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Efficient management of marine resources in conflict: An empirical study of marine sand mining, Korea

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ABSTRACT

This article develops a dynamic model of efficient use of exhaustible marine sand resources in the context of marine mining externalities. The classical Hotelling extraction model is applied to sand mining in Ongjin, Korea and extended to include the estimated marginal external costs that mining imposes on marine fisheries. The socially efficient sand extraction plan is compared with the extraction paths suggested by scientific research. If marginal environmental costs are correctly estimated, the developed efficient extraction plan considering the resource rent may increase the social welfare and reduce the conflicts among the marine sand resource users. The empirical results are interpreted with an emphasis on guidelines for coastal resource management policy.

1. Introduction

Marine sand resources are used for many purposes such as industrial uses, restoration of coastal areas and wetlands, and nourishment of recreational beaches in coastal countries since the mid-1900s. At the same time, government agencies for marine sand development have regulated and provided guidelines or procedures for marine sand mining to mitigate the potential environmental damages from mining activities (Cayocca and Gardin, 2003; Vivian, 2003; Drucker et al., 2004; Birklund and Wijsman, 2005; Gubbay, 2005; Marine Mineral Services (MMS), 2006).

Marine sand resources have been exploited in the Ongjin District, Korea, since 1993, but environmental damage from sand mining has been an issue only since 2000. Since then, there is much interest in understanding social benefits and costs of marine sand mining in Korea. Until recently, large quantities of marine sand were freely mined to satisfy the demand from the Korean construction industry (as an input for concrete) to build infrastructure.[1] This has led to a variety of environmental damages, such as commercial and recreational fisheries, ocean habitat and ecosystem, and residential and recreational coastal area uses (Korea Aggregates Association, 2002; Grigalunas et al., 2004, 2005; Cho, 2006; Kim et al., 2006, 2008).

Unfortunately, very little attention has been paid to the environmental damages from marine mining, and the resource management policies of the Korean government—Ministry of Maritime Affairs and Fisheries (MOMAF)—have favored a stable aggregate supply of sand for the construction industry. This pro-development policy has induced conflicts among stakeholders, including fishermen, local residents, non-governmental organization (NGOs), local governments, and mining operators because of competition for marine resources, environments, and space (Douvere and Ehler, 2009). A decrease in fish catch, coastal erosion, and other environmental damages attributed to mining resulted in a temporary halt in marine mining in Ongjin area in 2004, followed by a moratorium on issuing a mining permits in the second half of 2005. Given Korea's current and future national development plans, however, this is not likely a feasible long-term solution.

When mining began in 1992, public awareness of the importance of ocean and coastal resources and their environmental costs were not well understood in Korea. The limited Korean research on this topic to date has examined the links between sand mining and harm to the marine environment based only on biological and physical studies, which alone cannot suggest an efficient extraction management plan. Instead there are a few economic studies to estimate the external costs of mining on commercial fisheries and

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[1] Marine sand mining operators had just paid 10% of sale amount to a local government as occupancy-and-use-of-public-water fee (a tax). Initially, this fee was not cost for environmental damages from marine mining activities, though a tax rate was increased up to 30% of sale amount for compensating fishermen and local residents affected from the mining in 2004. And extracted quantities of marine sand had been determined by the aggregate supply plans for five-year periods by the Ministry of Construction and Transportation (MOCT) regardless of environmental damages.

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recreational beach use (Grigalunas et al., 2004, 2005; Kim et al., 2006, 2008).

In summary, to date there is a dearth of conceptually sound, analytical studies for estimating environmental damages resulting for marine sand mining; hence, limited information exists on which sound management decisions can be made. Therefore, marine resource management may be improved if more rigorous scientific (biological and physical) and economic studies can provide information on the potential trade-offs between extraction of marine sand and preservation of the marine environment and support policies which might reduce conflicts and increase social benefits.

The main objective of this paper is to develop a dynamic model of efficient use of non-renewable marine sand resources in the context of marine mining externalities.[2] Specifically the model developed examines conflicts between marine mining and commercial fisheries and habitat damages, which are the main adverse environmental impacts from sand mining.

A fundamental question addressed herein concerns how closely current management polices mimic an efficient resource use plan. The maintained hypothesis is that marine sand resources have been extracted inefficiently because the opportunity cost of current extraction of non-renewable sand resources has not been considered (Hotelling, 1931; Krautkraemer, 1998). Furthermore, the effects of mining externalities have not been internalized by decision makers.

To examine how large the difference is between an efficient mining path including the external costs and the administratively set mining path by non-economic scientists who have studied marine sand resources, a Hotelling-type exhaustible resource model is developed and applied to a sand mining case in Ongjin District in Korea. This dynamic model examines the efficient extraction behavior of mining operators with an internalized Pigovian-tax (e.g., see Schulze, 1974), which represents the potential economic damage to commercial fisheries and habitat from marine sand mining.

Sensitivity analysis is used to test the uncertainties of natural environmental complexity associated with both marine sand mining and commercial fisheries. This focus is important because concerns about how proposed environmental controls would affect individual operators and society typically are a key issue in regulatory impact analysis. The model developed here will contribute to (1) development of guidelines for marine sand resource uses in Korea as a case study and, more generally, (2) contribute to the applied literature in environmental and natural resource economics dealing with social costs and resource use conflicts.

The following sections present the theory and assumptions of the models to be used, the data, the estimated results and discussion, and summary and conclusions.

2. Theory and assumptions of the models used

2.1. *Efficient extraction model for non-renewable marine sand resources*

The theoretical framework of this model is a direct extension of the well-known Hotelling's optimal extraction theory (Hotelling, 1931; Schulze, 1974). Here, we integrate both the net benefits of mining operators and the external costs of mining activities.

[2] Marine sand resources in Korea are considered as non-renewable resources here because the recharge rate of sand from inland is close to zero percent with a lot of dams and dikes. Furthermore there is no commercial and governmental effort to find new reserves of sand resources, so that the current total quantities of marine sand are fixed reserve quantities in Korea.

Table 1
Seasonal actual catch data for one unit area in Ongjin District in 2001.

Species name	Catch abundance (kg wet weight/km^2)				
	Winter	Spring	Summer	Fall	Total
Blue crab	50.9	77.2	0.0	1548.7	1676.8
Other crab	2.4	4.7	0.0	150.0	157.1
Shrimp	0.05	0.04	1.14	0.63	1.9
Trump shell	0.0	50.4	0.0	23.5	73.9
Jacopever	0.5	1.3	0.0	2.0	3.8
Flounder	0.0	0.5	0.0	5.3	5.8
Flatfish	1.3	0.0	0.0	3.9	5.2
Oyster	29.2	7.2	0.0	0.0	36.5
Total	84.4	141.4	1.1	1734.0	1960.9

Source: (1) Fishery statistical data, MOMAF.

If there are n identical firms in the marine sand industry, the socially optimum extraction rate with a fixed quantity of sand reserves can be obtained by maximizing the present value of net benefits to society:

$$\text{MaxPV} = \int_0^\infty e^{-rt}[B(nq_t) - C_t(q_t)nq_t - Enq_t]\text{d}t \quad (1)$$

$$\text{s.t. } \dot{S} = -nq_t, S(0) = S_0, \text{ and } q_t = 0,$$

where q_t is the quantity of sand extracted at time t by each of n identical firms, S_0 is the total stock of the sand resource available at the outset, r is a social discount rate, and $C_t(q_t)$ is extraction cost. The Pigovian-tax to internalize the marginal external cost is indicated by E. Here, $B(nq_t)$ are the total social benefits associated with the total quantity extracted, which is derived by integrating the inverse demand curve for sand given by:

$$B(nq_t) = \int_0^{nq_t} P(s)\text{d}s, \quad (2)$$

assuming that the inverse demand function for marine sand has negative slope for quantity, $\partial P(nq_t)/\partial q_t < 0$ and non-negativity property, $P(\bullet) \geq 0$.

This typical dynamic optimization problem can be solved by applying *optimal control theory* to decide quantity of marine sand resources, q_t over time to maximize net present value. Although many general extraction models assume increasing cost function as sand stock decreasing, for simplicity of analysis, I assume extraction cost is fixed over time, $C(q_t) = C$ because of data limitation as explains later. If total quantity extracted by all n-firms is denoted $Q_t(=nq_t)$ and costate variable for the sand resource stock is denoted λ_t, the current value Hamiltonian is:

$$H_t = \int_0^{Q_t} P_t(s)\text{d}s - CQ_t - EQ_t + \lambda_t(-Q_t), \quad (3)$$

where the costate variable λ_t is called marginal user cost (MUC or opportunity costs of exhaustible resources), which is the current value of the unextracted sand resource at time t.

The static efficiency condition is:

$$\frac{\partial H_t}{\partial Q} = P(Q_t) - C - E - \lambda_t = 0 \Rightarrow P(Q_t) = C + E + \lambda_t, \quad (4)$$

or

$$P(Q_t) - C - E = \lambda_t. \quad (5)$$

This condition (Eq. (4)) requires that the extracted quantity of marine sand should be chosen when marginal benefit of mining is