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Rent Dissipation and Potential Rents in the North Sea Herring Fishery

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ABSTRACT. *The paper assesses the potential for rent generation, distinguishing between resource and intra-marginal rent, in the North Sea herring fishery. A bioeconomic model combining fish population dynamics with the economic structure of the fishery is used to generate equations to compute the different rents. A combination of biological data with vessel-level economic data for UK pelagic trawlers is employed in estimations. In order to assess the dynamics of both resource and intra-marginal rent generation, the model is evaluated under various assumptions with regard to price, cost, and discount rate. Potential total rents are measured at £90-91 million annually of which resource rent makes up about £89.0 million with intra-marginal rent measured in the order of only £2.0 million. This compares to an actual rent in 2007 estimated at £ 16.3 million. The results show that, in this fishery, rent is dissipated almost entirely due to excess effort while very little is dissipated due to suboptimal stock size.*

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I. INTRODUCTION

Given the current state of the economic health of marine fisheries worldwide (World Bank 2009; FAO 2012), management measures that are effective in bringing the resources back to a healthy state hinge on accurate evaluation of the current performance as well as the potential performance of the fishery. The concept of resource rent has been a key indicator of performance in the fishery and has been a dominant theme in the fisheries literature (Holman and Wilen 2005; Coglan and Pascoe 1999; World Bank 2009). Dissipation of resource rent is due to mismanagement of the resource (e.g. Bjørndal and Munro 2012). From this, the degree to which a regulated fishery brings about desirable outcomes from what would emerge under open access is measured by rent generated (e.g. Squires and Kirkley 1995; Bertignac et al. 2001; Asche et al. 2008, 2009; World Bank 2009; Bjørndal and Munro, 2012).

Maximum resource rent is obtained by optimising effort and harvest as well as stock size. Without regulation, the common property nature of most fishery resources and the associated free entry of factor inputs lead to the dissipation of resource rent (Gordon 1954; Homans and Wilen 2005). While this is true, Copes (1972) argues that the notion that open access fisheries yield no rent ignores the rent that may be earned by intra-marginal factor units employed in the fishery.[1] Furthermore, since unit operating costs are sensitive to stock size (Bjørndal 1988; Hannesson 2007), there will be rents associated with this 'stock effect' (Stoeven and Quaas 2012). What this tells us is that fisheries rent is really the combination of resource rent and intra-marginal rent, in which the latter is associated with the earnings of intra-marginal factor units. Thus, resource rent is the

[1] See, Coglan and Pascoe (1999); Bromley (2008); Geen and Nayar (1988); Nugeyen et al. (2012).

return to the fish as an input while intra-marginal rent results from cost differences in harvesting intra-marginal units. Cost differences for intra-marginal units result from the concavity of the aggregate harvest function.

The purpose of this paper is to assess the resource and intra-marginal rents for the North Sea herring fishery under current as well as optimal management. This is of great interest, as such a study has not previously been undertaken.

Data for the UK pelagic trawl fleet are used to approximate the profit structure for an average vessel fishing herring in the North Sea. Our empirical strategy follows Arnason (2011), who estimates a global fishery model and obtains numerical estimates of the rent loss in the world's ocean capture fisheries. *The Sunken Billions* report (World Bank, 2009) assesses the alternative trajectories of the management of global fisheries and estimates a maximum resource rent of $50 billion per year under optimal management, which compares to current aggregate rents of zero. In other words, rents are depleted due to overexploitation of stocks and excessive application of fishing effort.

The major departure of our study involves the use of a dynamic bioeconomic model that combines population dynamics with the economic structure of the fishery to estimate resource rent and intra-marginal rent under optimal levels of stock and harvest. Approaching rent in this way enables a more transparent assessment of the effectiveness of alternative management instruments on the dynamics of the two types of rent in a unified framework.

The paper is organized as follows. Section II defines resource and intra-marginal rent and provides a review of the relevant literature on rent in the fisheries. This is followed in section III by an overview of the North Sea herring fishery as well as a description of UK fleet and vessel statistics including an evaluation of current economic profits in the fishery. A bioeconomic model, consisting of a model of population dynamics and an aggregate profit model, is formulated and conditions for a dynamic optimum are derived in section IV. Estimation, calibration and simulation results of the dynamic optimization are reported in section V. Concluding comments are offered in the final section.

II. RESOURCE AND INTRA-MARGINAL RENTS

The concept of resource rent extends from the more general concept of returns to a factor in fixed supply and is defined as the payment to a resource in fixed supply (Robinson 1939; Arnason 2011). With supply restricted, the marginal net benefit of using the resource is positive and represents rent. Technically, the difference between marginal revenue at the socially optimal level of output (the level at which the marginal social revenue equals the marginal social cost) and the opportunity costs of labour and capital (social cost) is the rent yielded by the resource (Cook and Copes 1987; Copes 1972).[2]

Rent in the fishery is maximised at the output level corresponding to the maximum present value of returns from the fishery, subject to resource dynamics, with supply price equal to the shadow value of the resource. If the fishery is not optimally managed, marginal returns will be less than the shadow price. If there are no restrictions on the harvest rate the price associated with supply will be zero and consequently rent is zero. This coincides with the popular statement that for an open access fishery with no harvest constraints, resource rent is zero (Arnason 2011).

[2] It is important to note that resource rent depends on prices of capital, technology and previous investments as well as variable inputs and not only the resource itself.

Even in open access where the resource rent accrued is zero fishermen could enjoy benefits from the fishery in the form of producers' surplus (Copes 1972; Jonsson and Libecap 1982; Jonsson 1995; see also economic analysis of UK fleet below). Producers' surplus consists of the rent that intra-marginal inputs of labour and capital receive (Stoeven and Quass 2012; Edwards 2005). There are two sources of intra-marginal rent; those associated with efficiency differentials of units of factors employed in the fishery[3] and those due to the stock effect. This latter effect exists due to increasing cost of harvest with respect to the level of the stock. This is an important point; constant unit cost per harvesting implies no intra-marginal rent but costs increasing per unit of harvest with respect to declining stock levels will generate intra-marginal rent. Increasing costs with respect to harvest implies that the harvest function and, the dual profit function are concave in inputs (Bjørndal, 1987).

Figure 1 shows profit and marginal profit curves for different levels of harvest and helps clarify the distinct values of resource and intra-marginal rent. The profit function increases at a decreasing rate because of the concavity of the harvest function. As stock levels decrease, the unit cost of harvest increases, resulting in concavity of the harvest function. From this the marginal profit function, i.e., the derived demand for fish, is downward sloping. Under regulation optimal harvest is enforced at H^*, resulting in a return to the fixed factor, resource rent, of the rectangular area of *ABDE*. In other words, resource rent per unit is constant. The triangular area *BCD* is defined as intra-marginal rent (producer surplus), i.e., return to factors of production in excess of opportunity cost. The sum of intra-marginal and resource rents is the total variable profit associated with

[3] Copes (1972) argues that efficiency differences across vessels and differences in opportunity for factor inputs can generate intra-marginal rent.

the extraction of a fishery resource, i.e., total revenues minus variable costs (Arnason 2011).

Understanding the distinction between the concepts of resource and intra-marginal rents has important resource management implications. In particular, the maximisation of overall societal benefits from fishery resources depends on whom the respective benefits accrue to and who manages the resource.[4] In line with this, Bromley (1990, 2009) argues that exclusive property rights necessary for sustainability disregards the distributive aspects of resource use. Indeed, Bromley (1990) argues that the efficiency criterion (Pareto test)[5] does not fully comprehend what the public and its decision makers need and expect from economists as the collective interest transcends the reductionist Pareto rule.

Similarly, Copes (1972) argues that the consideration of resource rent should be balanced with that of competing social benefits derived from the exploitation of a fishery. Indeed, the benefits to society of renewable resources are maximised when resource rent, consumer surplus and producer surplus are taken into consideration in resource harvesting (Copes 1972; Stoeven and Quaas 2012).

Stoeven and Quaas (2012) extend Copes (1972) by focusing on the dynamic aspects of the fishery and the distribution of benefits from a fishery resource when stock effects are taken into account. Accordingly, they find that sole ownership increases the

[4] A common theme is that rent is generated from a reduction in fishing effort. One might also suspect that optimal management may alter the structure of the harvest process itself and moreover, the basic supply-demand relationships in the market (Homas and Wilen 2005; Arnason 1993).

[5] Efficiency via the Pareto test does not lend itself to precise or objective measurement of the ability of the gainers to compensate the losers and does not lead to an unambiguous improvement in social welfare. There is no discernible social consensus for economic efficiency via the Pareto test (Mishan 1980; Bromley 1990).

present value of consumer surplus and labour surplus if harvesting costs do not depend on stock size. With stock effect however, only producers are bound to definitely benefit, with consumers and labourers (fishermen) preferring open access to sole ownership. This is because harvesting productivity increases with stock size and optimal steady-state stock size under sole ownership is lower with the stock effect than without. This negatively affects labourers because the unit labour requirements are lower at high stock sizes. Similarly, consumers also lose out on privatization if the stock effect is strong enough and the discount rate small enough for the quantity supplied in the market to be small.

III. THE NORTH SEA HERRING FISHERY

North Sea autumn-spawning herring (*Clupea harengus L*) consists of three spawning stocks with spawning grounds east of Scotland, east of England and in the English Channel. The three stocks mix on the feeding grounds and in the central and northern North Sea, and it is customary by ICES and others to treat North Sea herring as one stock. Herring become sexually mature in age group two and can live as long as 15 years. The herring fishery has a season running from May until September.

After World War II, the stock may have been close to the carrying capacity of the environment due to low fishing pressure. After this period, open access, combined with the development of new technologies in the 1960s and 1970s substantially increased fishing pressure. This caused the stock to be driven to near extinction in 1977, when a moratorium was introduced (Bjørndal 1988). Various regulations have been in effect ever since so as to allow for a sustainable fishery (Bjørndal and Lindroos 2004).

Spawning stock biomass (SSB) for the period 1960-2007 is illustrated in Figure 2. There have been substantial variations in stock size over this period. In 1960, the SSB stood at 1.85 million tonnes, increasing to almost 2.2 million tonnes in 1963. This year saw the introduction of the power block[6] that led to rapid stock depletion, with the stock reaching a minimum of 47,000 tonnes in 1977, when the moratorium was introduced. The figure shows that the stock recovered reasonably quickly. For the years 1988-90, SSB averaged around 1.2 million tonnes. In the period 2001-06, SSB varied in the range 1.3–1.8 million tonnes but it was reduced to 977,000 tonnes in 2007. The Blim[7], the level below which the stock should not be reduced as this would endanger future sustainability is set at 800,000 tonnes, implying that the current fishery is sustainable.

Since the introduction of Extended Fisheries Jurisdiction (EFJ), North Sea herring is jointly managed by Norway and the European Union (EU). A Total Allowable Catch (TAC) quota is determined for the sustainable management of the stock; Norway receiving a 29% share and the rest to the EU. The sharing is largely based on the zonal attachment of the stock to the Exclusive Economic Zones (EEZs) of Norway and the EU. Within the EU, the TAC is shared according to the principle of relative stability. Quotas are allocated among member states in such a way as to ensure the relative stability of the fishing activities of each member state for each stock concerned. The principle of relative stability is based on historical catch levels and geographical distribution for the main commercial species among member states.

[6] A mechanical winch that was used to pull in the seines, allowing for much larger nets and eventually larger vessels.
[7] See Horwood (1999).

Total landings of herring are also graphed in Figure 2. Landings increased from about 700,000 tonnes in 1960 to almost 1.2 million tonnes in 1965, and were maintained at a high level into the 1970s, despite a declining stock size. Note that in the years 1968-76, annual catches exceeded the size of the SSB[8]. Landings were reduced to 46,000 tonnes in 1977, when the moratorium was introduced, and stayed at a low level until the fishery was reopened in 1981. Landings in 2006 were recorded at more than 500,000 tonnes, falling to 400,000 tonnes in 2007. Norway often records the highest catch followed by Denmark. The Netherlands and UK are also important participants in the fishery. In 2007, UK catches were 90,500 tonnes.

Regulations of the fishery vary from country to county. In Norway, vessels are regulated with individual quotas that are not transferable, whereas in Denmark and the Netherlands, individual transferable quotas are used. In the UK, firms receive quota allocations via producer organisations but larger companies can receive allocations directly from the government. The quotas are to a certain degree transferable.

In Figure 3, recruitment in year t+1 is plotted against spawning stock in year t.[9] The plot suggests recruitment is increasing in SSB but eventually levels off and declines. These data will form the basis for estimation of recruitment functions in empirical work.

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[8] Catches include juvenile herring that are part of the total biomass but not the SSB. For example, in 1974 total landings were about 275,000 tonnes. Total biomass and SSB, at the beginning of the year, were 912,000 and 162,000 tonnes, respectively. By the time the fishing season started, both total biomass and SSB would have grown. Thus, the harvest of 275,000 tonnes would be from a larger stock, and a substantial part of it would be immature herring.

[9] The data available for analysis is annual data for the period 1960-2007. The data includes information on recruitment, spawning stock biomass and landings. The data are available from the authors on request.

United Kingdom fleet and vessel economics

For the UK, pelagic trawlers over 40 m harvest most of the herring. These vessels are based predominantly in Shetland and the north east of Scotland. The vessels harvest mackerel, herring and blue whiting, of which mackerel is most important in terms of quantity and value. Mackerel and herring are mainly used for direct human consumption, while blue whiting is used for reduction into fish meal and oil. All three species represent targeted fisheries occurring in different seasons of the year and do not overlap in the catches.

The price of herring has been increasing in recent years and was recorded at £290/tonne in 2007. Herring is sold into an international market in competition with close substitutes such as Norwegian spring spawning and Icelandic herring. It is the total supply of herring of which North Sea herring is a small part that, in conjunction with demand, will determine price.

For the UK fishery we have available revenue data and some fleet statistics for pelagic trawls for 2007 (Table 1).

Table 2 also reports landings for each of the three species that make up total catch. In 2007, mackerel represented a 42.4% share of total catch quantity. Herring represented a 29.09% share and, blue whiting and others made up the remainder of total catch.

Cost data are also available for 2007 from Lappo (2013) and reported in Table 2. Column 2 reports accounting values and column 3 opportunity values (as defined below). The cost data represent vessel averages for total landings. For accounting values, fuel and other operating costs represented more than £1.5 million with crew share adding just less than £1.0 million. Total accounting costs for 2007 amounted to £3.7 million, which divides out to be £375.8/tonne. Based on average landings and revenue characteristics for 2007, vessel accounting profit is measured at £419,920.7 or average profit of £43.2/tonne

Lappo (2013) modifies the accounting data to obtain opportunity values. Labour is remunerated according to a share system and in 2007 average crew share per crewmember was £81,993.9. This is believed to be higher than the alternative cost of labour, which for these fishermen might be working on supply ships in the North Sea. For the current purpose, labour cost is set at £65,000 per man-year so that total annual labour (full-time equivalent, Table 1) costs represent £455,000. Further, capital costs are represented by depreciation and interest, where the latter should be estimated on the basis of the alternative/opportunity cost of capital. Capital costs are measured using the insurance value of the vessel on the assumption that this represents the alternative cost of boat and gear.[10] The interest rate is set at 5% with depreciation over 15 years. Using the annuity method, annual depreciation and interest opportunity value represent £1,235,161.4. The opportunity value[11] modifications are listed in column 3 of Table 2. Again based on average landings and revenue characteristics for 2007, vessel opportunity profit is much lower and measured at £281,812.3 or average profit of £28.96/tonne.

Next, using opportunity values we measure actual profit only for the herring fishery. In 2007, herring price is £290/tonne and UK herring catch is reported as 90,585 tonnes. We allocate fixed costs on a pro rata basis, i.e., according to proportion of herring in total catch (29.09% in 2007). This gives a 2007 average cost (opportunity value) of

[10] Insurance value for the vessel is only available for 2006 and valued at £12,630,800. Lappo (2013) assumes this value for 2007 adjusted for inflation.
[11] Fuel and other operating costs, and insurance, repairs and maintenance maintain their accounting value as opportunity value.

£390/tonne and results in a profit of -£9.1 million. On the other hand, if we allocate no portion of fixed costs to the herring fishery based on an argument that it is a marginal fishery for the fleet with the mackerel fishery as the most important in terms of catches and revenue (Bjørndal 1987) it would be profitable as long as revenues cover variable costs.[12] Variable costs per vessel, including repairs and maintenance, amount to £2,559,895.3 per year or £263.1/tonne. With the other assumptions in place, this would give rise to a profit for the UK herring fishery in 2007 of £2.4 million. It is interesting to note that, due to the sharing system in place in this fishery, some resource rents accrue to the crew.

In the next section, a bioeconomic model is estimated and calibrated to define optimal stock and harvest levels and predict potential rents. Based on potential total rents we calculate both resource and intra-marginal rents.

IV. THE BIOECONOMIC MODEL

Changes in the biomass of a fish stock over time will come from additions to the stock due to recruitment and natural growth, and deductions from the stock due to natural mortality and harvesting. The interactions between recruitment, natural growth, natural mortality and harvesting have been fundamental in the development of the model of population dynamics, which has previously been used as part of bioeconomic analyses of North Sea herring (Bjørndal 1987; 1988). The following delay-difference equation will be used to explain changes in the biomass over time:

[12] A good review of allocating costs in public arena is found in a collection of papers edited by Young (1983).

$$S_{t+1} = (S_t - H_t)e^{Z-M} + G(S_{t-\gamma}) \qquad [1]$$

where S_{t+1} spawning stock biomass in year t+1 and H_t is harvest in period t, both measured in tonnes. $G(S_{t-\gamma})$ is recruitment to the stock, taking place with delay of γ periods. Z and M represent natural growth and mortality, respectively.

The first argument on the right-hand side of equation [1] denotes stock changes due to natural growth, natural mortality, and harvesting. In the model, it is assumed that harvesting occurs in a short season at the beginning of the period.[13] The escapement, $S_t - H_t$, grows at the net instantaneous growth rate $Z–M$. The second argument on the right-hand side of equation [1] represents addition to the stock due to recruitment, which is assumed to occur at discrete time intervals. Moreover, recruits will normally join the parent population several years after spawning. We postulate that

$$R_{t+1} = g(S_t) \qquad [2]$$

where R_{t+1} is the number of recruits to the juvenile population as a function of the previous periods spawning biomass. A certain fraction, λ, will survive the juvenile stage and join the spawning stock, so that

$$g(S_{t-\gamma})\lambda \qquad [3]$$

is the number of recruits joining the spawning stock with a delay of γ periods. The delay occurs while the juveniles mature to spawning age. Letting w denote the weight of new recruits, we get

$$G(S_{t-\gamma}) = g(S_{t-\gamma})\lambda w \qquad [4]$$

[13] Alternatively, we could assume that the fishery takes place at the end of the period, without affecting the qualitative nature of the model.

where $G(S_{t-\gamma})$ denotes recruitment in weight to the spawning stock.

Herring spawn in September and the following year recruits, called zero-group herring, join the juvenile population as indicated by equation [2]. After another two years the survivors (equation [3]) become sexually mature and join the spawning or adult population (equation [4]). Thus for this species, $\gamma = 2$, and the delay between spawning and recruitment to the spawning stock is three years.

Before proceeding to the production function, the behaviour of the model under natural conditions will be considered. In the absence of fishing, equation [1] is reduced to

$$S_{t+1} = S_t e^{Z-M} + G(S_{t-\gamma}) \qquad [1']$$

Under natural conditions, a fish population will grow towards its carrying capacity, which is the upper limit of the stock size $(\bar{S})$ as determined by environmental conditions. However, in equation [1′], it is assumed that Z and M are constants or $Z - M = \delta$. In reality, both natural growth and mortality will be density-dependent; the former because there will be relatively more food available to a small stock than to a large one and for the latter because predation and cannibalism depend on stock size. From this we can write $\delta(S_t)$, $\delta = \delta(\bar{S})$ and $\delta(\bar{S}) \leq 0$, and equation [1] can be restated as

$$S_{t+1} = (S_t - H_t)e^{\delta(S_t)} + G(S_{t-\gamma}) \qquad [5]$$

We assume the fishery is managed by a sole owner, with the objective to maximize the present value of net revenues from the fishery. The net revenue function is given by

$$\pi(H_t, S_t) \qquad [6]$$

Maximizing equation [6], subject to changes in the population level given by equation [5] gives a discrete time dynamic bioeconomic model, with H_t and S_t as control and state variable, respectively. The method of Lagrange multipliers can be used to derive equilibrium conditions for an optimum (Clark 1976):

$$L = \sum\{\alpha\pi(H_t, S_t) - q_t[S_{t+1} - (S_t - H_t)e^{\delta(S_t)} - G(S_{t-\gamma})]\} \quad [7]$$

where $\alpha = 1/(1+r)$, r is the interest rate and q_t is the discounted value of the shadow price. Carrying out the optimization, an implicit expression for the optimal spawning stock $S^*$is derived:

$$e^{\delta(S^*)}\{[\pi_S + \pi_H]/\pi_H\} + \delta'(S^*)[S^* - G(S^*)] + \alpha G'(S^*) = 1 + r \quad [8]$$

The term $((\pi_S + \pi_H)/\pi_H)$ is the marginal stock effect (MSE) in a discrete time nonlinear model (Bjørndal 1988). The MSE represents the impact of stock density on harvesting costs. This effect will cause an increase in the optimal stock level, in steady state. Intuitively, it can be understood by considering that an increase in stock size will increase catch per unit effort and hence reduce unit-harvesting costs.

V. DYNAMIC OPTIMISATION

The functional structure of the model of population dynamics[14] that will be used in the estimation of the optimal stock level is the combination of the Ricker stock-recruitment function and the linear net growth function. The estimated model of population dynamics is thus:

$$S_{t+1} = (S_t - H_t)e^{(0.894 - 0.39\cdot 10^{-3}\cdot S_t)} + 1.63\cdot 10^{-3}\cdot S_{t-2}e^{(0.96\cdot 10^{-3}\cdot S_{t-2})} \quad [9]$$

[14] Various functional forms both for stock recruitment and the net growth function have been estimated and are available from the authors on request.

where the carrying capacity, $\bar{S}$, is 2,386,000 tonnes, stock level corresponding to Maximum Sustainable Yield (MSY), S_{msy}, is 1,284,000 tonnes with MSY at 424,300 tonnes.

The model population dynamics is illustrated in Figure 4. To facilitate graphical representation of a function involving a time lag, a steady-state stock level is assumed. The harvest quantity is represented by the difference between S_{t+1} and the 45◦ line. It is noteworthy that the estimated steady-state harvest quantity is fairly constant over a wide range of stock values.

The harvest in period *t* is defined as:

$$H_t = \mathrm{H}(K_t, S_t) = aK_t^b S_t^g \qquad [10]$$

where K_t is fishing effort in period *t*, and *a*, *b* and *g* are parameters defining the harvest production characteristics. The number of participating vessels is used as a measure of fishing effort. Estimated parameters for equation [10] are based on Bjørndal and Conrad (1987) and calibrated as a=0.26, b=0.95, and g=0.5621. The parameter *g* is the output elasticity of stock size and indicates harvest will decrease with decreasing stock size, but relatively less than the change in stock size. The parameter *b* is the output elasticity of effort and indicates that increased effort is met with increased harvest but slightly less than one for one.

The schooling behaviour of herring has permitted the development of very effective means of harvesting. With modern fish finding equipment, harvesting can be viable even at very low stock levels.

We assume cost per unit of effort is constant. Under this assumption, we can write the cost function as:

$$C(H_t, S_t) = cK = c\left(\frac{H_t}{aS_t^{\,g}}\right)^{1/b} \quad [11]$$

where *c* is the cost per vessel per fishing season, which includes a normal return on capital. Using equations [10] and [11], industry profit is defined as:

$$\pi_t = pH_t - cK_t = pH_t - C(H_t, S_t) \quad [12]$$

where *p* is unit price of harvest.

According to the cost data for 2007 annual operating and fixed costs for a pelagic trawler is £3,795,056.7. In 2007, herring represented 29.1% of catches. We will assume that the costs in the herring fishery represent the same proportion out of total cost. Thus, the cost of operating one vessel in the herring fishery for one season is £1,104,000. We consider this the total variable cost of operating one vessel for one season, as such, it is the variable rental cost of operating a vessel for one season. Moreover, as we assume that cost per unit effort is constant, effort (i.e., the number of vessels) can be increased or decreased, without impacting total vessel variable cost.

The analysis of potential rents should be based on prices that will prevail in the future. We will set the price at £ 300/tonne in the analysis of optimal management and the analysis of potential rents, both corresponding to steady state levels. On this basis, we can establish the cost function as:

$$C(H_t, S_t) = cK_t = C\left(\frac{H_t}{aS_t^{\,g}}\right)^{1/b} = 1{,}104{,}000 \cdot \left(\frac{H_t}{0.26 \cdot S_t^{0.5621}}\right)^{1/0.95} \quad [13]$$

and from this industry rents:

$$\pi_t = 300{,}000 \cdot H_t - 4{,}558{,}216.4 \cdot H_t^{1.0526} \cdot S_t^{-0.5917} \quad [14]$$

It is important to note that the underlying assumption is that price and cost conditions for all countries participating in the North Sea herring fishery are similar to those in the United Kingdom.

To find optimal S^* and the corresponding H^*, we solve equation [8], using the estimated model of population dynamics, [9][15] and the profit function, [14]. As the model is nonlinear, the solution is found by numerical methods. Results are presented in Table 3 for discount rates between zero and 10%.

For the case with a zero discount rate, the optimal stock level is 1,409.7 million tonnes. Increasing the discount rate to 5% reduces the optimal level to 1,365.5 million tonnes. For all discount rates evaluated, S^* is greater than S_{msy}. It is also interesting to note that actual stock is larger than S^* in 2005 (1.621 million tonnes) but very much smaller in 2007 (0.977 million tonnes). Optimal harvest for all discount rates is fairly stable at about 427,000 tonnes. This is because the estimated model of population dynamics is fairly flat over a wide range of stock values.

The estimate of cost of effort is based on data for only one year, and it is difficult to allocate costs among the different fisheries. For this reason we will also presents results on the assumption that the cost of operating one vessel in the herring fishery for one season is £ 1,435,200, i.e., one third higher than in the base case. The assumption of a £300/tonne price is maintained. Results are presented in Table 4. Under these alternative assumptions, optimal stock level is higher by about 50,000 tonnes but steady state harvest is somewhat less by about 3,000 tonnes.

[15] Our solution method for the optimal stock and harvest is based on the underlying assumption that $S_t = S_{t+1} = S_{t+2}$, i.e., steady state stock

A sensitivity analysis was also undertaken for a price of £ 350/tonne, with cost per vessel per season at £1,104,000. For a 5% discount rate, the optimal stock level declines to 1.346 million tonnes with optimal harvest increasing by about 1,000 tonnes.

Overall, these results are somewhat robust to changes in price and cost of effort with the optimal stock level in the range 1.3-1.4 million tonnes.

We turn now to calculating potential rents, and resource and intra-marginal rents in the North Sea herring fishery. We estimate potential rents using equation [14] based on stock and harvest estimates as presented in Tables 3 and 4. Potential rents is separated into resource rent and intra-marginal rent in the following way;[16]

Resource rent = $\frac{\partial \pi}{\partial H^*} \cdot H^*$ [15]

Intra-marginal rent = $\pi(H^*, S^*) - \frac{\partial \pi}{\partial H^*} \cdot H^*$

While equation [15] is the expression we use for computing rent and intra-marginal rent, below we show an alternative derivation that analytically distinguishes between two sources of intra-marginal rent; stock effect and factor efficiency differential effect.

Following Stoeven and Quaas (2012), the optimal harvesting plan is derived based on equation [17], which is a combination of equations [10] and [12] and where stock is a choice variable. Note that harvest is a function of stock and taking the partial derivative of equation [17] with respect to stock would imply that taking a partial derivative with respect to harvest as well.

$$\pi(H, S) = pH(S) - c(H(S), S) \quad [17]$$

The first order condition becomes:

[16] See Arnason (2006, 2008, 2011).

$$\frac{\partial\pi(H,S)}{\partial s} = p\frac{\partial H}{\partial s} - \frac{\partial c}{\partial H} * \frac{\partial H}{\partial s} \qquad [18]$$

Rearranging [18] gives

$$\frac{\partial\pi(H,S)}{\partial s} = \frac{\partial H}{\partial s}(p - \frac{\partial c}{\partial H}) \qquad [19]$$

Accordingly, the expression of the intra-marginal rent is transformed to:

$$Intra - marginal\ rent = \pi(H(S),S) - H * [\frac{\partial H}{\partial s}\left(p - \frac{\partial c}{\partial H}\right)] \qquad [20]$$

The term within the square bracket in equation [20] captures the expressions essential in understanding the sources of intra-marginal rent. The first term $\frac{\partial H}{\partial s}$ captures the stock effect (the value of the marginal increase in harvesting productivity). By implication, therefore, this term is associated with the stock effect in intra-marginal rent. The second term is constituted of the difference between price and $\frac{\partial c}{\partial H}$, the change in marginal cost with respect to harvest, which is the source of intra-marginal rent associated with efficiency differentials. It should be noted that because of our assumption of constant marginal and average cost across boats, $\frac{\partial c}{\partial H}$ is zero, implying that in our analysis intra-marginal rent is only derived from the 'stock effect'.

Resource rent is equal to marginal profit evaluated at the optimal harvest level multiplied by optimal harvest level. Intra-marginal rent is equal to variable profits evaluated at optimal levels of harvest and stock minus resource rent. Potential rent, resource and intra-marginal rent, is evaluated under various discount and cost scenarios and the results reported in Table 5.

The top half of the table reports results for a price of £300 per tonne and total costs of £1,104,000 per vessel. Potential total rents are measured at about £90-91 million annually and vary little across alternative discount rates. Resource rent makes up 98% of this value at about £89.0 million with intra-marginal rent measured as the residual in the order of only £2.0 million. Although intra-marginal rent is small, this is what one would expect in a mature fishery. Resource rent represents roughly 69% of total revenue.[17]

The bottom half of the table repeats the exercise using the same herring price but for an increased total cost of £1,468,320 per vessel. Here we observe that potential total rent has fallen to about £79.0 million annually with resource rent representing about 96% of this value. Intra-marginal rent is now measured at about £2.5 million annually.

Table 5 represents potential rents for the entire North Sea herring fishery. Returning to the UK herring fleet and noting that the UK share of total harvest for herring is about 14%, results in a potential profit of about £12.7 million annually. With current profit for the UK herring fishery calculated at about -£9.1 to £2.2 million, depending on how fixed costs are allocated, efficient management of the fishery based on optimal stock and harvest levels allows for substantial improvement in profitable returns to the fishery.

Rent dissipation

We are now able to analyze rent dissipation. This is done in Table 6, for three scenarios. In scenario 1, ‘actual 2007 conditions’, we assume that UK technology, price and revenues are representative for the entire North Sea herring fishery. This year a total catch of 400,000 tonnes was harvested from a stock of 977,000 tonnes. With UK harvesting efficiency, a total fleet of 217.6 vessels would have been applied to the fishery, generating a total rent of £16.3 million.

[17] It is interesting to note that Bjørndal (2008) found potential rent in the Norwegian spring spawning herring fishery to be 69% of revenue, based on 2006 price and cost data.

In scenario 2, '2007 conditions with elimination of excess capacity', we maintain 2007 catch and stock levels but allow for elimination of excess capacity. In this scenario we allow vessels to harvest to capacity and results show that the harvest could have been landed by as few as 38.8 boats[18] (as compared to 217.6 in reality) and would have generated total rents of £87.2 million.

In scenario 3, 'Optimal policy (5% discount rate)', optimal management based on results from Table 5 where stock is allowed to increase to optimal levels (1,365.5 thousand tonnes) and optimal harvest is set at 427.6 thousand tonnes. The number of vessels increases slightly but the higher harvest levels results in a rent of £90.8 million

Table 6 is very informative in identifying the cause of rent dissipation as excess capacity. Moving from scenario 1 to 2 the only modification is allowing individual vessels to harvest to the capacity of the technology available and from this we measure greater than a 5-fold increase in rent. Moving to optimal fisheries management does increase harvest and rent somewhat but relatively minor compared to removing excess capacity in the fishery.

These results show that, in this fishery, rent is dissipated almost entirely due to excess effort while very little is dissipated due to suboptimal stock size.

VI. SUMMARY AND CONCLUSIONS

The purpose of this paper was to undertake an analysis of current rent as well as potential rents under optimal management and different economic scenarios for the North Sea herring fishery. An important contribution of the paper has been to estimate rent on the

[18] Vessel capacity is based on existing UK technology.

basis of a dynamic bioeconomic model, an approach that is not common in the literature. Moreover, we have been able to estimate both resource rent and intra-marginal rent for the UK herring fishery.

Optimal stock levels are estimated to be in the range 1.3–1.4 million tonnes. The estimates of optimal stock level are higher than the stock level giving maximum sustainable yield and compares to a 2007 stock level of 977,000 tonnes. Our results are consistent with the management scheme agreed between the EU and Norway, where the aim is to secure a spawning stock biomass over 1.3 million tonnes. Optimal harvest is predicted at about 427,000 tonnes.

Potential total rents are measured at £90-91 million annually and vary little across alternative discount rates. Resource rent makes up 98% of this value at about £89.0 million with intra-marginal rent measured in the order of only £2.0 million. This compares to an actual rent in 2007 estimated at £ 16.3 million.

Another major contribution of the paper is to analyse rent dissipation. The results show that, based on 2007 conditions, in this fishery, rent is dissipated almost entirely due to excess effort while very little is dissipated due to suboptimal stock size.

The estimations are based on UK harvesting efficiency. As noted in section III, there is limited transferability of quota in the UK and Norway, while Denmark hasITQs in their pelagic sector. Thus, the efficiency of the Danish fleet may be higher than that of the British and Norwegian fleets so that the magnitudes of excess capacity and rent loss may be somewhat overestimated. This remains an issue for further research. Nevertheless, it is not likely to change the qualitative nature of the results.

All in all, the results presented in this paper are very much in line with the predictions presented in the *Sunken Billions* report (World Bank, 2009).

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TABLE 1
Fleet Statistics 2007

Total Landings (tonnes)	311,362
Value £, millions	130.6
Avg. value £/t	419
Landings (tonnes)	
Mackerel	132,304
Herring	90,585
Blue Whiting	56,466
Avg. value £/t	
Mackerel	663
Herring	290
Blue Whiting	119
Vessels	32
Crew	12
Crew- Full time equivalent	7

Source: Lappo (2013).

TABLE 2
UK Pelagic Trawl over 40m. Revenues and Costs: 2007

	Accounting Values	Opportunity Values
Crew[a)]	983,926.8	455,000
Fuel and other operating costs[b)]	1,534,690.8	1,534,690.8
Insurance, repairs and maintenance	570,204.5	570,204.5
Interest and depreciation on capital	568,127.2	1,235,161.4
Total Vessel Costs	3,656,949.3	3,795,056.7
Average Cost/t	375.8	390.0
Profit	419,920.7	281,813.3
Avg. Profit/t	43.16	28.96

[a)] All values in £.
[b)] Commission, harbor dues, subscriptions and levies, shore labour, fuel and oil, boxes, crew travel, food stores and other expenses.

Source: Lappo (2013).

TABLE 3

Estimates of optimal stock level S* (‘000 tonnes) and the corresponding harvest H* (‘000 tonnes). Price = £ 300/tonne. Cost per vessel per season = £ 1,104,000.

Discount rate	S*	H*
0.0	1,409.7	425.0
0.035	1,378.6	427.0
0.05	1,365.5	427.6
0.10	1,322.2	428.9

TABLE 4

Estimates of optimal stock level S* (‘000 tonnes) and the corresponding harvest H*. (‘000 tonnes). Price = £ 300/tonne. Cost per vessel per season = £ 1,468,320.

Discount rate	S*	H*
0.0	1,456.6	420.8
0.035	1,427.9	423.6
0.05	1,415.8	424.5
0.10	1,375.9	427.1

TABLE 5

Estimates of potential rents for the North Sea Herring in £ million. Price = £ 300/tonne.

Cost per vessel per season = £ 1,104,000.

Discount rate	Total rents	Resource rent	Intra-marginal rent	Share of revenue (%)
0.0	91.0	89.1	1.92	69.8
0.035	90.9	88.9	1.99	69.4
0.05	90.8	88.8	1.97	69.2
0.10	90.4	88.4	2.01	68.6
	Cost per vessel per season = £ 1,468,320			
0.0	79.1	76.7	2.48	60.7
0.035	79.0	76.5	2.53	60.2
0.05	79.0	76.4	2.55	60.0
0.10	78.6	76.0	2.60	59.3

TABLE 6
Rent Dissipation

Scenario	Stock size '000 tonnes	Harvest '000 tonnes	Effort (fishing vessels)	Total rents (£ million)
1. Actual 2007 conditions	977.0	400.0	217.6	16.3
2. 2007 conditions with elimination of excess capacity	977.0	400.0	38.8	87.2
3. Optimal policy (5% discount rate)	1,365.5	427.6	41.5	90.8

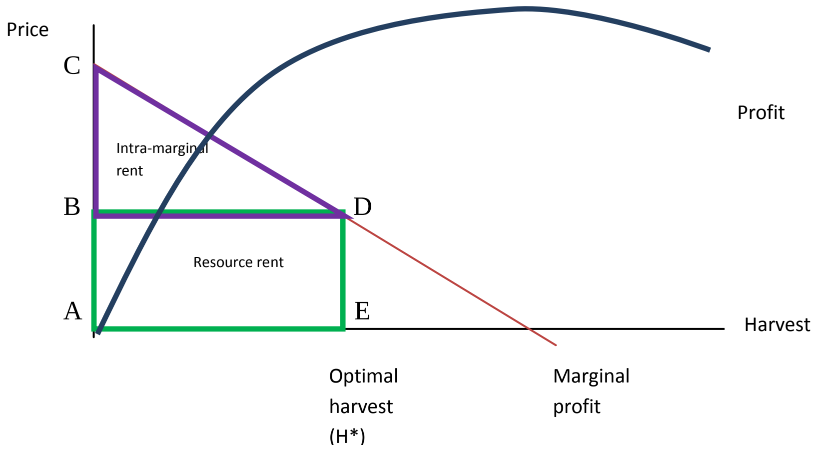

Figure 1: Resource and Intra-marginal Rent.
Adapted from Arnason (2011).

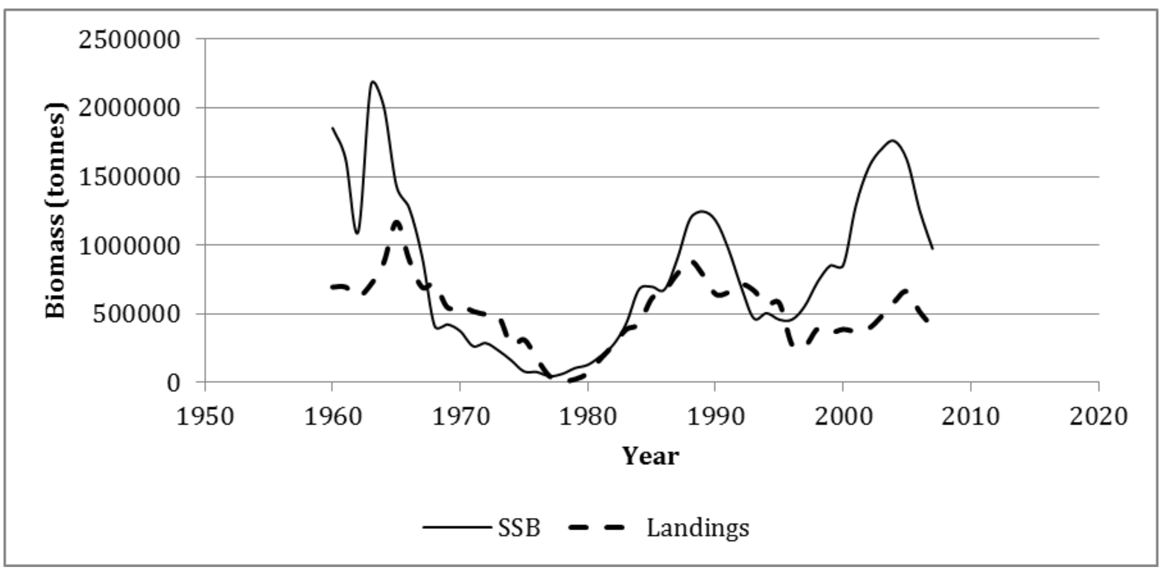

Figure 2. Spawning stock biomass and total landings 1960-2007, tonnes

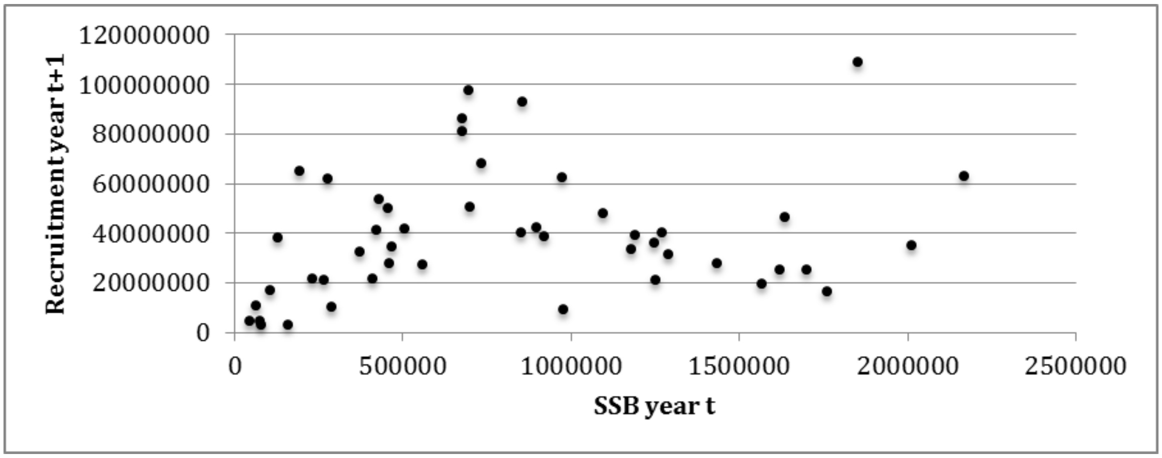

Figure 3. Recruitment in year t+1 (numbers) vs. spawning stock size in year t (tonnes)

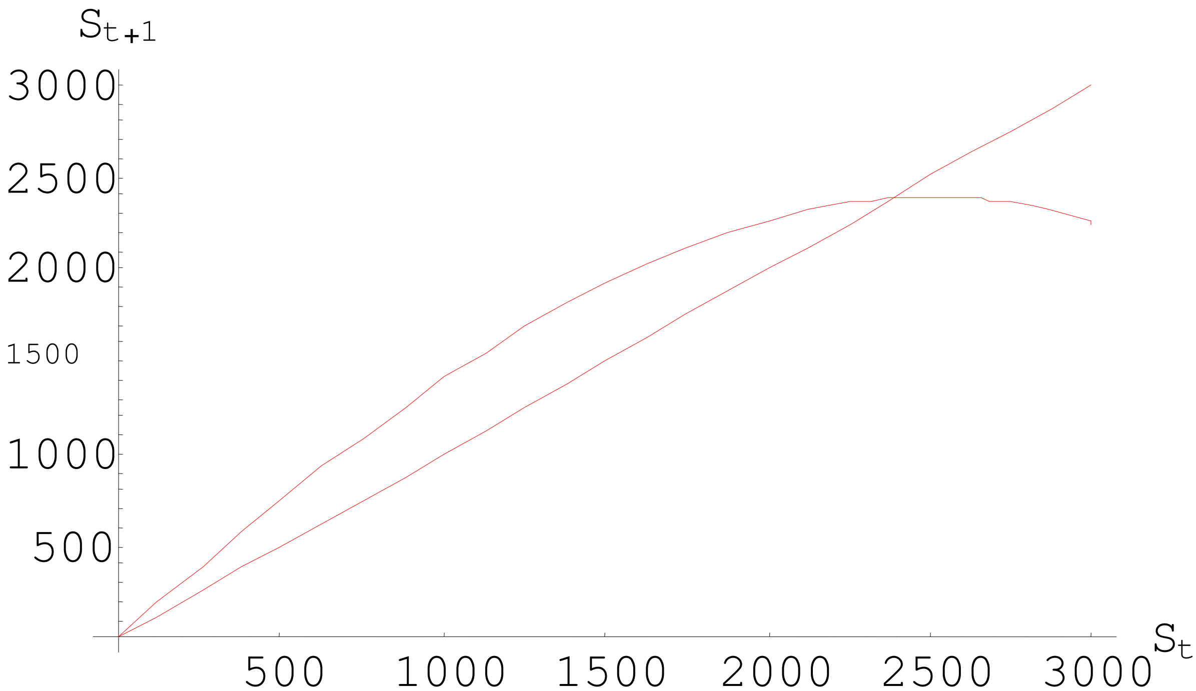

Figure 4. Stock dynamics (steady state stock levels), '000 tonnes

The paper assesses the potential for rent generation, distinguishing between resource and intra-marginal rent, in the North Sea herring fishery. A bioeconomic model combining fish population dynamics with the economic structure of the fishery is used to generate equations to compute the different rents. A combination of biological data with vessel-level economic data for UK pelagic trawlers is employed in estimations. In order to assess the dynamics of both resource and intra-marginal rent generation, the model is evaluated under various assumptions with regard to price, cost, and discount rate. Potential total rents are measured at £90-91 million annually of which resource rent makes up about £89.0 million with intra-marginal rent measured in the order of only £2.0 million. This compares to an actual rent in 2007 estimated at £ 16.3 million. The results show that, in this fishery, rent is dissipated almost entirely due to excess effort while very little is dissipated due to suboptimal stock size.

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