

## Linking Catchability and Fisher Behavior under Effort Management

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Catchability is crucial for the economic performance of fisheries and their management. However, in many bio-economic simulation models it is assumed to be either constant or it is largely ignored, despite the fact that it is known to vary due to technical, environmental and behavioral factors. Such variation can cause the relationship between effort and fishing mortality to be nonlinear. This paper provides evidence for the possibility of nonlinear optimizing behavior from the Dutch beam trawl fishery, provides a methodology for estimating the curvature of the resulting relation, and a simple way of implementing these processes within a bio-economic model. Moreover, it shows the influence of a nonlinear relationship between effort and fishing mortality in a model of effort management (EU long-term flatfish management plan).

**Keywords:** non-linearity, bio-economic modeling, FLR

1 **Introduction**

2  
3 In fisheries management, catchability is the link between fishing effort and the resulting  
4 fishing mortality. Catchability is defined as the proportion of available fish in a  
5 population that would be captured by a unit of effort. Because of this relationship,  
6 catchability is crucial to the economic performance of fisheries and their management.  
7 However, in many bio-economic simulation models catchability is assumed to be either  
8 constant or it is largely ignored, despite the fact that it is known to vary due to technical,  
9 environmental and behavioral factors (STECF, 2005, Overholtz, et al., 1995). Ignoring  
10 the variability of catchability is likely to bias the results of these models and lead to  
11 flawed management decisions (Ulrich et al., 2005, Pascoe et al., 2002).

12  
13 Variation in catchability has been studied extensively over the last decades, but most of  
14 the studies were done for different purposes than bio-economic modeling, namely to  
15 standardize catch per unit of effort (CPUE) data as an indicator of fish abundance (e.g.  
16 Addisson et al., 2003, Bishop 2006, Marchal et al., 2003, Olin et al., 2004). Many  
17 experimental studies provide information about the effects of technical gear  
18 characteristics, environmental factors and fish behavioral on catchability, and this  
19 knowledge is incorporated in the setup and analyses of fish surveys. Data from  
20 commercial fisheries can provide an inexpensive alternative for these surveys. However,  
21 the value of such data is limited by the targeting behavior of fishers. Because fishers  
22 search for concentrations of fish, in order to maximize their income they change overall  
23 catchability and thereby lower the value of CPUE as an indicator for the biomass. For  
24 example, Ellis and Wang (2007) showed for the Australian northern prawn fishery that  
25 targeting behavior increased catchability in some areas by 10%. However, in these  
26 studies no link was drawn to management measures and the effects changes in  
27 catchability can have on their results.

28  
29 Fisher behavior has been taken into consideration in management evaluations, but are  
30 most often concerned with the effects of spatial management measures, such as MPAs  
31 (Peletier and Mahevas, 2005). The main assumption in these models is that fishers  
32 optimize their behavior in order to maximize their utility (Hutton et al., 2004). However,  
33 with a few exceptions, these models only simulate short-term effort reallocation and do  
34 not assess the effects on catchability (Peletier and Mahevas, 2005).

1 Certain areas on the topic of catchability have been studied, but they have focused mainly  
2 on the impact of technical creep. It has been found that gradual technical developments in  
3 the fishing fleet may increase catchability over time which may bias assessments using  
4 catch data and predictions of bio-economic models (e.g. Pascoe et al., 2001, Ulrich et al,  
5 2002 and Rijnsdorp et al., 2006). Using historical data Pascoe et al. (2001) showed that  
6 management measures such as the introduction of the Plaice Box affected the technical  
7 efficiency of the fleet, partly through reallocation of fishing effort. Both Ulrich et al.  
8 (2002) and Rijnsdorp et al. (2006) studied technical creep in relation to restrictions in  
9 fishing effort. Ulrich et al. (2002) used a bio-economic simulation model to compare the  
10 sensitivity of output and input measures to trends in catchability caused by technical  
11 creep. They found that the outcomes of the TAE (total allowed effort limits) were  
12 especially sensitive to variability in catchability, while incorrect catchability parameters  
13 in the model resulted in underestimation of the fishing mortality and overestimation of  
14 the SSB. Rijnsdorp et al. (2006) introduced fishing mortality per unit of effort as a means  
15 to better understand the relationship between effort and fishing mortality and to fine-tune  
16 management regulations. They also noted that through the optimization behavior of  
17 fishers, fishing mortality could be affected less than proportionally by effort reductions.

18  
19 Since the introduction of management plans, effort limitations have become more popular  
20 in EU Atlantic fisheries. Insight into how fishers can be expected to react and thereby  
21 change catchability will be of critical importance to the success of these plans. The main  
22 goal of these plans to limit effort is to reduce excess fishing and the resulting discards  
23 caused by the misbalance in single species TACs.

24  
25 One of the models that takes changes in catchability into account is the EIAA model  
26 which was developed to evaluate the economic effects of TAC restrictions in the EU. The  
27 model calculates fishing activity using a Cobb-Douglas type inverse production function,  
28 and it uses information on all relevant TACs, SSBs and prices and historical landings of  
29 non-TAC species. The model assumes that all TACs can be taken and that landings of  
30 non-TAC species will not change. The price by species is included in the activity  
31 function, and assumes that fishers have an incentive to first use fishing effort on species  
32 with the highest value. The weighing procedure results in an average and less than  
33 proportional change of activity compared to changes of the TACs. The model tends  
34 therefore to produce lower catchability rates. EIAA is therefore not a very suitable tool

1 for the evaluation of effort restrictions when one would expect that the optimization  
2 behavior of fishers would result in increased catchability (Anon, 2005)

3  
4 The aim of this paper is to (1) estimate the potential effect of the optimization of fishing  
5 behavior on catchability in a situation in which effort (total number of sea days) is  
6 restricted and to provide empirical evidence for the possibility of optimization behavior  
7 by fishers within an effort regulated fishery and (2) show the effect of such behavior on  
8 catchability and, as a consequence, on fleets and stocks within a long-term management  
9 program. The analysis is divided into two sections. The first section uses historical data to  
10 estimate the relationship between cumulative effort and catch. The second section  
11 incorporates the findings into a simulation model.

12  
13 We use the case of the Dutch North Sea flatfish fishery to conduct our analysis. This  
14 fishery is the most important fishery for plaice and sole, contributing to 75% of the total  
15 plaice and 38% of the total sole catch from the North Sea (Taal et al., 2006). More than  
16 82% of the plaice and 93% of the sole landings of these species are realized by vessels of  
17 over 1500 hp engines. The two main target species make up more than 82% of the total  
18 value of the landings of these vessels. Since 2002 effort has been increasingly restricted  
19 for these vessels due to the cod recovery plan (EC, 2004). In addition, in 2007 a flatfish  
20 recovery plan (EC, 2005) with effort restrictions has been introduced. The aim of the plan  
21 is to reduce fishing mortality by half over the coming years by reducing fishing mortality  
22 by 10% each year until values of (0,2) for sole and (0,3) for plaice are achieved. These  
23 goals are to be reached through both TAC and effort reductions.

24  
25 In the analysis the fishing process is assumed to proceed as follows: As effort becomes  
26 more restrictive, fishers have to drop fishing trips. Because they want to optimize their  
27 utility, which we assume to be economic utility, they will drop those trips that they  
28 perceive to have the lowest economic benefit. The least efficient trips are thereby omitted  
29 from the fisher's portfolio. The sequence of events outlined applies to individual fishers  
30 as well as to the total fishing fleet if fishing rights can be easily transferred from one  
31 vessel to another thereby enabling fishers to redistribute fishing opportunities. Because of  
32 this desire to optimize, the average annual catchability of species will change: The  
33 catchability of target species, from which the catches are positively correlated with the  
34 total value of the catch, will increase (Figure 1). The catchability of non-target species

1 might increase or decrease, depending on the co-occurrence of the species with the target  
2 species.

3  
4 <<Figure 1 here>>

## 6 **Material and methods**

### 8 *Historical analysis*

9 The possibilities for optimization were analyzed by means of a cross-sectional analysis of  
10 landings data from large Dutch beam trawlers (> 1500 hp) from 2001 - 2006. Catch and  
11 effort data were analyzed at the trip level and taken from official logbook data gathered  
12 by the Dutch ministry of Agriculture, Nature and Food Quality. These data include catch  
13 and effort data per trip and species, the date and time at which ships depart and return  
14 from a trip, the name of the ship, the power of the main engine, and the ICES rectangle in  
15 which fish were caught.

16  
17 Total value per unit of effort (VPUE) was used as a proxy for the utility of a trip, where  
18 value is defined in terms of revenues and effort is defined as hp-days. They were  
19 calculated using logbook catch and effort information and monthly average price  
20 statistics from Dutch fish auctions.

$$22 \quad VPUE_t = \frac{\sum C_{it} \cdot P_{im}}{f_t} \quad (1)$$

Mis en forme : Anglais (États-Unis), Décalage bas de 15 pt

23  
24 where

25  $VPUE_t$  = Value per unit of effort of the trip,  
26  $C_{it}$  = Catch of  $i^{th}$  species in the trip,  
27  $P_{im}$  = Average auction price of  $i^{th}$  species in  $m^{th}$  month,  
28  $f_t$  = Effort of the trip expressed in hp-days,

Mis en forme : Ne pas ajuster l'espace entre le texte latin et asiatique

29  
30  
31 It was assumed that given a reduction in effort, fishers will skip those trips which they  
32 believe will add the least to their total utility. Fishers are not expected to incorporate the  
33 share of the value of a trip which derives from random variations into their decisions of  
34 which trips to take, therefore, an ANOVA was used to get rid of the random variation in

Mis en forme : Ne pas ajuster l'espace entre le texte latin et asiatique

1 total catch value and reveal the 'true' value of a trip which fishers then use to rank trips.  
2 The catches were log<sub>10</sub>-transformed to meet the conditions for parametric analysis of  
3 variance. The model used was:

$$LVPUE_{ijkl} = \mu + v_i + m_j + a_k + \varepsilon_{ijkl} \quad (2)$$

Mis en forme : Anglais (États-Unis), Décalage bas de 7 pt

7 where

8  $LVPUE_{ijkl}$  = log<sub>10</sub> Value per unit of effort,

9  $\mu$  = overall mean,

10  $v_i$  = effect of i<sup>th</sup> vessel,

11  $m_j$  = effect of j<sup>th</sup> month,

12  $a_k$  = effect of k<sup>th</sup> area,

13  $\varepsilon_{ijkl}$  = error.

Mis en forme : Ne pas ajuster l'espace entre le texte latin et asiatique

Mis en forme : Ne pas ajuster l'espace entre le texte latin et asiatique

15 Non-significant terms were removed from the model. Residuals were tested for normality  
16 and 95% confidence limits were calculated to compare main group means in case of  
17 significant effects.

19 The estimated values from the ANOVA were used as a proxy for the expected value of a  
20 trip and, in turn, to estimate the relationship between effort and the catchability of plaice  
21 and sole. The procedure used was to sort trips in descending order based on their  
22 estimated VPUE. Hereafter, catches of plaice and sole and effort were accumulated over  
23 the trips and the relationship between cumulative effort and cumulative catch was  
24 estimated for both species using a simple regression analysis. In the analyses the  
25 catchability is assumed to depend on the effort in the following way:

$$q_j = q_0 * \left( \frac{f_j}{f_0} \right)^\beta \quad (3)$$

Mis en forme : Anglais (États-Unis), Décalage bas de 16 pt, Crénage 14 pt

29 Where

30  $q_j$  = catchability in year j,

31  $q_0$  = catchability in year 0,

32  $f_j$  = fishing effort in year j,

33  $f_0$  = fishing effort in year 0 and

Mis en forme : Ne pas ajuster l'espace entre le texte latin et asiatique

1  $\beta_2$  = a constant which determines the curvature of the function.

2  
3 Because of the catch equation, the relationship between cumulative catch and cumulative  
4 effort can be used to estimate the beta by using the following model:

5  
6  $C_i = \alpha \cdot f^{\beta+1} \cdot \varepsilon_i$  (4)

Mis en forme : Anglais (États-Unis), Décalage bas de 6 pt

7  
8 where  $C_i$  = Cumulative catch of plaice or sole,  $f$  = cumulative effort expressed in hp-days,  
9  $\alpha$ ,  $\beta$  = regression coefficients,  $\varepsilon_i$  = error.

Mis en forme : Ne pas ajuster l'espace entre le texte latin et asiatique

10  
11  
12 *Model simulations*

13  
14 To demonstrate the effect of the non-linear relationship between effort and catches (and  
15 thereby fishing mortality), the estimated relationship between effort and catchability was  
16 incorporated into the IMARES model, a dynamic simulation model for the North Sea  
17 flatfish fishery built in the FLR framework (Kell et al., 2007). This model was built to  
18 evaluate the effects of the long-term flatfish management plan as evaluated by STECF  
19 (Scientific, Technical and Economic Committee for Fisheries, Anon, 2006) in September  
20 2006.

21  
22 On the basis of the STECF management plan, the harvest control rule within the  
23 IMARES model calculates fishing mortality rates using Article 4 to set a TAC for plaice,  
24 Article 5 to set a TAC for sole, and a complementary effort limit specified in Article 6.  
25 The IMARES model simulates the stock dynamics for plaice and sole, multiple fleets,  
26 and the fisheries management, including assessments and management decisions over a  
27 specified period of years. For the simulation years under consideration, 2006 to 2012, the  
28 model links effort reduction (Article 6) directly to a reduction of fishing mortality, which  
29 means that the effort multiplier is reduced by 10% per year and results in a reduction in  
30 effort from 21,255 in 2006 to 11,296 in 2012. More information on the model features  
31 can be found in Machiels et al. (2007).

32  
33 The approach taken was to adjust the catchability for each year using the following  
34 Formula 3, catches and fishing mortalities were calculated using the adjusted catchability

1 for each year of the simulation period. Simulations over a period of 6 years (2006 - 2012)  
2 were conducted for 3 values of beta for both species: 0 (in the case of constant  
3 catchability) and, -0.2 and -0.4, based on the estimated betas from the historical analysis.  
4 Simulation results for each of the scenarios were compared with regards to their impact  
5 on spawning stock biomass, catch, total value of the catch, gross added value to the  
6 fishery.

## 8 **Results**

### 10 *Historical analysis*

11  
12 Figure 2 was constructed using data from 9293 trips in 2006 and illustrates the  
13 relationship predicted in Figure 1; similar figures appear for the years 2001 to 2005. In  
14 short, using historical data and the behavioral assumptions specified in the previous  
15 section, it is possible to construct a plausible, *non-linear* relationship between ordered,  
16 cumulative value, less random fluctuations and cumulative effort.

17  
18 <<Figure 2 here>>

19  
20 <<Table 1 here>>

21  
22 Table 1 shows the key variables that might allow a fisher to distinguish between the  
23 values of a trip. The ship, area and month variables together account for 61% of the  
24 variability of the value of a trip.

25  
26 The most important factor responsible for the variation in VPUE was the vessel,  
27 accounting for 36% of the total variability. Additional analysis of the average VPUE for  
28 106 ships in the year 2006 shows a wide range in values among ships, from a low of 1.9  
29 Euros per unit of effort to a high of 6.4 with a mean of 3.7. Some ships, whether because  
30 of differences in the physical characteristics of the ship or differences in the skills of  
31 captain and crew or some other characteristic, are consistently and predictably better than  
32 others at catching fish, implying that the implications of a reduction of effort will  
33 impinge on some owners more than others.

1 <<Figure 3 here>>

2  
3 Similarly, differences in the average VPUE caused by differences in the month fished  
4 account for 18% of the observed differences in the value of a trip (Figure 3). Average  
5 values range from a low of 2.8 Euros per unit of effort in May, to a high of 4.5 in  
6 November. Therefore, a reduction in effort, all else equal, will mean that less profitable  
7 trips in the month May should be dropped from the fisher's portfolio before those trips  
8 made in, say, November. Finally, the area variable accounts for a modest 7% of the  
9 variability in the value per unit effort over the year. The decision as to where to fish  
10 appears to have less of an impact on the variation in the value of a trip than the other two  
11 variables; a reduction in effort will therefore have relatively little influence on where  
12 fishers fish.

13  
14 <<Figure 4 here>>

15  
16 Figure 4 shows that, just as in the case of value, catch for both plaice and sole is  
17 decreasing per unit of effort expended. A reduction in effort will mean first dropping  
18 those trips with less expected catch. However, it's the differences in the two figures that  
19 are of real interest. Comparison of the two figures indicates a greater curvature for sole  
20 than that for plaice, perhaps, implying that sole was the species driving fisher behavior.

21  
22 Regression results from running Equation 4 and reported in Table 2 confirm a  
23 preliminary examination of the above figures and indicate that the curvature of total  
24 VPUE to effort is greater for sole than for plaice in 2006.

25  
26 <<Table 2 here>>

27  
28 However, the greater observed curvature of sole in 2006 is not consistent over time.  
29 While the means for the coefficients for the two variables over the years are nearly  
30 identical (plaice = 0.89, sole = 0.84), they are, as show in Figure 5, negatively correlated  
31 over the period 2001-2006. The figure indicates that for years 2002 and 2004 the value of  
32 sole and plaice per unit effort could both have been of nearly equally importance in  
33 motivating the priority of fishing trips. In other years, the value of sole per unit of effort  
34 was the primary motivation behind decisions of when and where to fish, a motive that

1 appears to be of increasing importance in recent years as shown by the fall in the  
2 coefficient for sole and the increase in that of plaice.

3  
4 <<Figure 5 here>>

### 6 **Simulation analysis**

7  
8 The parameters were implemented within the IMARES model by using Equation 3  
9 above. The following results compare three scenarios, the Exp 00 is the linear case, while  
10 the Exp -0.2 and Exp -0.4 represent non-linear cases when the beta in Equation 3 are,  
11 respectively, -0.2 and -0.4. An effort that is smaller than the base year, raised to a  
12 negative power, will result in a larger catchability for the simulated year (Figure 6).

13  
14 <<Figure 6 here>>

15  
16 As previously discussed, the EU harvest control rules implemented in the IMARES  
17 model resulted in a reduction in effort of 10% for each year of the simulation. That, along  
18 with the negative betas we estimated, results in the continuous increase in catchability in  
19 every year for both non-linear scenarios for both sole and plaice and caused an increase  
20 of around 28% in 2012 in the case of the scenario for sole with beta = -0.4 compared to  
21 the linear case.

22  
23 A larger catchability than that predicted by the linear case has both biological and  
24 economic implications. In comparison to the linear case, both non-linear cases result in  
25 smaller SSBs (Figure 7). The figure shows the situation for sole, the impact on plaice is  
26 similar; for instance, in the last year of the simulation with an exponent of -0.4, the SSB  
27 for plaice was about 18% smaller than that of the linear case.

28  
29 A higher catchability, all else equal, means that the chance that an individual fish will be  
30 caught by gear will increase, so that a lower SSB doesn't necessarily translate into a  
31 lower catch. In fact, the economic results predicted by the IMARES model show that the  
32 economic implications continue to be positive; the results for the non-linear cases are  
33 better than predicted by the linear case because the increase in catchability for a given  
34 amount of effort will more than offset the reduction in SSB (Figure 8).

1 <<Figure 7 here>>

2  
3 <<Figure 8 here>>

4  
5 However, there appear to be limits to the ability of higher catchability to offset the lower  
6 SSB. Figure 7 shows that while landings for both non-linear cases are greater than the  
7 linear case for each year of the simulation; landings for the non-linear cases appear to  
8 converge. As simulation time progresses, landing when the exponent is equal to -0.4 falls  
9 toward the landings when the exponent is equal to -0.2, indicating that the higher rate of  
10 catchability may not offset the smaller SSB forever; eventually, a higher catchability  
11 reduces the SSB to such a degree that landings in both non-linear scenarios are nearly  
12 equal. As previously noted, landings in both non-linear scenarios never fall to those  
13 levels of the linear case and revenues in both scenarios remain above the linear scenario.  
14 Results for plaice were similar to those reported for sole, in the last year of the simulation  
15 landings for plaice both converge, but both remain above that of the linear case. Finally,  
16 as a direct result of the higher catches for both species in the non-linear cases, total  
17 revenues for those cases were above the linear case for each year of the simulation. Once  
18 again, revenues for the non-linear cases converged in later years as landings converged.

19  
20 **Discussion**

21  
22 Results from the historical section confirm that it is theoretically possible for fishers to  
23 rank trips in terms of their utility. Trips can be distinguished by the value they are  
24 expected to provide, different ships, areas and seasons will yield trips of different values  
25 per effort, thereby allowing the possibility to rank trips. This ranking can occur at the  
26 level of the fisher, and, given tradable fishing rights and a well-functioning market for  
27 those rights, across the entire fleet. Our contention is that a reduction in total allowed  
28 effort will cause average catchability to rise as fishers drop less profitable trips from their  
29 portfolios, a contention that is in agreement with conclusions drawn by Rijnsdorp et al.  
30 (2006). In turn, an increase in average catchability means that a reduction in effort will  
31 have less of an impact on SSB than that implied by a linear relationship linking catch to  
32 effort. Results from the simulation model show that under-estimating catchability will  
33 result in a lower than expected SSB, a larger than expected catch, and higher than  
34 expected revenues for the years simulated. If the possibility of such behavior is accepted,  
35 then a policy to reduce effort should take such behavior into account.

1 One straightforward explanation that accounts for the negative correlations observed in  
2 Figure 5 is the fact that our observations come from a mixed fishery. In years when  
3 variation in revenue per unit of effort is caused by highly variable sole landings per unit  
4 of effort, plaice landings per unit of effort have been more stable. Variability of landings  
5 per unit of effort may be caused by various reasons, for example, given effort limitation,  
6 fishers made their choices of which trips to conduct based primarily on the TAC they  
7 perceive to be less constraining. Other causes of variable landings per unit of effort are  
8 seasonal price changes and temporal closures of the fishery (in 2001 and 2003).

9  
10 Our method of valuing and ranking trips has the advantage of being easy to implement  
11 and understand, in addition, it is a general approach that can be applied across fleets.  
12 However, the parsimony leads to some drawbacks.

13  
14 Our model for estimating the curvatures of catch is simplistic. However, adding terms,  
15 such as a non-linear variable for the month fished, did not appreciably change the results.  
16 Residuals from the model show a slightly periodic structure that should be better  
17 accounted for in further studies. The results were also skewed by data with a higher catch  
18 per effort. The decision was made to keep these data (less than 20 data points out of more  
19 than 8600 for year 2006) within the data set until there is positive evidence that they  
20 represent errors.

21  
22 Our measures are perhaps not as refined as we would like them to be. For instance, we  
23 use monthly in the ANOVA when an analysis based on weekly data (Rijnsdorp, 2006)  
24 would have yielded more variation and thereby greater curvature. However, initial  
25 analysis shows that the effects of such refinements are limited. Greater refinement in the  
26 differentiation of areas and ships might also be possible and lead to better results. In  
27 addition, we are underestimating the ability of fishers to vary their behavior by only  
28 including the effects of the ship, area and season. Fishers undoubtedly have other means  
29 to change their behavior, our variables account for only around 60% of the calculated  
30 variation. These factors taken together mean that our beta estimates, and therefore the  
31 resulting catchability variables, will be lower than the potentially achievable estimates.

32  
33 In addition, our analysis is simplistic in that it only looks at the direct impacts of a  
34 reduction in effort, and not the resulting reactions of fishers. Two examples will help to  
35 illustrate the issue. First, in our analysis we reasonably assume that less valuable trips

1 will be dropped because they are less valuable, but from the perspective on an individual,  
2 if a fisher believes that everyone else is going to drop a trip, then it may be to his  
3 advantage to make the trip. For example, if everyone decides to drop trips in May, the  
4 resulting increase in price means that it will be in at least someone's advantage to fish in  
5 May. . The second example involves the trips that become available as a result of a  
6 reduction in effort. Given that some ships will be more susceptible to a reduction in effort  
7 than others due to worse economic performance, it's not difficult to imagine that less  
8 profitable ships might be forced to withdraw from the fleet given a big enough reduction  
9 in effort. The impact of ships leaving the fleet may cause the remaining ships to assume  
10 the disregarded trips. If the surviving ships have enough sea days and they can take on  
11 the trips profitably, then they will fish the newly available trips. A more complete model  
12 would take into account these reactions and interactions between the values of fishing  
13 trips after an effort reduction, but this would quickly become highly complex.

14  
15 There are some other limits to the analysis used in this paper, some of which can be  
16 surmounted using more data and better analytical techniques, and some of which are less  
17 tractable. First, we are limited to six years of data from 2001-2006, and only during the  
18 last two years did effort become the limiting constraint. Ideally we would have used more  
19 years in which effort was a constraint, but such is the available data. This analysis is  
20 limited to the reaction of fishers to changes in effort, making years 2005 and 2006 the  
21 most relevant years. This comes about because our analysis is based on the idea that  
22 presumed behavior in previous years will be repeated in the future. The form of the data  
23 would ideally reflect effort restricted behavior.

24  
25 Second, we use only large beam trawlers (horsepower  $\geq 1,500$ ). Although all sizes of  
26 ships could have been included in the analysis, the added complexity required to account  
27 for technical differences among the various classes of ships and the possibility that ships  
28 of different classes will target different species would make the analysis far too complex  
29 for current purposes. Therefore, for reasons of parsimony, we concentrate our analysis on  
30 large beam-trawlers which target plaice or sole.

31  
32 Third, the measure of utility is not ideal, we use the value of a trip, measured in terms of  
33 the total value of all fish caught during a trip, divided by effort, measured by the  
34 horsepower of a ship multiplied by the number of days at sea of a trip; while an ideal  
35 measure would include a more thorough estimate of utility, for instance, one that

1 included the major variable costs of a trip. Better data does exist for calculating profits  
2 for part of the fleet, but is not included in the paper. In a related issue, we make the  
3 simplifying assumption that the behavior of fishers is expressed in their ability to choose  
4 among different seasons and areas, as well as those differences due to specific ship  
5 characteristics. There are undoubtedly other factors influencing utility, but we are limited  
6 in our ability to decipher those factors by a lack of data. DEA analysis could be used in  
7 future studies to identify these factors.

8  
9 Despite these drawbacks, the method used can be used to get an idea of the changes in  
10 catchability resulting from effort restrictions. These can be very important in impact  
11 assessments of management plans which include effort limitations as a means to reduce  
12 fishing mortality.

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## Table and Figure Captions

Table 1. Analysis of variation for the model including ship, quadrant and month variables.

Mis en forme : Retrait :  
Gauche : 0 pt, Première ligne  
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Table 2. Linear regression estimates for plaice and sole for 2006. A smaller  $\beta_2$  indicates greater curvature.

Mis en forme : Retrait :  
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Figure 1. Relationship between catch of a target species and effort (both as the percentage of the initial value) in the case of random exclusion of fishing trips and catch value optimization.

Mis en forme : Retrait :  
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Figure 2. Historical relationship between the ANOVA adjusted cumulative value and cumulative effort for 2006.

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Figure 3. Differences in VPUE per month over the year 2006.

Figure 4. Relationship between the cumulative catch of plaice and sole versus cumulative effort for Dutch large beam trawlers for 2006.

Mis en forme : Retrait :  
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Figure 5. Coefficients of curvature for plaice and sole. A smaller coefficient, all else equal, results in greater curvature.

Mis en forme : Retrait :  
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Figure 6. Three exponents of curvature and their respective impact on the catchability of sole and plaice.

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Figure 7. Evolution of SSB estimates of sole for model runs with different values of beta. SSB will be lower given a smaller, more negative, exponent.

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Figures 8. Evolution of sole landing and net profits for model runs with different values of beta. Higher catchability for a given effort means higher than expected landings and profits.

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Table 1. Analysis of variation for the model including ship, quadrant and month variables

	<b>Df</b>	<b>Sum Sq</b>	<b>Mean Sq</b>	<b>F value</b>	<b>Pr(&gt;F)</b>
Ship	105	319.84	3.05	79.520	< 2.2e-16
Area	91	64.76	0.71	18.577	< 2.2e-16
Month	11	159.66	14.51	378.902	< 2.2e-16
Residuals	9085	348.01	0.04		

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Table 2. Linear regression estimates for plaice and sole for 2006. A smaller  $\beta_2$  greater curvature.

	Estimate	Std. Error	t value	Pr(> t )
<b>Plaice<sup>1</sup></b>				
B1	0.0373354	0.0112657	3.314	0.000923
B2	0.9575419	0.0006794	1409.335	< 2e-16
<b>Sole<sup>2</sup></b>				
B1	1.318146	0.005257	250.8	<2e-16
B2	0.829380	0.000317	2616.1	<2e-16

<sup>1</sup>Adjusted R-squared: 0.9956  
<sup>2</sup>Adjusted R-squared: 0.9987

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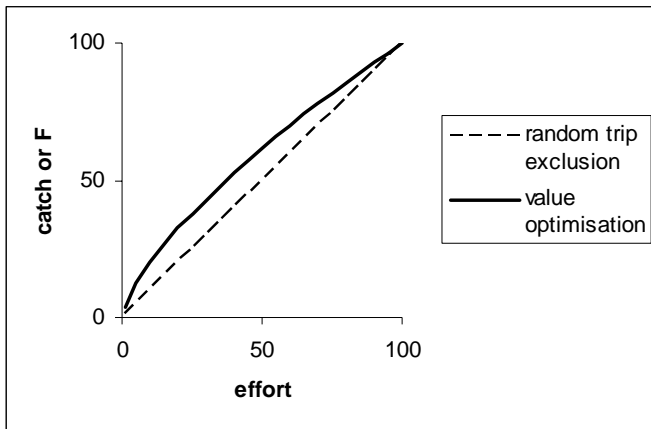
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Mis en forme : Anglais (États-Unis)

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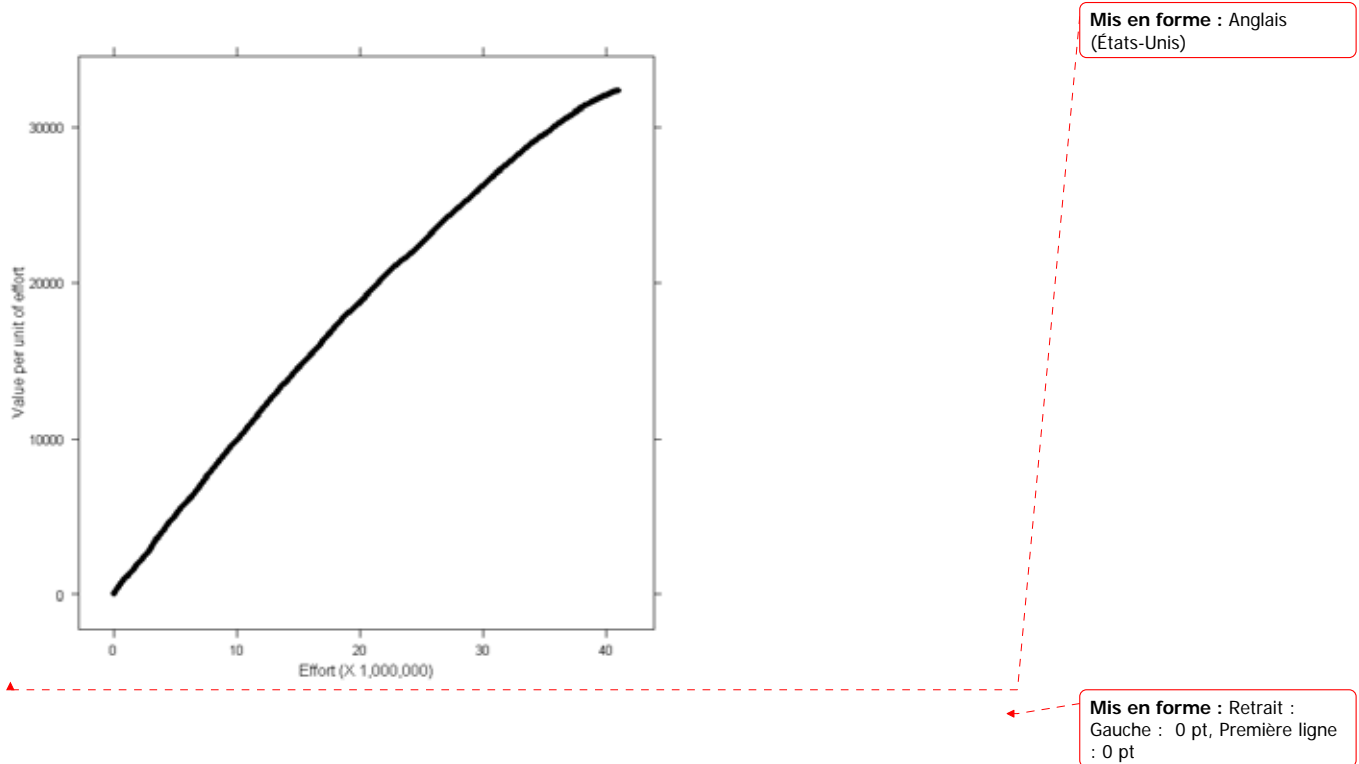
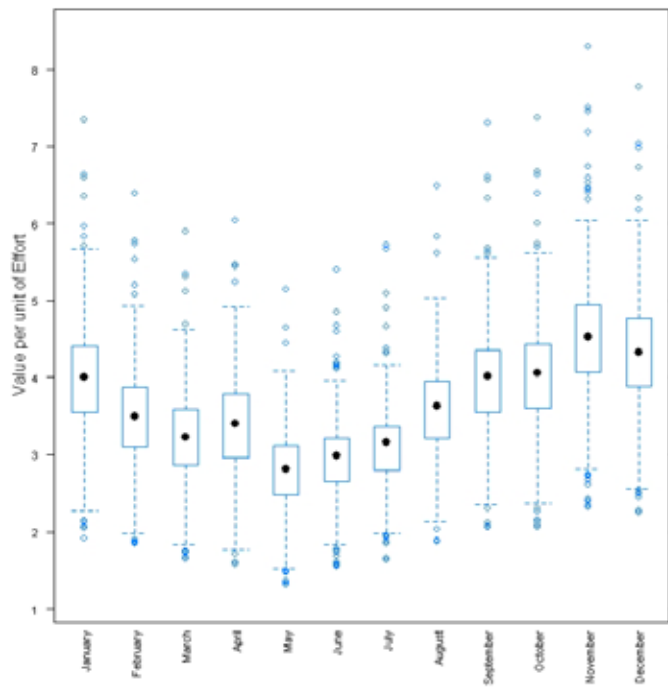


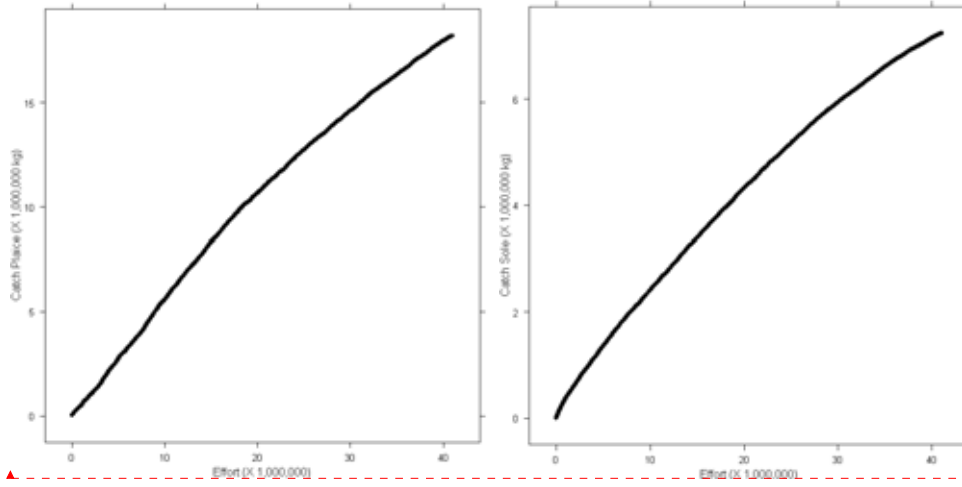
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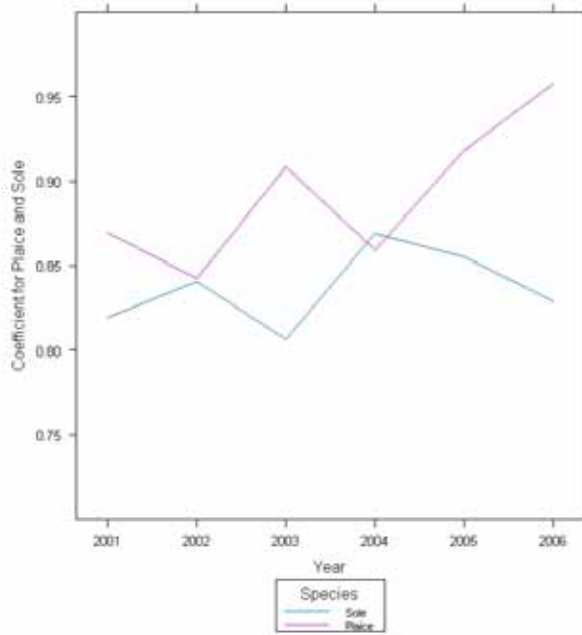
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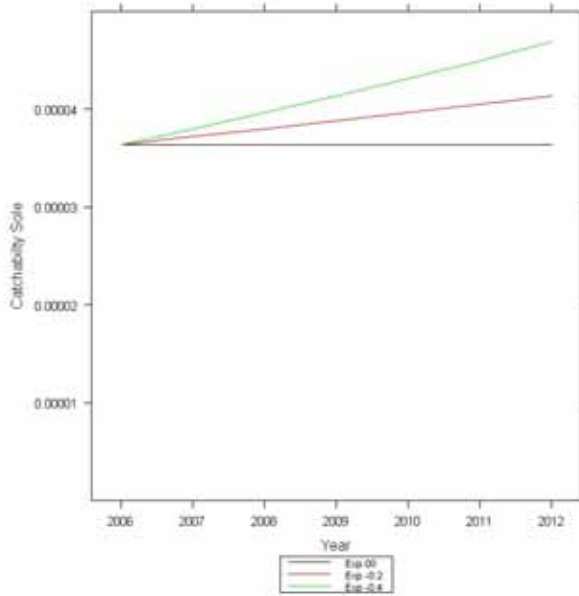
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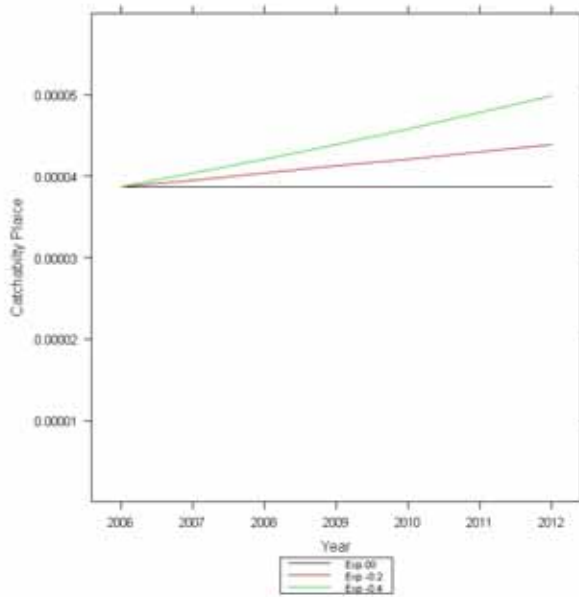
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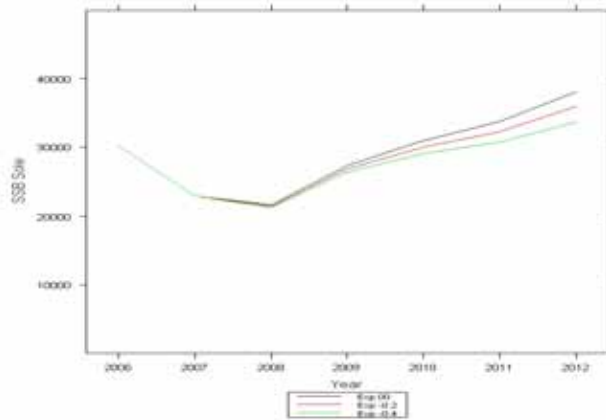
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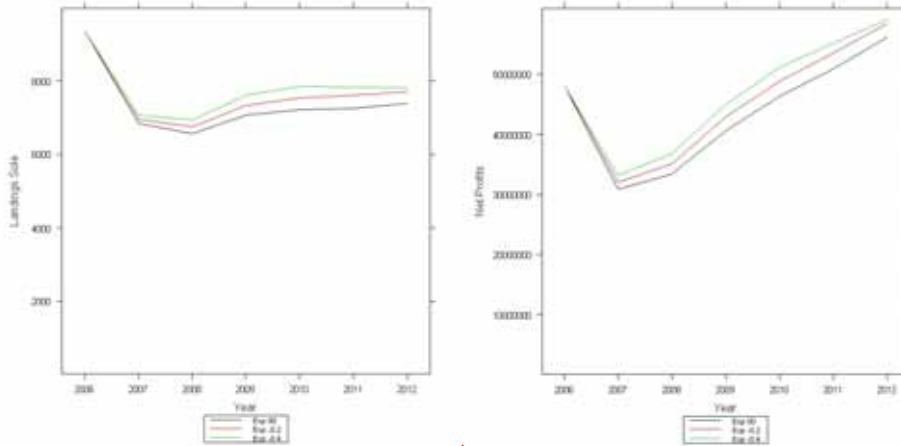
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