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Effect of Price, Costs and Social Discount Rate on Maximum Economic Yield: The Case of Mackerel Fishing in South Korea

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Abstract: Effective management of harvesting within fisheries requires setting of a management target for the stock biomass of the fishery and harvest strategies that maintain the stock biomass at levels that maximize the Maximum Economic Yield (MEY) of a fishery. The management structure, stock level and nature and extent of fishing effort that generates MEY depends on a combination of biological and economic factors, or the relationships between harvest, stock and recruitment and on the way in which fishing behavior, revenue and costs relate to those factors. A generic dynamic fishery model is used where the transition path of the fish population has deterministic and stochastic components. The deterministic component is the difference between a logistic fish growth function and harvest. Considering a transboundary stock like mackerel, which is being shared by South Korea, China and Japan; in order to simulate the effect of changing in price and costs also in social discount rate on catch and stock size, helps us to generate a solution to bring closer these countries to a stable cooperation level. We have considered South Korean data in order to simulate these effects and give more realistic results.

Key words: Maximum Economic Yield · Social Discount Rate · Fishing Cost · Market Price · Mackerel · South Korea

INTRODUCTION

Fisheries resources have the potential to generate net benefits or welfare for the community, but this potential is only realized with effective management of fishing effort. Without management of fishing effort, fisheries tend to an outcome where too many of society's resources are devoted to fishing and where the opportunity for society to earn the maximum possible returns from fishing over the longer term is lost. At a fishery level, effective management implies that a management objective/target is set and enforced-either in the form of input controls or output controls-at levels that ensure remaining stock (after harvest) remains both sustainable and at a level that ensures maximum economic yield (MEY) is obtained. The biomass level associated with a MEY is referred to as B_{MEY} when MEY is being measured against the total stock size and MEY when MEY is being measured against the spawning stock size. The MEY yield will be one that provides the maximum possible returns to fishers from their effort, given the biological characteristics of the stocks/species the fishery targets and the requirement of biological sustainability.

The Fisheries Act of Korea (1953), which is the basic legal framework for Korea's fisheries, contains the provisions on the management, control, restrictions, regulation and limitations of fisheries, including licenses, authorization, notifications, enforcement and penalties. Some of the major legal instruments for fisheries include the "Fishery Resources Management Act", which governs the management (conservation, utilization and development) of fisheries resources; the "Inland Water Fisheries Act" for the management of fisheries and aquaculture in inland waters; the "Distant Water Fisheries Development Act" for the management of high seas fisheries and the promotion of international fisheries cooperation and the distant water fishing industry; the "Aqua Farm Management Act" for the effective and

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efficient operation of aquaculture and pollution mitigation. Other laws and regulations include the "Aquatic Animal and Plant Disease Control Act"; and the "Agricultural and Fishery Products Quality Management Act".

Korean coastal-offshore fisheries may utilize offshore waters of the East Sea, the West Sea, the East-China Sea and sea waters above 25 degrees northern latitude and to the 140 degrees east longitude of the Pacific Ocean. Waters outside the designated area are considered as international fisheries where overseas fishing is carried out.

Total Allowable Catch (TAC) system was first introduced in 1999 to manage and control the harvest from the Exclusive Economic Zone(EEZ) of Korea, to be consistent with the UN Convention on the Law of the Sea, which took effect in 1994. As of 2011, Korea's TAC system covers 11 species, such as the Mackerels, Jack Mackerel, Squid, Red Snow Crab and Blue Crab, with a total TAC of 425,000 tones. Under the system, individual vessel quotas are allocated by respective Fishers Cooperatives.

In 2001, Community Based Fisheries Management (CBFM) was introduced, whereby fishers are the partners and initiators of management actions for their fisheries in addition to the already-established rules and regulations for the sustainability of their local fisheries.

Under the CBFM, fishers' groups are taking voluntary management measures on their own fisheries and actively participating in decision-making processes for dispute settlement; income generation; fishing ground and resource management; and stock enhancement in the framework of relevant fisheries laws and regulations. An increasing number of fishers' groups are joining the CBFM.

In 2011, the "Korea Fisheries Resources Agency (FIRA)," a government-funded body dedicated to fisheries stock enhancement, was established. Main task areas of FIRA include artificial reefs, fry release, marine ranches and marine forests. The Agency also deals with research and development programs and projects related to stock enhancement, relevant technologies, feasibility studies and ecology surveys.

Ministry of Ocean and Fisheries (MOF) provides a framework for managing Commonwealth fisheries, with an aim to maximize net economic returns while maintaining stocks at biologically safe and productive levels. Specifically, harvest strategies based on the policy and associated guidelines seek to:

- Maintain fish stocks, on average, at a target biomass equal to the stock size required to produce MEY
- Ensure fish stocks will remain above a limit biomass level where the risk to the stock of biological collapse is regarded as too high
- Ensure stock stays above the limit biomass level at least 90% of the time.

However in order to have an economically efficient fishery South Korea will need to follow these three characteristics:

- Total catch and/or effort are restricted to the point that maximizes net economic returns over time allowing for the future costs of fishing and the impact of current catch on future stocks and catches-this prevents fishers from expanding their effort until all profits are dissipated. This is known as fishery level efficiency.
- Revenues are maximized and catching costs minimized for a given quantity of catch. While fishers can be relied on to choose the combination of inputs that minimizes costs and maximizes revenue for their particular operation (given the constraints imposed by fisheries management), management measures used in a fishery can have a significant impact on the costs and revenues of fishing. This is known as vessel level efficiency.
- Fisheries management services are provided effectively and at least cost for the given level of management (not necessarily at lowest cost overall). This is known as management efficiency.

In this paper we will first explain the MEY , then next part provides an illustration of the relationship between target and path in MEY and how MEY and its path can be calculated using an MEY analysis. Third part discusses the practical considerations of the discount rate and the divergence between private and social discount rates in MEY analysis. Forth section analyses a generic dynamic fishery model with both deterministic and stochastic settings and the impacts of fish price, fishing costs and the discount rate on the MEY path for South Korea.

Effective management of harvesting within fisheries requires the setting of a management target for the stock biomass of the fishery. Harvest strategies that maintain the stock biomass at levels that provide maximum economic yield (MEY) of a fishery, or those that provide a maximum sustainable yield (MSY) are two examples.

Achieving such targets requires the control of the harvest that fishers extract from the fishery (or overall effort levels) during a given period of time.

Fisheries managers typically use either input controls, such as vessel size and gear restrictions, or output controls, such as setting total allowable catch limits, or a mix of both to control harvest. In order to meet management's specified target for the fishery changes over time, in line with changes in economic and biological conditions affecting the fishery; the harvest size required. Hence, managers need to consider all these factors when moving from one harvest level to another. For example, the issues that can influence the magnitude of the costs and benefits along the optimal transition path to harvest levels consistent with management targets and also change which path is optimal are, irreversible investment decisions, society's preference for present consumption over future consumption, prevailing management arrangements and uncertainty about biological stock status and more complex biological dynamics.

A common objective in fishery management, both internationally and in South Korea, has been to maximize the sustainable catch of a fishery-deriving the MEY from applied effort. While this target maximises the gross value of production for a fishery, it does not ensure that the fishery is maximizing economic returns. Depending on the price of fish and the cost of fishing it is also possible that economic returns from fishing at MEY may be zero or negative.

If harvest strategies concentrate on sustainable yields alone, economic efficiency occurs when the sustainable catch or effort level for the fishery as a whole maximizes profits, or creates the largest difference between discounted total revenues and the total costs of fishing. This point is referred to as MEY . For profits to be maximized it must also be the case that the fishery applies a level of vessel capital and other resources in combinations that minimize the costs of harvest at the MEY catch level. The fishery, in other words, cannot be over-capitalized and vessels must use the right combinations of such inputs as gear, engine power, fuel, hull size and crew to minimize the cost of a given harvest.

There are several things to note about MEY at the outset.

- For most practical discount rates and costs,MEY will imply that the equilibrium stock of fish is larger than that associated with MEY .
- The catch and effort levels associated with MEY will vary, as will profits, with a change in the price of fish or the cost of fishing. If the price of fish increases it pays to exploit the fishery more intensively, albeit at yields still less than MEY. If the cost of fishing rises, it is preferable to have larger stocks of fish and thus less effort and catch.
- As long as the cost of fishing increases with days fished, as it generally will, MEY as a target will always be preferred to MEY from an economic perspective and of course to any catch or effort level that corresponds to stocks that are smaller than those associated with MEY.

Regardless of what happens to prices and costs, targeting catch and effort at MEY will always ensure that profits are maximized. Profits may be relatively low when the price of fish is low and the cost of fishing is high, but profits will still be maximized. With a biological target of MEY alone, however, it is possible that profits may be very small or even zero. According to Grafton *et al.* [1] even though fisheries economists have explored the concept of MEY over many decades, it is only recently that dynamic MEY has started to become accepted as an important and implementable target in fisheries management, such as in the Northern Prawn Fishery in Australia.

Estimating MEY for Mackerel Fisheries in South Korean Waters: From Atlantic to Indian ocean Mackerel is widely distributed. This stock lives in 300m depth in the ocean and usually migrates seasonally. In South Korea the total catch of mackerel increased from 50,000 in year 1975 to 100,000 in 1988. The amount increased to 170,000 from 1993 and reached to its' highest level in 1996. Figure 1 shows the total mackerel catch in 80 years in South Korean Waters.

Mackerel as one of the valuable species in South Korean fisheries draw lots of attention over the last 15 years. This encouraged South Korean government to consider this specie under TAC regime. We can see in Figure 2 under TAC species, also we can note that Mackerel and Squid are among the highest given licensed species in South Korean waters.

Korean Maritime Institute (KMI) [2], already calculated the intrinsic growth rate r, catch-ability coefficient q and environmental carrying capacity k. Here we will use the same calculation and point it in Table 1.

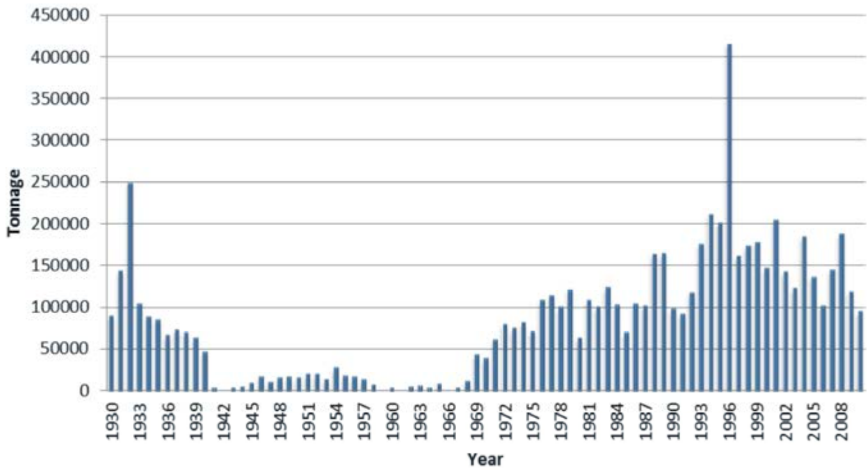

Fig. 1: 80 Years Mackerel Catch in South Korean Waters

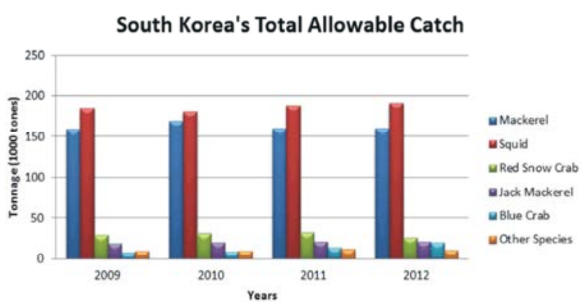

Fig. 2: South Korean Total Allowable Catch

Table 1: Estimated Variables for Mackerel fishery in South Korean Waters

Variables	Model Exponential Model Calculation
q (Catch-ability Coefficient)	0.00000274
k (Environmental Carrying Capacity)	16067267
r (Intrinsic Growth Rate)	0.081489
c (Cost per Haul)	10875000 Won
p (Price per Kg)	1515 Won
D (%)(Social Discount Rate)	6.64
E_{MSY} *	29562.0438
E_{MEY} *	23176.83835

*Author Calculation Source: Korean Maritime Institute (KMI) Report (2012)

MATERIAL AND METHODS

The discount rates individuals use in terms of their investment and consumption decisions should, in general, be different to the rates decision makers investing on behalf of society use. This is because individuals do not live forever while a society which values the welfare of both current and future generations has a much longer planning horizon. In the case of an individual, the planning horizon is unlikely to exceed more than a few decades. Indeed, in financial markets the longest-lived instruments rarely exceed 40 years in duration. Consequently, individuals will discount the future costs and benefits more heavily, the further they occur into the future, than will a decision-maker acting on behalf of society.

Private discount rates will exceed the social discount rate if taxes create a wedge between the actual and after-tax returns. To compensate for the tax, an individual requires a higher rate of return (and thus discount rate) for a private investment to be profitable. Private discount rates can also be higher than the social discount rate if individual investments impose external costs on current and future generations [3]. It can also be argued that the discount rate for publicly funded projects should reflect a risk-free rate of return because of the pooling of risk available to governments which cannot be done to the same extent by individuals undertaking risky investments.

Economic theory provides guidance on how to determine the social discount rate. The derivation of a social discount rate assumes that social welfare be maximized over an infinite time horizon subject to a constraint where an aggregate capital stock yields an output or income that can be either saved or consumed. Assuming that social welfare can be represented by an infinitely lived representative agent and welfare is a function of consumption, the following result (sometimes called the Ramsey rule) can be derived:

$$D = \delta + \gamma f \quad (1)$$

where D is the social rate of time preference (the discount rate society should use) that discounts consumption, δ is the 'inherent' discount rate that discounts future utility or welfare, γ is the curvature of the welfare function and is defined as the income elasticity of marginal utility or the extent to which marginal utility of income is reduced as income increases and *f* is the rate of growth in per person consumption.

Ramsey [4] argued that $\delta = 0$, that placing a lower weight on the utility of future generations is 'ethically indefensible'. It should be clear, however, that setting $\delta = 0$ does not imply that the social discount rate or D is zero. By contrast, individuals have a pure rate of time preference that is positive because they must discount their own utility or welfare as no one lives forever. It seems reasonable to set δ very low or even zero, as proposed by Ramsey.

Historical rates of gross domestic product (GDP) growth in western economies over the past 30 years have ranged from about 2 to 3% [5].

In South Korea the smallest constant social discount rate that should be for projects with a long-term planning horizon is 6.5 which assumes parameter values of $\delta = 0.5$, $\gamma = 3$, f = 2.

Now we analyze the effect of various parameters on the path to MEY in a generic dynamic fishery model. The model is formulated as a continuous time optimal control problem. Both deterministic and stochastic settings are considered. In this study uncertainty components in the stochastic setting are represented by Brownian and Poisson diffusions with state-dependent magnitudes. The level of MEY biomass at any point in time is not constant, but can change following changes in fish prices, fishing costs and the discount rate. Here we explores how changes in these three factors affect the MEY harvest size and stocks in any given year and the trajectory of MEY harvests and stocks over time. The simulation was carried out for the baseline scenario (Mackerel case) and three scenarios, modeling the effect of changes in fish prices, fishing costs and the social discount rate change, respectively.

Both deterministic (full certainty) and stochastic (uncertainty) settings were considered. In the stochastic setting, uncertainty takes two forms, namely:

- Expected variation in year-to-year catch-per-unit effort-the catch quantity associated with a unit of effort, such as number of times net has thrown in the sea-as a result of seasonal variation in stock abundance and fisher behavior (included in the model as a Brownian diffusion)
- Periodic events that affect either fish stocks or fisher behavior strongly enough to change the trajectory of catch-per-unit effort (included in the model as a Poisson diffusion).

Both diffusion patterns incorporate assumptions on state-dependent magnitudes. The Brownian motion is represented by the normal random motion of the stock of fish through time, representing positive and negative natural shocks. The Poisson process involves jumps (due to unpredicted events) in the stock of fish at a point in time and is incorporated in the model as negative shocks caused by, for example, harvest activities.

Under these stochastic assumptions, analysis shows that the MEY harvest size in each time period will be more conservative than in the deterministic case and the optimal stock sizes greater. This will be the case for any change in fish prices, fishing costs or the social discount rate.

The technique used to solve optimal control problems of this sort is the parametric linear programming approach, as introduced in Kompas and Che [6]. For each scenario, the dynamic optimization problem is solved separately, without using a perturbation technique, to guarantee the highest possible accuracy. After a problem is solved, the optimal trajectory is simulated over the time interval (0, 25). The initial fish stock is assumed to be at MEY in all scenarios, but this value can be set at any arbitrary starting point. In addition to graphs that show the entire time horizon, some key points in time are also presented, that is t = 0, 5, 10, 15, 20and 25 years. At each point and under each scenario, the MEY harvest size and associated fish stock level is reported as a percentage deviation from the baseline scenario. Among these, the deviations at timet = 0 and t = 25 years convey the most important implications. As the initial fish stock is assumed to be at MSY for all cases, the difference in harvest at t = 0 represent the immediate impact of a shock. At time t = 25 years when the fish stock becomes stable at the steady state, the difference in stocks of different scenarios represents the long-run impact. This shows how a shock affects MEY harvest or biomass.

For illustrative purposes, a generic dynamic fishery model is used where the transition path of the fish population has deterministic and stochastic components. The deterministic component is the difference between a logistic fish growth function and harvest. The stochastic component consists of two types of diffusions:

a Brownian motion and a Poisson process with negative magnitude. The Brownian diffusion represents neutral natural shocks while the Poisson (diffusion represents negative shocks caused by, for example, harvest activities. The magnitudes of both shocks are stock size dependent.

In equation 2,X is the fish stock, K the maximum carrying capacity, r the intrinsic growth rate or key biological parameter, H harvest, W a standard Brownian diffusion, σ a Poisson diffusion with an arrival rate $\theta > 0$, the transition of the fish population is described by the stochastic differential equation:

$$dB = \left[rX\left(1 - \frac{X}{k}\right) - H \right]dt + \mu_B(X)dW + \mu_P(X)d\sigma \quad (2)$$

Where $\mu_B(X) > 0$ and $\mu_P(X) < 0$ are the magnitudes of the Brownian and Poisson diffusions.

The profit function for fishing activities is standard. Fishing revenue is $\left(\frac{\text{p}}{\text{H}^{\alpha}}\right) \times H$ with $0< \alpha < 1$ where $\frac{\text{p}}{\text{H}}$ is the sale price, with the price elasticity α. Fishing cost per unit is proportional to fish density with a cost parameter c , so that the return to fishing or profit is

$$\pi(X,H) = \left(\frac{\text{p}}{\text{H}^{\alpha}}\right) \times H - \left(\frac{c}{X}\right) \times H \quad (3)$$

The optimal harvest profile and/or the maximum net present value function is

$$NPV(X_O) = \max_{H(t)} E_0 \int_0^{\infty} e^{-Dt} \left\{ \left(\frac{\text{p}}{\text{H}^{\alpha}}\right) \times H - \left(\frac{c}{X}\right) \times H \right\} dt \quad (4)$$

In this generic model the *k* or the virgin biomass is set equal to 16067267, the discount rate is 6.5% and the growth rate *r* is 0.081489. Both deterministic and stochastic models are solved. In the deterministic model, there is no uncertainty. In the stochastic model, the parameters are also taken from Grafton *et al.* [7] with specific uncertainty values: $\theta = 0.10$, $\mu_B(X) = 0.05x$, $\mu_P(X) = -0.13x$.

RESULTS AND DISCUSSION

Effect of change in Mackerel Market Price: The fish price is assumed to increase/decrease by 10, 20 and 30% from the reference case. In particular, the analysis focuses on the evolution of the optimal harvest and the path to MEY in these three scenarios relative to the baseline case. The price decline directly influences the optimal harvest. With a fall in the price of fish it is economically profitable to harvest less and thus decrease the per-unit cost of fishing. On the other hand, price increase will make fisherman eager to catch more and increase her/his profit. In Figure 3 and 4 we show the harvest Evolution both with Deterministic Model and Stochastic Model.

The exact price effect in terms of path to MEY harvest is measured first in terms of the immediate impact of the price shock to harvest levels at t = 0 in all cases. At this point, there is no stock effect as the stock size is the same in all cases. The dynamics of the shock effect on the harvest are also illustrated in Table 2. For example, in the deterministic model a reduction of 10 per cent in the fish price, will result in around a 10.25 per cent drop in the optimal harvest size while the drop will be 20.45 per cent if the price reduction is 20 per cent and 30.37% if the price reduction is 30% (Table 2). Along a row, the difference reduces slightly over time as the 'stock effect' (less harvesting increases the stock of fish) starts to take place. However, the price effect still dominates even when the fishery reaches its MEY at t = 25 .

Effect of Change in Mackerel Fishing Cost: This section presents analysis of the effect of shocks to the cost of fishing on the path of t = 0 harvest. The fishing cost is assumed to increase/decrease by 10, 20 and 30%. The effect of the shocks on the optimal harvest is again characterized by two components, the cost effect and the stock effect. The cost increases, relative to the base case, directly influence the MEY harvest through the incentive to catch fish. The number of fish caught will be fewer and1 the stock will be greater which generates the stock effect. The cost effect can be measured by comparing the harvest at t = 0 as there is no stock effect at this point. This is the immediate impact of a cost increase. The reductions in harvest for the three scenarios are 11.39, 21.31or 30.81%. It is clear that at a higher cost of fishing, the optimal harvest will be less. The dynamics of the shock effect on the harvest are illustrated in (Table 3).

Figure 5 and 6 show the harvest evolution with Deterministic and Stochastic Model.

Effect of Changes in the Discount Rate: Here the problem is solved for 4 different rates of time discount: 6.64 (Actual) per cent, 10 per cent, 15 per cent and 20 per cent. Results show that an increase in the discount rate increases harvest, as fishers prefer more current to future income. A lower discount rate has the opposite effect.

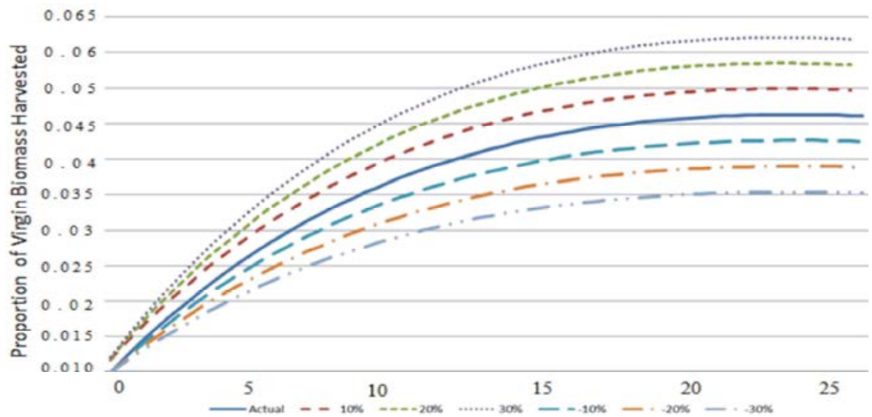

Fig. 3: Harvest Evolution of the Deterministic Model with Different Mackerel Prices

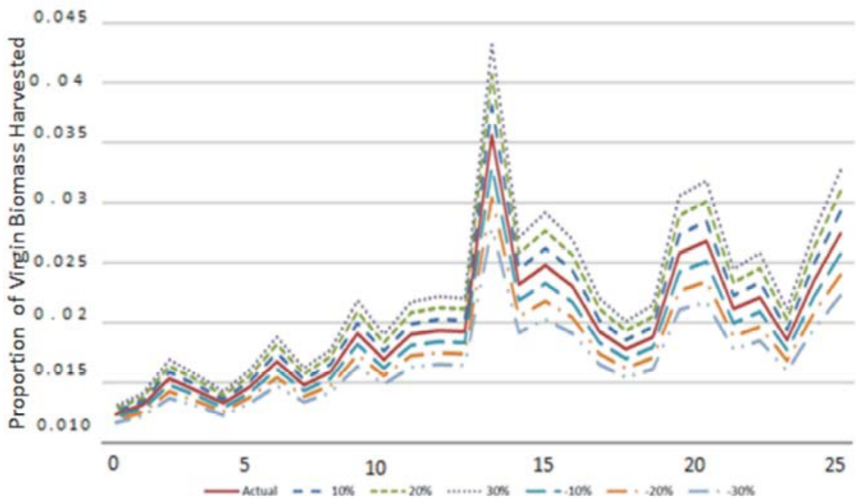

Fig. 4: Harvest Evolution of the Stochastic Model with Different Mackerel Prices

Table 2: Mackerel Fishing Price Shocks and Optimal Harvest in the deterministic Model (H_{MEY})

	Change in Optimal Harvest Relative to the Reference Case (%)					
Price Increase/Decrease by/Year	-10%	-20%	-30%	10%	20%	30%
0	-10.25	-20.45	-30.37	9.69	19.31	28.81
5	-10.19	-20.35	-30.48	9.76	19.47	29.09
10	-10.15	-20.29	-30.40	9.80	19.56	29.25
15	-10.13	-20.25	-30.35	9.82	19.61	29.34
20	-10.12	-20.23	-30.32	9.84	19.65	29.40
25	-10.11	-10.21	-30.30	9.85	19.67	29.44

Table 3: Mackerel Fishing Costs Shocks and Optimal Harvest in the deterministic Model (H_{MEY})

	Change in Optimal Harvest Relative to the Reference Case (%)					
Cost Increase/Decrease by/Year	-10%	-20%	-30%	10%	20%	30%
0	12.75	22.15	31.22	-11.39	-21.31	-30.81
5	12.59	24.059	32.48	-11.15	-21.17	-30.54
10	13.25	24.25	33.40	-10. 94	-20.56	-30.33
15	13.45	24. 66	34.35	-10.45	-20.56	-30.33
20	13.45	24.76	34.46	-10.45	-20.56	-30.33
25	13.55	24.85	34.70	-10.46	-20.50	-30.25

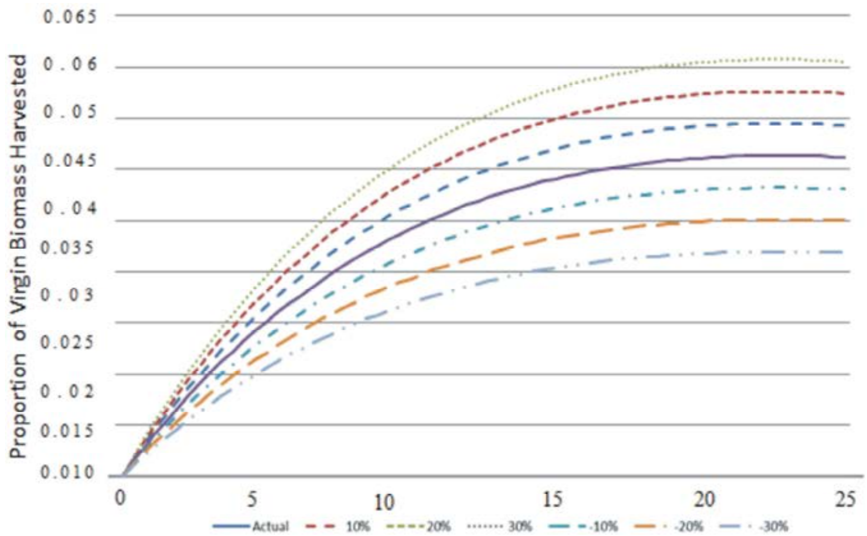

Fig. 5: Harvest Evolution of the Deterministic Model with Different Mackerel Fishing Costs

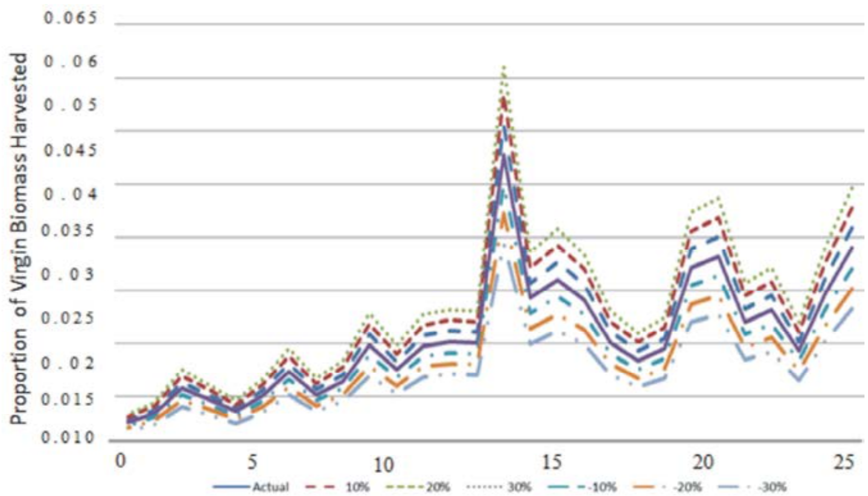

Fig. 6: Harvest Evolution of the Stochastic Model with Different Mackerel Fishing Costs

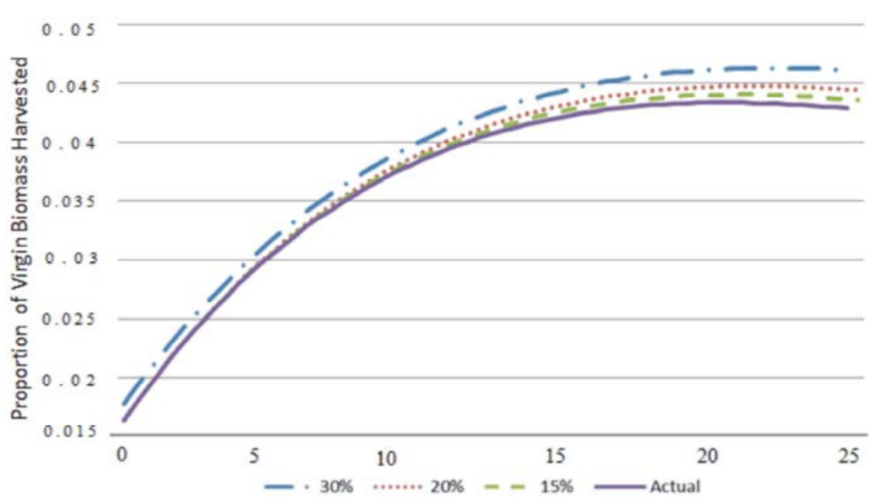

Fig. 7: Harvest Evolution of the Deterministic Model with Different Discount Rate

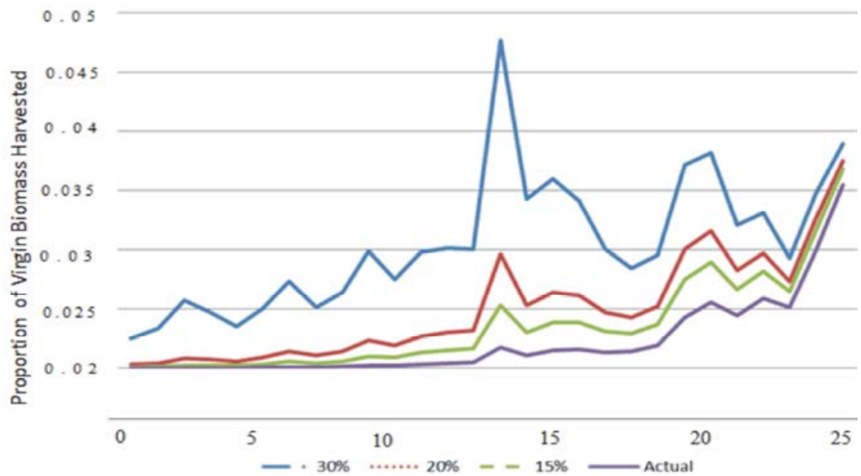

Fig. 8: Harvest evolution of the stochastic model with different discount rates

Table 4: Mackerel Fishing Discount Rates Shocks and Optimal Harvest in the deterministic Model (H_{MEY})

Cost Increase/ Decrease by/Year	Change in Optimal Harvest Relative to the Reference Case (%) 6.64%	15%	20%	30%
0	-2.67	2.61	4.64	6.27
5	-1.92	1.80	3.23	5.45
10	-1.67	1.60	2.91	4.60
15	-1.61	1.57	2.87	4.55
20	-1.61	1.57	2.87	4.55
25	-1.60	1.55	2.87	4.55

High social discount rate will push fisherman to catch more and start an Olympic race among fishermen. Hence, low social discount rate will make fisherman to leave the stock. This is illustrated in Figures 7 and 8.

The overall effect of a change in the discount rate is not as strong as for changes in the price of fish and fishing costs. The deviations from the baseline scenario at some key points in time are in Table 4. At t = 0, the deviations are less than 5% in all cases. The effect of changes in the discount rate depends on the specific characteristics of this fishery.

DISCUSSION

Mackerel is transboundary specie that migrates in waters between China, South Korea and Japan. As the lack of data is always an issue we decided to analyze the effect of change in fishing costs, market price and discount rate change in Mackerel Fishing for South Korean fisheries. As we have showed changes in cost and prices have more effect on increasing harvest and so over-exploiting the stocks. Also Discount rate can force fishers to be more eager in order to harvest.

Setting a proper MEY for each country helps South Korea, China and Japan to become closer and reach to a cooperative solution for this transboundry stock. These countries need to negotiate on their discount rate and the ways they can reach to stable discount rate among themselves. For this reason China need to decrease, South Korea need to make stable and Japan need to increase its discount rate. As we discussed social discount rate is usually not related to only one factor, so it is not easy for countries to

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