A Model of Marine Litter in Sustainable Fisheries

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Abstract
This paper studies the dynamics of an economy specialized in fisheries facing a rising marine litter problem. We present a dynamic optimization model to explain the mechanism through which marine litter causes inefficiencies in the fishery sector. We study the dynamic properties of the model when the externality of marine litter is not taken into account and when it is internalized via the price of fish. We find that when the litter is internalized through the price of fish, the ocean quality is improved but fish catch decreases. We explore the possibility of introducing an incentive scheme where marine litter can be traded on a hypothetical market. The introduction of a market removes the inefficiencies caused by marine litter and provides the right incentive for fishermen to maximize the overall welfare.
Keywords: marine litter, plastics, fishery sector, dynamic optimization, incentive scheme

1. Introduction

Marine litter is now present in every ocean (Cheshire et al., 2009) and 50-80% of it is made up of plastics (Barnes et al., 2009). Although marine litter has attracted increasing attention in recent years, very few studies have investigated the economic impacts of marine litter on coastal communities (Brouwer et al., 2015). Therefore, the objective of this research is to examine how marine litter affects the fishing sector, one of the key sectors that rely on the marine environment. Marine litter causes negative impacts on the fishery sector in a variety of ways, all of which result in either reduced revenues or increased costs. This paper aims to incorporate the impacts of marine litter on marine fisheries in a dynamic economic optimization model in order to explain how marine litter leads to inefficiencies. The main research questions are what challenges that the fishery sector faces when the externalities of marine litter are taken into account and how they can be mitigated to benefit the fishery sector. To this end, we explore the possibilities of internalizing the economic welfare loss due to marine litter in the price of fish and through the introduction of a new market where the fishing for litter schemes enable selling the litter caught as part of inter-national resource recovery programs. The manuscript is organized as follows: section 2 describes an optimal control model related specifically to the economics of fishery without the litter externality respectively. This baseline model is extended in section 3 where litter is introduced, and in section 4 where an economic market for fishing for litter is introduced. Finally, section 5 concludes.

2. A Fisherman's Problem

In the baseline model, we assume that a fisherman chooses the number of fish catch in order to maximize the lifetime profit taking the price of fish $\boldsymbol{p_C}$ as a constant. By taking the price as given, a fisherman does not realize that the externality of marine litter can affect his revenues. Hence, he solves the following problem:

$$\max_{\{C_t\}} \int_0^{\infty} \{\ln(C_t p_C) - \ln(\beta O_t^{\sigma} C_t^{\eta})\} e^{-\rho t}\, dt$$
$$\text{s.t}: \dot{O}_t = (r - m_0)(\bar{P} - O_t) - \alpha C_t$$

3. Hidden Price Burden

Although the fisherman might not be aware of it, plastic pollution in fact influences the public's choices. In reality, what happens is that the consumers' WTP for fish falls when they are concerned about the health consequences of micro-plastics through the food chain. Thus, the fisherman has to bear a hidden burden in his revenues because he cannot control what influences the fish price. He solves the following problem:

$$\max_{\{C_t\}} \int_0^{\infty} \{\ln[(1+\gamma) C_t O_t^{\phi}] - \ln(\beta O_t^{\sigma} C_t^{\eta})\} e^{-\rho t}\, dt$$
$$\text{s.t}: \dot{O}_t = (r - m_0)(\bar{P} - O_t) - \alpha C_t$$
$$L_t = \gamma C_t p_C$$

Here the price per fish is no longer a constant. As a result, the externality of ocean quality is internalized in this model. Additionally, in this problem we assume that fishermen also earn some income from voluntarily catching litter which is represented by the term $\boldsymbol{L_t}$.

Comparative Statics

$\frac{\partial C_{pb}}{\partial \phi} < 0$: A higher public preference for clean oceans reduces the level of fish catch.

$\frac{\partial O_{pb}}{\partial \phi} > 0$: A higher public preference for clean oceans increases the ocean quality.

A Comparison

$$O_{pb} > O_{ss};\ C_{pb} < C_{ss}$$

When the externality of litter is internalized via the price of fish, fish catch is lower which allows for higher ocean quality than when litter is not taken into consideration. An explanation for this result is the hidden price burden. When there is litter in the oceans (O_t is small), the general public is more concerned about the health impacts of litter and thus will demand cleaner oceans by lowering their WTP for fish. This in turns drives down the level of

fish catch ($\frac{\partial C_{pb}}{\partial \phi} < 0$). A benefit of internalizing the litter externality in the fish price is that the ocean quality is improved ($\frac{\partial O_{pb}}{\partial \phi} > 0$). However, a low level of fish catch causes fishermen to suffer from low profits. The inefficiencies of this case indicate that a large part of the burden caused by litter is unintentionally borne by the fishery sector.

We find that $\frac{\partial L_{pb}}{\partial \phi} < 0$ which means a higher public preference for a litter-free ocean is accompanied by a reducing revenue from catching litter for fishermen. This implies that the public's preference for clean oceans discourages fishing for litter activities from fishermen. An explanation for this seemingly counter-intuitive result lies in the hidden price burden. The consequence of letting fishermen bear the costs of litter pollution via the internalization in the fish price is a misalignment in the interests of the general public and fishermen. If fishermen are inadvertently made accountable for the problem, even when society starts demanding less litter pollution, fishers have no intention to support the general public's interest.

Thus, the model points out a need to find the right incentive so as to align the interests of the general public and fishermen in such a way that the issue of litter can be mitigated and the price burden borne by fishermen can be shared.

4. Fish-For-Litter

We saw before that fishermen unknowingly bear the burden from plastics through the internalization of litter in the price of fish. What we will see in this section is that with the onset of "Fish-for-Litter" incentive schemes, the internalization of litter causes the society to effectively take up some of the burden. The fisherman's optimization problem now becomes:

$$\max_{\{C_t\}} \int_0^{\infty} [\ln(C_t O_t^{\phi}) + \ln(L_t p_L) - \ln(\beta O_t^{\sigma} C_t^{\eta})] e^{-\rho t}\, dt$$

$$\text{s.t}: \dot{O}_t = (r - m_0)(\bar{P} - O_t) - \alpha C_t$$

A comparison

Comparing the results of all models, we have:

$$O_{ss} < O_{pb} < O_{fl};\ C_{ss} > C_{pb} > C_{fl}$$

A market for litter reduces fish catch even further compared to when no action is undertaken but improves ocean quality substantially. At first glance, this may look similar to the price burden case's results. Previously, fishermen face a rising public demand for fewer plastics without the right actions needed from the public themselves to tackle the matter. Fishers thus collect litter just to regain the lost revenue caused by litter being a by-catch in their nets. The lack of incentive leads to not only fewer litter catch even when there is a higher public preference for clean oceans (as shown by $\frac{\partial L_{pb}}{\partial \phi} < 0$) but also fewer fish catch which ultimately reduces fishermen's profits.

However, the fishermen's burden is now shared by a public demand for litter as they can make up for the low fish catch with litter catch. This is shown by one of the predictions from this model $\frac{\partial O_{fl}}{\partial \phi} > 0$. Since ocean quality is equivalent to litter catch by definition, $\frac{\partial O_{fl}}{\partial \phi} > 0$ implies that $\frac{\partial L_{fl}}{\partial \phi} > 0$ meaning a higher public preference for clean oceans increases the litter catch from fishermen. The incentive scheme has successfully aligned the interests of both the general public and fishermen. A public demand for clean oceans now encourages fishing for litter activities among fishermen. This is possible because the general public starts to take up some of the burden by paying for litter. As a result, fishermen are given the right incentive to catch more litter and their profits do not suffer as much.

5. Conclusions

This paper presents a dynamic economic optimization model in which a fisherman has to choose the number of fish catch and devote a fraction of his income to litter collecting activities. We analyse the dynamic properties of the model in two distinct versions, not taking into account the externality of marine litter and internalizing litter via the price of fish. We find that when litter externality is internalized in the price of fish, fish catch decreases and ocean quality improves. Fishermen suffer low profits and have no incentive to catch litter even if it is the desire of the society to have clean oceans. We then analyse a possible solution, an incentive scheme where the public's willingness to pay for litter encourages fishing-for-litter activities. The solution allows the burden on fishermen caused by marine litter to be shared with the general public. Though fishermen still face a reducing fish catch when litter externality is internalized in the price of fish, they can make up for it with the income from litter catch. Fishing-for-Litter provides the right incentive such that both the public's and fishermen's interests are met.

The results chart a way forwards toward a circular economy in which all plastics produced are recovered and reused or repurposed for alternative use, and/or recycled into a new product. The shift toward a sustainable plastics economy, i.e. an economy with plastics that have a more durable or even sustainable life cycle, can bring about better ocean quality and ultimately more marine resources for the fishery sector.

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