuna	940	na/363	15	na
Tokelau	<50	na/210	2	na
Samoa	490	na/211	179	90
American Samoa	220	150/212	65	na
Tonga	1500	na/218	102	149
Niue	170	na/189	2	na
Cook Islands	1120	51/172	20	75

Data Source: “World Atlas of Coral Reefs”, University of California Press, 2001

Table 2. The Summary Statistics Of Coral Reef Survey In Pacific Island Economies

Country	year	fish	survey mean	total stock estimation
Fiji	1999	Sea Cucumber	0.142857143	3578.571429
Fiji	2000	Sea Cucumber	2.888888889	72366.66667
Fiji	2001	Sea Cucumber	4.545454545	113863.6364
Fiji	2002	Sea Cucumber	6.714285714	168192.8571
Fiji	2003	Sea Cucumber	1	25050
New Caledonia	2001	Sea Cucumber	7.166666667	107141.6667
Palau	2000	Sea Cucumber	3.5	10062.5
Palau	2001	Sea Cucumber	0.75	2156.25
Palau	2002	Sea Cucumber	0	0
Guam	1999	Sea Cucumber	6	3300
Guam	2001	Sea Cucumber	3.833333333	2108.333333
CNMI	1999	Sea Cucumber	26	3250
CNMI	2000	Sea Cucumber	20.5	2562.5
CNMI	2001	Sea Cucumber	20.5	2562.5
FSM	2000	Sea Cucumber	1.4	15190
FSM	2001	Sea Cucumber	0.538461538	5842.307692
FSM	2002	Sea Cucumber	2.611111111	28330.55556
French Po	1999	Sea Cucumber	3.25	48750
PNG	1999	Sea Cucumber	2.111111111	73044.44444
PNG	2000	Sea Cucumber	2.625	90825
PNG	2001	Sea Cucumber	9	311400
PNG	2002	Sea Cucumber	3.454545455	119527.2727
CNMI	2001	Parrotfish	16	2000
FSM	2001	Parrotfish	26.46153846	287107.6923
FSM	2002	Parrotfish	21.33333333	231466.6667
PNG	2001	Parrotfish	2	69200
PNG	2002	Parrotfish	2.636363636	91218.18182
Fiji	2000	Parrotfish	0	0
Fiji	2001	Parrotfish	10.27272727	257331.8182
Fiji	2002	Parrotfish	24.9047619	623864.2857
Fiji	2003	Parrotfish	25	626250
New Caledonia	2001	Parrotfish	5.4	80730
Palau	2000	Parrotfish	8	23000
Palau	2001	Parrotfish	21.75	62531.25
Palau	2002	Parrotfish	4	11500
Guam	2001	Parrotfish	2.833333333	1558.333333

Data Source: "The Global Coral Reef Analysis: Trends and Solutions 1997-2001", University of California Press, August 2002 and "World Atlas of Coral Reefs", University of California Press, 2001

Table 3 . The Summary Statistics of Number Of Sites Included In Coral Reef Survey

Country	1997	1998	1999	2000	2001	Total
American Samoa	1					1
Australia	14	7	9	1	10	41
Bahamas			2	1		3
Bahrain	1	5	4	4		14
Barbados	5				8	13
Belize	2				1	3
Bonaire	2	2		1	2	7
Brunei	1					1
BVI	3	1	3		4	11
Cambodia		1			1	2
China				5	17	22
China-Hong Kong	7	9				16
China-Taiwan	3	7				10
CNMI			2	3	1	6
Colombia	2	13	9	10	2	36
Cuba					2	2
Egypt	49			10	12	71
Eritrea				2		2
Fiji Island	6		6	8	8	28
French Polynesia			2			2
FSM				10	13	23
Grand Cayman Island	1	1				2
Honduras	1		2			3
India		1				1
Indonesia	25	1	18	38	85	167
Iran			1	2	2	5
Israel	1	3			2	6
Jamaica		1		2	3	6
Japan	2	5	8	16	21	52
Madagascar					3	3
Malaysia	39	31	7	28		105
Maldives	30				8	38
Mauritius			6	2	2	10
Mexico	8			4	1	13
Mozambique	1			1	2	4
Myanmar					5	5
Netherlands Antilles		4		4		8
New Caledonia	5	24			6	35
Palau	2			4	2	8
Panama	1	1				2
Philippines	3	11	6	5	9	34
PNG		4	14	5	1	24
Saudi Arabia			17			17
Seychelles	6				1	7
South Africa				1	5	6
St. Lucia			4	2	2	8
Tanzania	2	3	1			6
Thailand		2	10	7	55	74
USA-FL	31	19	6	1	12	69
USA-GUAM	1	3	3		4	11

USA-HI	1	5	2	1	7	16
Vietnam		8	10	11	16	45
Yemen		1			2	3
Total	256	173	152	189	337	1107

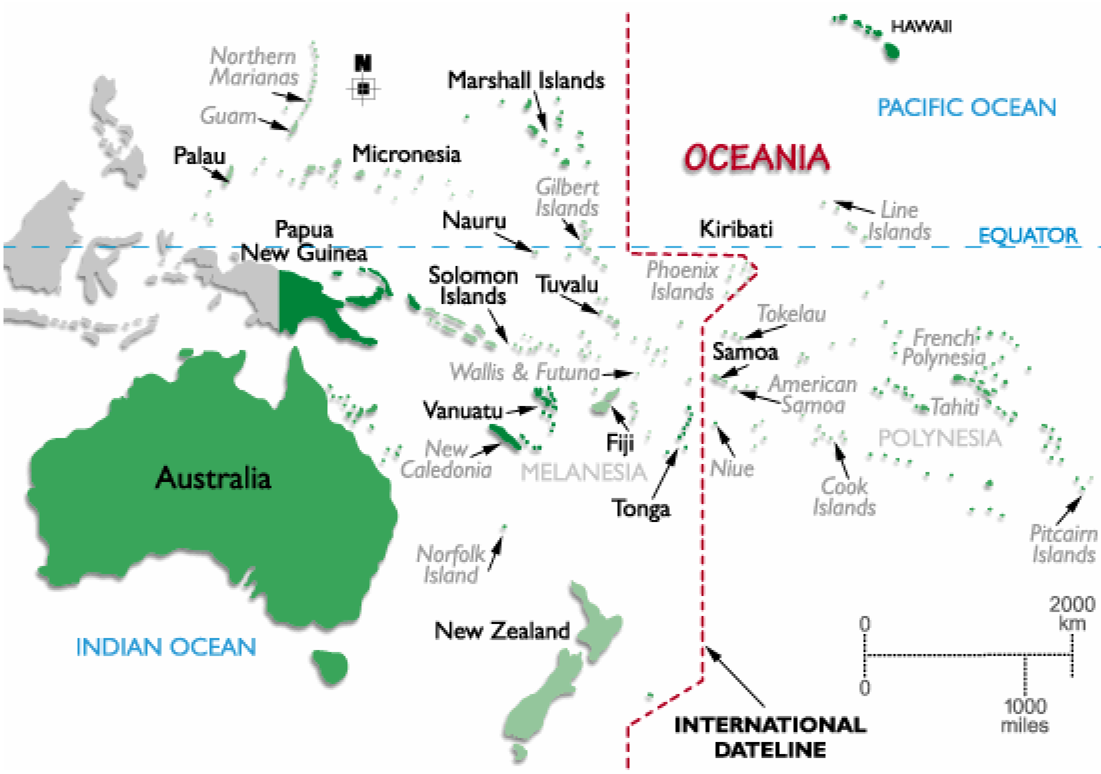
Data Source: "The Global Coral Reef Analysis: Trends and Solutions 1997-2001", University of California Press, August 2002

Table 4. The Summary Characteristics Of Economies In Coral Reef Survey

Country	Reef Area(km2)	Coral Diversity	Population(thousands)	GDP(million US$)
American Samoa	220	150/212	65	na
Australia	48960	428/461	19165	359913
Bahamas	3150	32/58	295	3712
Bahrain	570	na/68	634	5308
Barbados	<100	33/57	274	1768
Belize	1330	46/57	249	504
Brunei	210	na/na	336	4034
BVI	330	28/57	20	210
Cambodia	<50	na/337	12212	1187
China	1510	101/365	1261832	101885
China-Taiwan	940	255/444	22191	na
CNMI	<50	na/na	72	664
Colombia	940	49/77	39686	51800
Cuba	3020	29/57	11142	14694
Egypt	3800	126/318	68360	55680
Eritrea	3260	na/333	4136	1431
Fiji Island	10020	177/398	832	1602
French Polynesia	6000	174/168	249	3109
FSM	4340	92/391	133	223
Grand Cayman Island	230	35/57	35	612
Honduras	810	31/57	6250	3725
India	5790	208/345	1014004	418720
Indonesia	51020	443/581-602	224784	161324
Iran	700	na/68	65620	716326
Israel	<10	145/na	5842	79610
Jamaica	1240	36/57	2653	4383
Japan	2900	420/413	126550	3300625
Madagascar	2230	135/315	15506	3264
Malaysia	3600	281/568	21793	70402
Maldives	8920	212/244	301	215
Mauritius	870	161/294	1179	3544
Mexico	1780	78/81	100350	264715
Mozambique	1860	196/314	19105	2089
Myanmar	1870	77/277	41735	33665
Netherlands Antilles	420	40/57	210	1813
New Caledonia	5980	151/359	202	2987
Palau	1150	154/384	19	92
Panama	720	52/84	2808	7114
Philippines	25060	421/577	81160	52072
PNG	13840	378/517	4927	4730
Saudi Arabia	6660	187/314	22024	102677
Seychelles	1690	206/310	79	449
South Africa	<50	na/na	43421	114585
St. Lucia	160	na/57	156	478
Tanzania	3580	na/314	35306	na
Thailand	2130	238/428	61231	136773
USA-FL	1250	na/58	275563	6392711
USA-GUAM	220	140/220	155	3066
USA-HI	1180	na/49	2020	6392711
Vietnam	1270	278/364	78774	10487
Yemen	700	na/344	17479	15387

Data Source: "The Global Coral Reef Analysis: Trends and Solutions 1997-2001", University of California Press, August 2002

Figure 1. The Map of Pacific Island Economies



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