# Method

The economic model is a short term constrained optimization problem, which is based on the notion of a *fishery* (*f*)*,* which is a combination of using a particular *segment* (*seg*, type and size of vessel) with a particular *gear* in a particular geographical *area*. Each fishery has a fixed distribution of catch across the available species *s*, so that the observed average composition of the catch is replicated. Fishermen are assumed to choose fishing effort for each fishery as to maximize their profit including subsidies or taxes, using a given vessel fleet and a fixed fish stock (Equation 1). The marginal catch is assumed to decline with increasing fishing effort following a Cobb-Doublas production function (c.f. XXX), as shown in Equation 4, where the (constant) stock factor is included in the factor . Thus, combines the distribution of catch across species with the scale of the total catch. Therefore, bears some relation to CPUE, Catch Per Unit of Effort, sometimes used in the literature, but is not fully equivalent since our catch is not constant. Decreasing marginal catch at constant fish stock would arise if the fishermen chose the best fishing spots and timings first. The marginal variable costs of fishing activities are assumed to increase in proportion to fishing effort, reflecting an assumption that higher efforts imply longer trips. The objective function also contains a calibration term per fishery that ensures that the observed fishing pattern is replicated by the model. Fixed costs per vessel are included in order to render the accounting complete, but have no impacts on behaviour since the number of vessels per segment is fixed.

Equation 1: Objective function

where

is fishing effort in days per fishery   
 are the prices of Sort A and Sort B respectively, for each fishery and species   
 are the (variable) quantities caught of sort A and sort B  
 Landing Obligation, parameter {0,1} defining whether catch has to be landed or not  
 Subsidy per day to fishery   
 Constant part of the marginal variable cost  
 Slope parameter of marginal variable cost function  
 The number of vessels operating in each segment *seg*  
 Is the fixed cost per vessel in each segment (impacting only on profits)  
 Calibration constant cost (or revenue if negative) term

Equation 2: Catch of sort A

Equation 3: Catch of sort B

Equation 4: Total catch as a function of effort

Catch comes in two qualities: A and B. The former is suitable for the market, whereas the second commands a significantly lower price. If discards are allowed, the agents are likely to discard all of the B-quality in order to fill their quotas with the more valuable catch. The shares of A and B in total catch are fixed. This is implemented in Equation 2 and Equation 3.

Fishing efforts are constrained by quotas and effort restrictions. Only landed catch counts against the quotas, and hence there is a strong incentive to discard SortB if quotas are filled. The discards are currently modelled exogenously, assuming that all of SortB is discarded if there is no landing obligation () as defined in Equation 5 and Equation 6.

Equation : Landings

Equation : Discards

Quotas are defined for sets of fishing areas called *Quota Area* (*qa*) and for sets of species called *Quota Species* (*qs*). Quotas are modelled by Equation 7, where the indicator set defines (=1) if species *s* belongs to quota species *qs* AND fishery *f* is active in quota area *qa*. *TAC* is the quota (Total Allowable Catch), whereas *TACadj* is a calibration factor that is defined in the estimation/calibration step, allowing the quota to be binding even if the observed catch is not exactly equal to TAC, or conversely.

Equation 7: Catch quotas

Effort restrictions come in three types. For each segment there is a maximum number of annual fishing days available, based on the number of vessels (Equation 8). For each fishery, there is also a maximum number of days of fishing possible, based on e.g. season length and number of vessels (Equation 9).

Equation 8: Effort restriction per segment

Equation 9: Effort restriction per fishery

In the effort regulation, there are various rules that apply to groups of fishing activities (sets of fisheries in our model) and sets of fishing areas. This is implemented in Equation 10, where is the installed engine class in kilowatts, *I* the indicator set defining (=1) if fishery *f* belongs to effort group *eg* and is active in effort area *ea*, and *maxEffortPerGroup* is the upper bound defined in regulation.

Equation 10: Effort regulation

# Seal damage compensation

Iterative exhaustion of budget

# Calibration

Stepwise smooth approximations

# Data

Log book data for 2012