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Mixing economic and administrative instruments: the case of shrimp aquaculture in Thailand

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ABSTRACT. Economic instruments offer the potential to reach pre-determined environmental goals at a lower aggregate cost than less incentive-based measures, but administrative underpinnings crucial to the effective functioning of economic instruments may be lacking in developing countries. For this reason, pragmatic analysts and policymakers often advocate the use of so-called 'mixed' instruments that combine incentive mechanisms with improved administrative arrangements. This paper explores such possibilities with reference to intensive shrimp aquaculture, which dominates shrimp farming and is an important economic sector in Thailand. This activity has been cited as a major contributor to environmental degradation in Thailand and several other countries through destruction of mangrove forests, salinization of land, sludge disposal, and, in particular, water pollution. An analytical model is presented that highlights some of the key opportunities and limitations of mixed instruments applied to shrimp aquaculture. Mixed instruments are then proposed and evaluated.

1. Introduction

This paper focuses on the use of economic instruments for environmental management in the shrimp aquaculture sector in Thailand. Though less common than in high-income countries, economic instruments are used in

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developing and transition economies, and because of the potential to protect the environment at lower aggregate cost, their use is if anything increasing.[1] For example, pollution charges are widely used in China (Dasgupta *et al.*, 2001), Central and Eastern Europe, and the former Soviet Union (Bluffstone, 2003; Bluffstone and Larson, 1997), and in Malaysia (Vincent *et al.*, 1997). As Bluffstone (1999) and Dasgupta *et al.* (2001) point out, even low charge rates can have significant effects when few abatement measures have previously been undertaken. Due to the existence of very low-cost pollution abatement opportunities, economic instruments are indeed likely to be especially useful in developing countries.[2]

But economic instruments offer flexibility in countries that may have serious public administration problems. Environmental regulatory agencies are often poorly funded and staffed, leading to monitoring, enforcement, and administrative problems. Economic instruments can also impose additional public administration burdens. For example, when using pollution charges, extra monitoring and reporting requirements may be created. Institutions for assessing, accounting for and collecting charges are also needed, as well as more enforcement because charges may increase incentives for evasion. It is also unlikely, given information imperfections and political pressure from powerful polluters, that charges would be set at anything close to Pigouvian levels. The best we can hope for, therefore, is a cost-effective rather than an efficient allocation of abatement effort. Also, while social costs are lower with pollution charges, private sector costs are higher. Mechanisms are therefore typically needed for recycling charge revenues back to private sectors. Environmental funds are often used for this purpose, which creates its own set of challenges (Bluffstone, 2003; Anderson and Zylicz, 1999).

Putting these critical pieces in place is certainly much less than foolproof in most developing countries. For this reason, analysts often advocate the use of so-called 'mixed' instruments that introduce incentives that improve efficiency, but also contain safeguards to allow for implementation realities, even if such accommodations imply efficiency costs. Key features of such systems are simplicity, clarity, limited demands on regulators, and political feasibility.

As discussed in Sterner (2003) and illustrated in several examples, designing instruments always involves tradeoffs, but developing and transition country policymakers typically face many more constraints than their counterparts in richer countries. Substantial compromises therefore must be made to put feasible instruments in place. Bluffstone and Larson (1997), for example, make this point with regard to the design of pollution charge systems in Central and Eastern Europe. After reviewing the

[1] Environmental regulation using pollution control technology and emissions standards predominates worldwide. Often such methods are called 'command-and-control', which we consider too pejorative. Policy instruments come in many forms. For a state of the art discussion, please see Sterner (2003).

[2] Tradable emission rights, like those used to help control sulfur-dioxide emissions in the US, are much less common, probably because of their sophisticated administrative support requirements.

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experience of eleven countries, Seroa da Motta *et al.* (1999) conclude that, while substantial experimentation with economic instruments has occurred in Latin America and the Caribbean, institutional and administrative constraints must and are being accommodated when using such tools.

The point that environmental policy instruments must accommodate institutional and political contexts when the reverse is unlikely has also been made for pig farming in Mexico (Drucker and Latacz-Lohman, 2003), water trading (Bjornlund and McKay, 2002), and vehicle emissions in India (Pandey, 2004). Jurado and Southgate (1999) discuss the use of very rudimentary economic instruments for addressing air pollution problems in Quito, Ecuador as a way to accommodate regulatory and political difficulties. To reduce forest degradation due to fuelwood cutting in Nepal, Bluffstone (1998) even advocates the use of subsidies.

This paper seeks to add to the literature on the use of mixed instruments in developing countries through an examination of shrimp aquaculture in Thailand. We concur with much of the literature and argue that combining economic instruments with targeted administrative measures and creatively adapting them to on-the-ground realities can make policy systems workable and allow more to be accomplished with fewer resources. The following section provides an overview of the economic and environmental issues associated with shrimp aquaculture in Thailand and discusses the existing set of environmental policies. Section 3 presents an analytical model that highlights some of the key incentive issues and properties of candidate combinations of economic and administrative instruments. The model suggests that taking administrative realities into account through the creation of mixed instruments improves efficiency, but leaves systems short of first-best outcomes. Section 4 fleshes out the full set of mixed instruments and section 5 concludes.

2. Background

The cost effectiveness offered by economic instruments is especially important when a sector is an important source of output, employment, and foreign exchange. Shrimp aquaculture in Thailand certainly fits this description and has seen dramatic growth during the past 20 years. From around 15 thousand tons produced in the early 1980s, shrimp aquaculture output rose to over 160 thousand tons by 1991. By 1995, production reached 260 thousand tons, making Thailand the largest producer of farmed shrimp, with approximately 25 per cent of world output. Due to disease outbreaks and intensified competition, Thailand no longer is the top producer, but it remains the world export leader with one-third of the world market (foodmarketexchange.com).

Starting late in 2000 there was a downturn in demand from Japan and growing competition from Vietnam, China, and Brazil. As shown in table 1, these developments caused prices to fall 50 per cent during 1999–2003, which contributed to a substantial contraction of Thai shrimp aquaculture (www.Seafood.com; www.foodmarketexchange.com). Shrimp aquaculture in the developing world is a small-scale business. The Thai industry, for example, is characterized by a large number of small owner-operated farms developed from land converted from other uses. In 1995 there were

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Table 1. *Farmgate prices of black tiger shrimp*

Year	*Nominal price (baht/kg)**	*Exchange rate*	*Price per kilogram*
1991 average	153	25.1	$6.10
1995 average	226	24.7	$9.14
1999 average	385	37.1	$10.38
2002 average***	300	42.3	$7.00
2003 (16 January)**	280	42.8	$6.54
2003 (12 September)**	218	42.8	$5.09

Notes: 1991 to 1999 prices from AEA Technologies (2001).
*Based on 30 pieces/kg.
**www.FoodMarketExchange.com based on 40 count per kg.
***www.fishround.com. 31 July 2002; Fein (2002) based on 40 count per kg.

Table 2. *Original use of land converted to shrimp farming (per cent of total area) in 1996–1997*

Original land use	*Total*	*East*	*Inner Gulf*	*Andaman Coast*
Rice field	53.2%	45.8%	66.0%	41.2%
Mangrove forest	12.9%	33.3%	6.0%	3.9%
Rubber plantation	10.9%	0.0%	2.7%	33.3%
Fruit orchard	7.2%	7.3%	8.0%	5.9%
Idle land	8.9%	3.1%	14.0%	6.9%
Other	6.9%	10.5%	3.3%	8.8%

Source: Patmasiriwat (1997) based on 348 observations.

approximately 26,145 shrimp farms in Thailand occupying a total of 468,385 *rai*.[3] Approximately 80 per cent of farms are less than ten *rai* and over half of all shrimp farm owners have only basic levels of education (Midas Agronomics, 1995; Patmasiriwat *et al.*, 1998). According to the FAO, shrimp farming has helped many avoid serious poverty (PERASA, 2002).

Rice paddies have been a particular target for conversion to shrimp farms. Table 2 presents the pattern of land conversion during 1996–1997. Important regional variations exist, but rice fields are by far the most important former use. The profit from paddy cultivation has generally been less than 20 per cent of a well-run intensive shrimp operation (AEA Technology, 2001)[4] and publicly funded technical change is one reason for this superiority. Major improvements in hatchery production by the Thailand Department

[3] One *rai* equals approximately 0.16 hectares (0.4 acres). Statistics on total area and total numbers of farms should be treated as approximations. Only farms over 50 *rai* are required to register their operations.

[4] Patmasiriwat *et al.* (1998) quotes sources that suggest the break-even price for intensive shrimp aquaculture is approximately $4.00 per kilogram. Even current prices are well above this level.

of Fisheries resulted in lower prices of seed stock, and improvements in feed technologies allowed for dramatically increased yields. Before 1984, Thailand harvested 90 per cent of its shrimp from large tidal ponds established along the Gulf of Thailand. Most of the mangrove forest loss occurred during this period of 'extensive' shrimp farming (Barbier and Cox, 2004).

In the late 1980s the approach to shrimp production changed as the economic potential of large, highly prized, black tiger prawns (*Penaeus monodon*) became clear. Production systems became more intensive, with stocking rates of 40,000 larvae per *rai* versus 800–3,200 for extensive farms. Ponds also moved further inland, but remained in contact with salt water via canals. As of 2000, approximately 80 per cent of farms were intensive (KPMG, 2001). Intensive shrimp aquaculture is the most productive and profitable mode of shrimp farming, but it is also risky. Intensively stocked shrimp are fed high-quality fish meal and require paddle wheels and air jets to maintain dissolved oxygen at acceptable levels. Even with careful management, low oxygen and high ammonia concentrations are common.[5] Shrimp can and do coexist with bacteria and viruses, but stress from intensive stocking increases susceptibility to diseases. Without proper management, disease can over-run ponds, making them too contaminated for production (Patmasiriwat *et al.*, 1998).

While the 1990s market boom was good news for poor villagers, adverse environmental impacts of intensive systems also became apparent. Kasetsart University (1999) estimated total external environmental costs of shrimp aquaculture at about $5,000 per hectare per year, but if mangrove clearing was involved those costs jumped to $9,000.[6] High stocking densities produce toxic effluents that pollute coastal ecosystems, reducing fish catches and tourism. BOD, nitrates, phosphates, bacteria, antibiotics, and fungicides are regularly released into waterways (Thongrak *et al.*, 1997; Tookwinas, 1998; Dierberg and Kiattisimkul, 1996), but the majority of pollution problems occur when large quantities of highly concentrated effluents are discharged from ponds at the end of production cycles. Controlling those periodic releases (an average of 2.5 per year) is therefore the key to reducing pollution from shrimp aquaculture (Tookwinas, 1998; KPMG, 2001).[7] Each *rai* of pond area also produces about one-half ton of dry weight sludge per crop. The main problems associated with sludge are that it is often dumped into canals and on land. Throughout shrimp farming regions there are

[5] These conditions would kill many shrimp, but are less harmful to black tiger shrimp.

[6] Sathirathai and Barbier (2001) estimated the welfare loss from mangrove deforestation in Surat Thani Province at $27,264 to $35,921 per hectare (cited in Barbier and Cox, 2004). This is substantially higher than in Kasetsart (1999).

[7] In his study of Kung Krabaen Bay, Tookwinas (1998) finds that effluent quality during harvests can be extremely poor. He also finds, though, that despite discharges of approximately 135,000 tons of wastewater per hectare per year, 'during normal farming operations, the combination of high flushing and low nutrient loadings appeared unlikely to cause significant eutrophication of the Bay'.

sludge piles that contribute to salinization of land and groundwater (Boyd and Musig, 1992; Brigg and Funge-Smith, 1994).

Virtually all shrimp aquaculture systems in Thailand are open, meaning management of pond water quality involves regular exchanges with outside waterways. The spread of disease from one farm to another is therefore an ever-present risk, and epidemics have been a major problem. For example, in 1990 an epidemic wiped out 90 per cent of farms along the Inner Gulf of Thailand. Farmers abandoned their ponds and many migrated to the southern Gulf of Thailand and Andaman Sea coasts. However, disease soon reached those areas and in 1996 there was a sharp decline in production, causing farmers to move on. Farms using open systems typically survive two to five years.[8]

It is highly unlikely that shrimp farmers consider that their wastewater emissions increase the probability of disease for neighboring shrimp farmers when making production and water management decisions. Each farmer is a small contributor to the overall problem and reducing one farm's emissions would have a marginal impact. The problem to be overcome is therefore fundamentally one of open access of the type discussed by Gordon (1954) and Hardin (1968).

More closed systems in which infrequent or no exchange occurs with common water channels are a possible solution, but so far these are rare in Thailand. Under such systems, effluent is discharged only after having been recycled a number of times and sludge has been removed. The problem with closed systems is that water must periodically be moved to holding ponds so that waste settling can occur. This requires approximately double the land of open systems and substantially increases costs (Barbier and Cox, 2004). More sludge is also generated. There are therefore two distinct effluent-related goals: (1) to reduce effluent concentrations, particularly during harvests and (2) to reduce the spread of disease. The principal, though perhaps not only, technical means for achieving those goals, installation and management of reservoir and settling ponds, is well known. Indeed a government regulation adopted in 1998 mandates these steps for all shrimp farms. Small farmers need half as much settling pond area as feeding pond area. Large farmers face a one-to-one ratio. There is also a BOD effluent discharge standard of 10 mg/l, as well as a prohibition against dumping pond sludge in waterways and on public lands.

The problem, though, is that where regulations exist, there are huge gaps. For example, environmental permits are required only for farms larger than 50 *rai*, which means less than 5 per cent of farms need permits (Patmasiriwat, 1997). Most farmers therefore do not even report their activities. Monitoring and enforcement of even permitted farms is virtually non-existent and it is highly unlikely that illegal dumping of pond sludge would be penalized. There is also very little outreach, causing many farmers not to understand

[8] According to Patmasiriwat (1997), the most important factor increasing the probability of disease is whether farmers regularly exchanged pond water with surrounding waterways. Regular exchange was estimated to increase the probability of disease by 42 per cent. With proper restoration, it normally takes five to seven years before the land can again be used for agricultural purposes.

environmental regulations, and no real penalties for violating settling pond area and effluent discharge standards. It is therefore difficult to hold violators accountable. Many, though not all, of these problems are due to insufficient funding and local environmental agencies are extremely poorly staffed and equipped. Any mechanisms for internalizing externalities, therefore, must economize on monitoring and enforcement resources and ideally cover their own costs.

In sum, therefore, environmental protection of any kind in the Thai intensive shrimp aquaculture sector is minimal. Most farmers do nothing to reduce effluent emissions, but face no sanctions. At present, they pay nothing for freshwater to dilute seawater in shrimp ponds; disposal of wastewater, including the disease risks they impose on other farmers; disposal of sludge and remediation of abandoned shrimp ponds. In the following section a model of the shrimp sector in Thailand is presented, which highlights the incentives of shrimp farmers and the relationship between their choices and social welfare. A model of a self-interested operator is first considered and that model is contrasted with a model of socially optimal behavior. Finally, mixed instruments are introduced into the self-interested farmer model and it is shown how such additions improve performance, but fail to achieve the idealized first-best outcome.

3. A model of shrimp aquaculture

It is assumed in the model that shrimp farmers use intensive systems and maximize profits. Land is a pure private good. A total of '*k*' price-taking farmers (subscripted by '*i*') face a common exogenous output price (P) and choose their target output levels (q_i), which are realized at the end of the period, based on the amount of feeding pond (L_i) they invest in at the beginning of each period. Other inputs, such as feed, antibiotics, and electricity, are assumed to be proportional to L_i. Farmers use open production systems and draw on water from bays and other coastal waterways. This key production input is assumed to be a quasi-public good and not priced. Because farmers use common pool water, output is uncertain and farmers have only a probability (p_i) they will avoid disease and be able to harvest their crops. With probability $(1 - p_i)$, ponds are struck by disease and farmers receive no revenues. Under such a circumstance they incur only costs. Farmers can, however, choose the degree to which their production systems are closed by the amount of settling pond area (S_i) they have. More closed systems (increases in S_i) increase the probability of successful harvesting, but with diminishing returns. Significant externalities also exist. The probability of any agent '*i*' harvesting is decreasing in the output of all other farmers and increasing in the degree to which they use more closed systems relying on settling ponds (S_j), though again with diminishing returns. These assumptions are formalized in (1) and (1a).[9]

$$p_i = p_i(q_1 \ldots q_{k-1}, S_i, S_1 \ldots S_{k-1}) \tag{1}$$

[9] In the following equations, $p_i = p_i(q_1 ... q_{k-1}, S_i, S_1 ... S_{k-1})$, $c\,(L_i, S_i, D_i)$, $q_i(L_i)$, $E_i\,(q_i\,(L_i), S_i)$ and $S_{Li}\,(D_i, S_i, q_i\,(L_i))$ are general form functions. All other expressions of the form $X\,(Y, Z)$ indicate multiplicative relationships.

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$$\partial p_i/\partial S_i > 0; \partial p_i/\partial q_j < 0; \partial p_i/\partial S_j > 0; \partial^2 p_i/\partial^2 S_i < 0; \partial^2 p_i/\partial^2 S_j < 0 \quad (1a)$$

$$Max E(\pi) = p_i(q_1 \ldots .q_{k-1}, S_i, S_1 \ldots S_{k-1}) P q_i(L_i) - c(L_i, S_i, D_i) \quad (2)$$

$$\partial c_i/\partial L_i > 0; \partial c_i/\partial S_i > 0; \partial^2 c_i/\partial^2 S_i > 0; \partial c_i/\partial D_i > 0; \partial^2 c_i/\partial^2 D_i > 0 \quad (2a)$$

A farmer's maximization problem is given in (2) and restrictions on the cost function are presented in (2a). Total cost is increasing in production pond area (L_i) and (S_i). Marginal cost is increasing in S_i due to the need for better pumping equipment and land as aquaculture systems are closed. Total and marginal costs are also increasing in the portion of pond sludge farmers choose to dispose (D_i) of properly at the end of the production cycle rather than dump on land and in waterways at no cost. Possible ways to define 'proper' disposal are discussed in the next section. The cost function is also separable. Maximizing expected profits by choosing L_i, S_I, and D_i and rearranging yields the three first-order conditions in (3a), (3b), and (3c).

$$P p_i(q_1 \ldots . q_{k-1}, S_i, S_1 \ldots S_{k-1}) = \partial c_i/\partial L_i \quad (3a)$$

$$P q_i(L_i)(\partial p_i/\partial S_i) = \partial c_i/\partial S_i \quad (3b)$$

$$-\partial c_i/\partial D_i = 0 \quad (3c)$$

Equation (3a) says that a profit-maximizing farmer will choose the output level where probability-weighted marginal revenue equals marginal cost. The second equation says that farmers choose S_i such that the marginal cost of an increase in S_i equals the probability-weighted value of the output from an increase in S_i. In equilibrium, therefore, shrimp growers invest in safety as long as expected marginal benefits exceed marginal costs. Equation (3c) says that profit maximizers facing positive marginal costs do not utilize proper sludge disposal methods.

The model changes quite a bit if a social welfare-maximizer governs resource allocation. A guardian of common welfare would seek to maximize the difference between total expected profits from shrimp production, including the risk of disease, and the total external damages caused by the sector. These damages include (a) the risk of spreading disease to other farmers (i.e. a reduction in p_j caused by farmer i); (b) marginal damages (α) of water pollution emissions when feeding ponds are purged (E_i) and (c) marginal damages (β) of improperly disposed sludge (S_{Li}).[10] Emissions are a positive function of q_i and negatively related to S_i. Improperly disposed sludge, which is dumped in canals and on land, is a negative function of properly disposed sludge (D_i) and positively related to the amount of settling pond used (S_i), because more sludge is created with more settling

[10] α and β are assumed for simplicity to be constants. This does not affect the results.

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ponds. E_i and S_{Li} are deterministic based on the choices of L_i, S_l, and D_i. For each shrimp farmer '*i*' the social welfare function in (4) is maximized.

$$\text{Social Welfare} = \sum_{i=1}^{k} [p_i\,(q_1 \ldots q_k, S_1 \ldots S_k) P\, q_i\,(L_i) - c(q_i\,(L_i), S_i, D_i) - \alpha\,\{E_i\,(q_i\,(L_i), S_i))\} - \beta\,\{S_{Li}\,(D_i, S_i, q_i(L_i))\}] \quad (4)$$

Maximizing (4) by choosing L_i, S_l, and D_i optimally and rearranging implies the first-order conditions in (5a), (5b), and (5c).

$$P\left[\sum_{\substack{j=1\\ \forall j}}^{k-1} \{(\partial p_j/\partial q_i)(\partial q_i/\partial L_i)q_j\} + p_i(q_1 \ldots q_k, S_1 \ldots S_k)(\partial q_i/\partial L_i)\right] = (\partial c_i/\partial q_i)(\partial q_i/\partial L_i) + \alpha\{(\partial E_i/\partial q_i)(\partial q_i/\partial L_i)\} + \beta\{(\partial S_{Li}/\partial q_i)(\partial q_i/\partial L_i)\} \quad (5a)$$

$$P\left[\sum_{\substack{j=1\\ \forall j}}^{k-1} \{(\partial p_j/\partial S_i)q_j\} + (\partial p_i/\partial S_i)q_i\right] = \partial c_i/\partial S_i + \alpha(\partial E_i/\partial S_i) + \beta(\partial S_{Li}/\partial S_i) \quad (5b)$$

$$-\partial c_i/\partial D_i = \beta(\partial S_{Li}/\partial D_i) \quad (5c)$$

Comparing (5a) with (3a) we see that, while an individual farmer would choose production pond area so that marginal revenue equals marginal cost, a welfare maximizer would net out from marginal revenue the probability-weighted negative effects on other farmers of increases in pond area and output. Added to the cost side also would be the pollution effects associated with additional output. This implies that production pond area is less under welfare maximization than if only private costs were considered.

Comparing (5b) and (3b) we find that a welfare maximizer would take into account the benefits to other farmers when choosing the degree to which production systems are closed. S/he would also include water pollution at the end of production cycles. The marginal benefit of settling ponds is therefore greater than in the private maximization model, but also is the cost, because of the increased sludge generated by more settling ponds. As long as the additional benefits from reduced disease and water pollution exceed the extra costs associated with more sludge generation, the welfare-maximizing model would yield a higher equilibrium settling pond area. In (3c) we found that no sludge would be properly disposed of in the private equilibrium. Equation (5c) suggests an interior solution that balances the private costs of proper sludge disposal against the social costs of *ad hoc* dumping.

The comparison of social and private optima identifies the key inefficiencies of the uncontrolled system. We now consider instruments for moving Thai shrimp farming toward a more efficient set of outcomes. As was discussed in the previous section, it is not reasonable to assume an idealized policymaking environment and so mixed instruments that combine incentives and administrative safeguards are most relevant. In putting together a package of feasible policies, a number of compromises must be made. For example, we would ideally like to offer incentives for optimizing water exchange and discharges at all points in time. Differentiated water pollution charges that capture the effects of discharges on the environment and disease risk for other farmers would be ideal, but due to information imperfections, monitoring difficulties and enforcement problems, such charges would not be feasible. We know, though, that when ponds are purged at the end of production cycles most of the damage from effluent emissions occurs. We also know that settling ponds are key tools for reducing water pollution and the spread of disease. This type of information is now used to develop less-demanding economic instruments.

$$Max E(\pi) = p_i(q_1 \dots q_{k-1}, S_i, S_1 \dots S_{k-1}) P q_i(L_i) - c_i(L_i, S_i, D_i) \\ - t\{E_i(q_i(L_i), S_i))\} - F_1(L_i - a\,S_i) - F_2\{S_L(D_i, S_i, q_i(L_i))\} \quad (6)$$

The individual farmer model is amended to include three economic and two administrative instruments.[11] In the mixed instruments model, farmers are required to meet a minimum ratio of settling pond to production pond area (a). This is part of current Thai policy. What is missing from existing legislation is a fine (f_1) that penalizes producers for each *rai* they fall below the minimum ratio. We would also like to offer incentives for improvements in water quality when ponds are purged. This is done using a pollution charge (t) that applies only at the end of production periods and therefore greatly economizes on monitoring. Finally, there is a need for incentives for proper sludge disposal. This is achieved using a fine (F_2) levied on all sludge disposed improperly. The inclusion of these instruments generates the revised maximization problem in (6).

Maximizing (6) yields the three first-order conditions in (6a), (6b), and (6c).

$$P q_i(L_i)(\partial p_i/\partial S_i) = \partial c/\partial S_i + t(\partial E_i/\partial S_i) - F_1 a + F_2\{(\partial S_L/\partial S_i) \quad (6a)$$

$$P p_i(q_1 \dots q_k, S_1 \dots S_k)(\partial q_i/\partial L_i) = (\partial c_i/\partial q_i)(\partial q_i/\partial L_i) \\ + t(\partial E_i/\partial q_i)(\partial q_i/\partial L_i) + F_1 + F_2(\partial S_L/\partial q_i)(\partial q_i/L_i) \quad (6b)$$

$$-\partial c_i/\partial D_i = F_2(\partial SLi/\partial D_i) \quad (6c)$$

[11] In the next section additional instruments are presented to make the policy inferences derived more realistic and further strengthen our economic instruments.

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Evaluating these results we see that production pond area (L_i), settling pond area (S_i), and proper sludge disposal (D_i) decisions are more efficient than in the first model, but do not fully achieve social optima. Production pond area is unambiguously lower and settling pond area higher than without mixed instruments. These results are closer to the social optimum than without those policies, but they fall short in at least two important ways. First, direct account is not taken of disease externalities, much less differential effects across farmers, other than through settling pond requirements and F_1, the fine for insufficient settling ponds. In effect, the parameter (a) and the fine (F_1) imperfectly proxy for the complex interplay between S_i and p_j $\forall j$.

Second, as in the welfare-maximizing model, effects of production and settling pond decisions on emissions (E_i) and improperly disposed sludge (S_{Li}) are included, but the levels of the pollution tax (t) and fine for improper disposal (F_2) determine the degree to which those aspects of land use decision making are efficient. If fees were set equal to marginal damages, decisions would be efficient, but as damages are likely to be unknown, efficiency would not be expected. Indeed, as is often the case, fees are likely to be set based on a variety of *ad hoc* criteria, including political feasibility, 'fairness', and ability to pay (Sterner, 2003; Bluffstone, 2003).

4. Potential mixed instruments for controlling environmental degradation associated with shrimp aquaculture

The models predict that profit-maximizing farmers will ignore the effects of their actions on other farmers and the environment. They therefore have more production pond area than is socially optimal, spend nothing on proper sludge disposal, and have more open production systems than is desirable. Taxes and fines linked with standards, though, move farming systems closer to optimal levels, though they do not achieve the first-best due to reliance on settling pond area and imperfectly set fees as anchors for policy. In practice, though, even the instruments in the model would not be sufficient given the realities of the Thai context. The remainder of this section discusses additional measures that must be imposed and suggests magnitudes for charges and fines.

As discussed in section 1, the permitting system is sorely in need of reform. Creating a permit system that covers more than a small fraction of polluters would help shrimp farmers believe their activities are observed by environmental regulators and annual renewal would improve clarity and provide incentives for better environmental performance. The 50 *rai* permitting threshold therefore needs to be reduced. Based on Patmasiriwat (1997), reducing the threshold to 6 *rai* would cover approximately 46 per cent of all shrimp farms. This could be a reasonable short-term goal, with a long-run objective to include a greater percentage of farmers.

As was already mentioned, a reality of environmental protection in Thailand is very limited public sector funding, which has led to poor environmental management. Shrimp farmers should therefore cover the administrative costs associated with their environmental management. Fees of baht 600–1,000 per *rai* per year would generate the revenues necessary to cover document processing, record-keeping, and monitoring. Table 3

Table 3. *A potential set of mixed instruments for the shrimp aquaculture sector*

Instruments	*Expected on-farm measures*	*Nature of the benefits*
Fine of baht 10,000/*rai* of below-prescribed area of settling ponds and reservoirs; Fine of baht 4,000/*rai* of active pond area for each instance of a failure to submit a third party harvest effluent monitoring report; Pollution charge of baht 200/rai/harvest for each 1 mg of BOD in excess of the maximum permissible discharge concentration of 10 mg/l.	Shrimp farmers monitor and report their effluent emissions during harvests; Shrimp farmers build water reservoirs and settling ponds; Shrimp farmers also use settling ponds as a tool to reduce their effluent concentrations.	Shrimp production systems become more closed and at the time of harvest, when most water pollution occurs, BOD concentrations are reduced to the standard of 10 mg/l. Benefits resulting from these changes include improved fisheries, more attractive tourist sites and a reduced probability of spreading disease to other shrimp farms.
Fine of baht 2,900/ton of wet weight sludge for non-observance of permit conditions on sludge disposal.	Farmers will dispose of their sludge in more environmentally sound ways than is currently the case.	Unsightly piles of sludge on roadways and abandoned lands and salinization of land will be reduced. Reduced dumping into waterways improves water quality.
A once-only environmental performance bond of baht 20,000/*rai* of active pond area to encourage remediation of ponds after economic life is complete.	When building shrimp ponds, farmers will plan for and undertake site remediation after economic activities cease.	The creation of unsightly abandoned ponds reduced; Pond lives extended as farmers attempt to push remediation costs further into the future; Land that would otherwise have no economic use will be useful for agriculture or other activities.

overviews a potential package of measures for internalizing the key externalities associated with shrimp aquaculture in light of political and regulatory limitations. These instruments are discussed in turn.

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The construction and use of settling ponds is the key to reducing water exchange and improving effluent quality. Standards already exist, but no non-compliance penalties are in force. A reasonable way to set the fine for insufficient settling pond area is to use the estimated damage from one *rai* of uncontrolled production pond. Estimates by Kasetsart University suggest that an appropriate penalty would be baht 10,000 per year per missing *rai* (Kasetsart, 1999). Tookwinas (1998) and others also make clear that emissions at the time of harvest must be closely monitored. Without this requirement it is possible that settling and reservoir ponds would be built, but go unused due to the costs of operating them. This has been the fate, for example, of many wastewater treatment plants in the developing world.

Monitoring of BOD levels is not difficult, but it must occur exactly when ponds are purged, with the burden borne by shrimp farmers to avoid putting additional stress on already stretched regulators. To address such concerns, private laboratories could be trained and certified to test pond effluents. Each pond must be tested and farmers should arrange for testing. A discharge report could then be sent directly by laboratories to government authorities, with copies to farmers. Failure to arrange for testing or report results could trigger a penalty of baht 4,000 per *rai* per harvest. Assuming 2.5 crops per year, this is 40 per cent of the estimated damage from uncontrolled emissions (Kasetsart, 1999).

Incentives for improving the quality of harvest period effluents at least to the level of the effluent discharge standard of 10 mg/l of BOD are also needed. Each 1 mg/l of BOD emissions above 10 mg/l could result in a charge of baht 200/*rai*/harvest.[12] This instrument is rough. It assumes constant marginal environmental costs, creates incentives for dilution and does not reward reductions in concentrations below the standard, but it is understandable, easy to calculate, economizes on monitoring, and offers incentives for farmers to avoid uncontrolled discharges.

Markets exist for treated and untreated pond sludge and if it is soaked in fresh water for one year we understand it can be used as fertilizer. It is therefore possible that better regulations could improve recycling markets. The proposed permit and registration procedures allow the opportunity to agree on sludge disposal methods and, if better effluent management were to be adopted, information would be available about the timing of sludge movements. To improve disposal, government regulators could prepare a list of options (e.g. disposal in permitted landfills, sale as fertilizer, treatment in own sludge ponds, or use for own agriculture). Permit applicants could then select one or more of the options. The simple step of committing to disposal regimes would reduce illegal dumping considerably, but a penalty equivalent to baht 2,900 per ton wet weight sludge, which is the estimated cost of simple remediation, could be levied for permit condition

[12] We assume that raw discharges have BOD concentrations of approximately 30–40 mg/l and cause damages of baht 10,000 per *rai* per year or baht 4,000 per *rai* per harvest. We further suppose concentrations of 10 mg/l having no damages, implying that an average damage would be baht 167 per *rai* = 4,000/(35–10)].

violations (Kasetsart, 1999). Partial fines could be levied for late submissions of disposal reports.

Returning environmental fees to polluters can undermine the effectiveness of charges and penalties. Nevertheless, because of highly imperfect capital markets and potentially debilitating political opposition, it is desirable to keep a significant proportion of fee revenues within the regulated community (Bluffstone, 2003; Lovei, 1995; Sterner, 2003). To maximize the benefits of revenue recycling and maintain marginal incentives, though, payments to farmers must favor those who take steps toward better environmental management, be unrelated to fees paid, and should be viewed positively by communities. For example, a significant portion and perhaps all taxes and penalties (excluding permit processing fees) could be allocated to a sub-account of the national Environmental Fund to finance loans for settling ponds and equipment to reduce the openness of shrimp farms. Funds could also be used to train shrimp farm operators in the monitoring of pond discharges, rehabilitate abandoned sites where responsible parties are not known or refuse to cooperate, and for environmental education programs. Given the disastrous effects of extensive shrimp farming on mangroves, it also seems appropriate to use charge and penalty revenues for mangrove rehabilitation.[13]

Though not part of the formal model, abandoned ponds have effects that also deserve attention. Abandoned shrimp ponds lower the amenity values of coastal environments and pollution of adjoining lands may continue after shrimp farming terminates. As part of the permitting process, shrimp farm operators could be required to post a one-time performance bond that would earn interest in bank accounts managed by third parties.[14] To redeem bonds, owners would need to be certified by the Ministry of Environment that they remediated shrimp ponds to levels stipulated in agreements. In the event of ownership transfers, new owners would assume bond obligations. Failure to remediate or sell sites would result in forefeiture and local agencies would use the money to finance remediation. The cost of bonds should approximate the remediation cost plus a premium to create incentives to remediate rather than leave the job for the government. A bond of baht 20,000 per *rai* of active pond area is expected to create such incentives.

5. Conclusions

As shown by our theoretical model, the environmental economic problems of shrimp aquaculture are largely a matter of internalizing externalities,

[13] The Environmental Fund was established in 1992 to provide environmental finance for public and private environmental projects. To date, the fund has been capitalized by government and donor sources. Channeling penalty and charge revenues to the Environmental Fund would likely require legislative changes.

[14] Such instruments have been used to manage a variety of natural resource problems, including forest concessions in the Philippines (Paris *et al.*, 1994). Thailand has significant experience with private management of public resources for environmental management. For example, the loan program of the national Environmental Fund is managed by a private bank.

but the context in which they occur makes dealing with them difficult. Shrimp aquaculture is a largely small-scale industry that has raised many poor villagers out of poverty. Furthermore, it is an important source of foreign exchange. Regulatory capacity and finance are quite limited in developing countries such as Thailand, and politically driven enforcement problems also exist. Simply assuming away these difficulties would be counterproductive.

The models of self-interested farmers and a social welfare maximizer highlighted the key externalities associated with shrimp aquaculture, but how to internalize them is the key question. Theory tells us that economic instruments allow polluters to identify and implement low-cost abatement options and are therefore preferred, but regulatory realities can often impede successful implementation. The mixed instruments model, however, suggests that combining economic instruments, such as pollution charges and non-compliance fines, with carefully designed performance standards may be able to improve efficiency while addressing implementation concerns.

Most countries have such standards, but as in Thailand there may not be the penalties and fees or the regulatory resources to enforce those limits. Using economic instruments to support existing regulations (e.g. effluent concentration limits) may be more politically palatable than introducing unfamiliar and likely more complex requirements. In Thailand and most other developing countries, though, even more basic measures are needed. To support the use of economic instruments, permit systems and reporting requirements need to be strengthened. Monitoring and other administrative deficiencies must also be considered, because for the foreseeable future local environmental agencies will have insufficient human and financial resources. Under such circumstances monitoring and enforcement should be decentralized.

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