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Catchability in Icelandic trawl fishing of cod, haddock and saithe 1985-2001

(Preliminary draft, not to be quoted without consulting authors)

by

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Introduction

This is a preliminary report on an examination of catch per unit effort indices, from trawl fishing of Icelandic cod, haddock and saithe. Two types of indices were calculated and analyzed jointly with catch-at-age data by time series methods.
The analysis indicates substantial permanent changes of catchability of cod and saithe from 1985-2001.

Logbook data

Reporting catches at sea in logbooks became mandatory in 1991 for all commercial fishing vessels operating in Icelandic waters. For the trawl fishery substantial information reported on a voluntary basis extending back to the early 70s exist. From each set of the trawl, the composition of catches is reported, as is the duration of the set, along with some additional information.

Cod are the most important species in a mixed trawl fishery at Iceland, while haddock and saithe are generally caught in far smaller quantities. Logbooks give no indication at which species effort was directed.

Two different sets of indices of CPUE in numbers at age in commercial trawler catches were included in this study:

- A 'glm'-index, or the year effect from a multiplicative general linear model, including also fishing vessel, month and location (as statistical square of 1° longitude by 1/2° latitude) of capture.
- A 'raw' -index or the annual mean CPUE of the data used as input for the model for the 'glm'-index.

Data from 1985-2001 were chosen as this coincides with the Icelandic GroundFish Survey and logbooks and catches cover that period. The fishery is year-round but here separate indices are calculated for the periods January-May and June-December. Only one region is used here although in previous exercises using these data the Icelandic shelf has sometimes been split into north and south regions. All vessels operating with a bottom trawl for groundfish, reporting to the MRI logbook database were included, both stern trawlers and smaller boats.

'Glm'-indices

The 'glm'-indices used in this study were derived in the same way as in Stefánsson (1997, 1988), using the multiplicative modelling approach of Gavaris (1980).

Catches and towing time from all trawl sets where the species under consideration constitutes more than 50% of the total catch were summed for cells of year, month, statistical square and vessel. An observation in the model is thus a measurement of total catch and effort for a trawler in one month in a single square (Stefánsson 1988). The basic model is:

$$C_{srmt} = \alpha' T_{srmt}^{\beta} \gamma'_s \delta'_r \varsigma'_m \eta'_t$$

which, after linearization, becomes:

$$\ln(C_{srmt}) = \alpha + \beta \ln(T_{srmt}) + \gamma_s + \delta_r + \varsigma_m + \eta_t$$

where C is catch, T is towing time, index s denotes vessel, r statistical square, m month and t the year. The year effect $\eta_t = \ln(\eta'_t)$ is our index of abundance.

The choice of sets, in which the species studied was more than 50% of the catch, for inclusion in the analysis is admittedly *ad hoc*, but this percentage has been used earlier when indices of this ilk have been used in the Icelandic assessments and experience indicates that the results are not very sensitive to the choice of percentage. However, the approach has to be modified if all catches, including zeros, are to be included in the analysis.

'Raw'-indices

Annual arithmetic averages of the data used as input to the model above were calculated and are used directly as an index of biomass.

Age-disaggregation

Age distributions from samples from commercial landings and catches from bottom trawl were set up for the two periods. Only aged fish were used for setting up these distributions. Weight of sampled fish was estimated with a 'natural' length-weight relationship, i.e. $W = 0.01L^3$ where L is in cm and W in g. For a given year, the biomass index ('raw' or 'glm') is divided by the total weight of sampled fish and numbers at age multiplied by this proportion.

Model of catchability

Catchability is estimated in a joint time series analysis of catch-at-age data and CPUE data. The models and estimation procedures are presented by Gudmundsson (1994 and 2002) and we include here only a description of the model and parameters directly concerned with the catchability with the same notation as in the paper from 2002.

We model the relationship between catch per unit effort observeations and the stock as

$$U_{at} = \varphi_a \psi_t N_{at}\, e^{-\tau Z_{at}} + \varepsilon_{U,at}$$

where

U_{at} is the catch per unit effort of age a in year t,
N_{at} is the stock of age a at the beginning of year t,
Z_{at} is the total rate of fishing mortality,
$\varepsilon_{u,at}$ = residuals, serially uncorrelated, $N(\mathbf{0};\sigma_U^2\mathbf{\Omega}_{Ut})$. The matrix $\mathbf{\Omega}_{ut}$ is predetermined to account for the main changes in magnitude by age and cohorts.

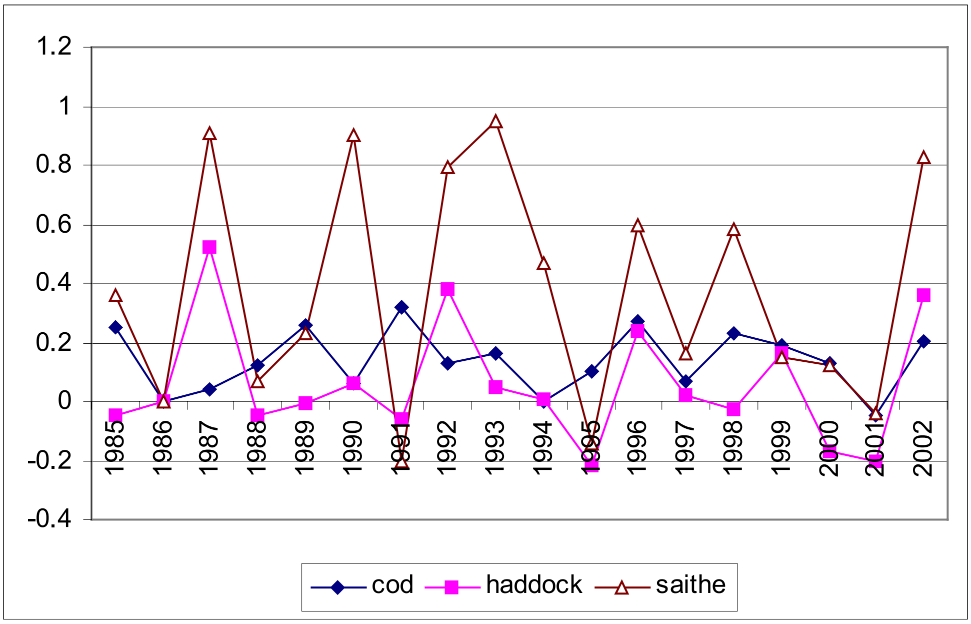
The catchability is the product of a function of age, φ_a, and a function of time, ψ_t, which is our main concern here. It is modelled as

$$\ln\psi_t = \eta_{t-1} + \delta_{7t},$$

$$\eta_t = \eta_{t-1} + \lambda + \delta_{8t}.$$

The residuals δ_{7t} and δ_{8t} are defined as independent $N(0;\sigma_7^2)$ and $N(0;\sigma_8^2)$. The parameter λ represents a constant annual change in $\ln\psi_t$.

Let us now consider how catchability variations of different kind are expressed by the magnitude of the various residuals in our model. Independent transitory variations at each age and time cannot be separated from measurement errors and are included in $\varepsilon_{U,at}$. Joint transitory variations in catchability at all ages are represented by δ_{7t}. Variations of this kind are large in CPUE from our trawl survey of the present stocks and could be caused by environmental variations. In the survey the variations associated with λ and δ_{8t} are negligible and the estimated values of $\ln\psi_t$ are presented in the following diagram:



Permanent catchability variations are represented by the function η_t and consist of a linear trend and random walk variations, engendered by λ and the residuals δ_{8t}.

The parameters of this model are λ and the residual variances σ_7^2 and σ_8^2. Our series are very short for the estimation of a three parameter time series model and in a free estimation of the full model we rarely find both trend and random walk significant in the same data set.

In this study we are not trying to establish a close approximation to a correct stochastic model of catchability but merely to estimate its variation over the years 1985-2001. A highly significant value of λ does not entail a strong support for the hypothesis that there was a linear trend in catchability; this could be the result of any form of catchability changes involving considerably higher values at the end than the beginning of the series. Over a short interval of time random walk can produce a resemblance to a large variety of highly correlated variations, regardless of whether it is the correct model or not. In fact it is obvious that neither linear trend and random walk cannot be a fair approximation to the actual process generating the data in the very long run.

Estimation

The catchability was estimated in a joint analysis of catch-at-age data and the CPUE data. For cod and saithe the ages included in the catch-at-age were from 4-11 years and 3-9 years for haddock. For cod the CPUE index for 3 years age was used as a recruitment index for cod and the index for 2 years age for haddock. The recruitment index for saithe was the average over 3-5 years age from respective cohort in the survey index.

Four data sets from each species were analysed, i.e. January-May and June-December for glim- and raw indices. For cod the ages for which CPUE indices were included were 4-8 years in all data sets. For haddock ages 3-7 were included except for the glim indices in January-May where the ages were 4-8. For saithe the ages 6-8 were included in January-May and 4-9 in June-December.

Parameters are estimated by maximising the likelihood function of prediction errors of catch-at-age and CPUE data as described by Harvey (1989) and

Gudmundsson (1994). Three models of catchability were estimated with each data set. One estimation included no permanent catchability variations, i.e. both λ and δ_{8t} were fixed as zero. The other estimates included either λ or δ_{8t} as well as δ_{7t}. Occasionally the estimated permanent variations were negligible and for saith in the autumn the estimation was performed with δ_{7t} fixed at 0 in order to obtain and estimation with random walk.

Results

The estimated values of $\ln\psi_t$ are presented in diagrams where each figure contains the results with the three models estimated from each data set. The scale is selected so that all $\ln\psi_{1986} = 0$. (The observations in the first year are mainly used to initiate the Kalman filter so don't attempt serious interpretation of ψ_{1985}). We have also collected in a table comparison of the log-likelihood functions and the estimated total catchable biomass at the beginning of the last year, 2001. The likelihood functions are only comparable within each data set so we set the value of ln(L) as 0 for the estimate where no permanent changes in catchability are allowed.

In the estimates where permanent variations are included in the model the diagrams for cod and saithe exhibit large increases in catchability during this time period. The variations are reduced, but not eliminated, by the glim-modelling compared with the raw indices. The likelihood function gives a strong indication that estimates with permanent variations should be preferred for cod, but for saithe this is sometimes less clear. Serial correlation is somewhat higher in the estimates where permanent changes are not modelled, but a detailed analysis and comparison of various estimated parameters and residual statistics has not yet been finished.

Technological progress is an obvious explanation of the observed increase in catchability, but this will be subject to further examination. Possible connection with the state of the stocks should also be considered.

There is no distinct trend in the estimated catchability of haddock. The glim indices exhibit less variation than the raw indices but the patterns are similar.

The modelling of the catchability has considerable effect upon the stock estimates. We estimated the stock of cod at the end of 2001 as 660 and saithe as 137 thousand tonnes using catch-at-age and the full survey results, but no CPUE from trawlers. The risk involved in joint analysis of catch-at-age data and CPUE from commercial fleets without attention to possible permanent catchability variations is obvious.

References

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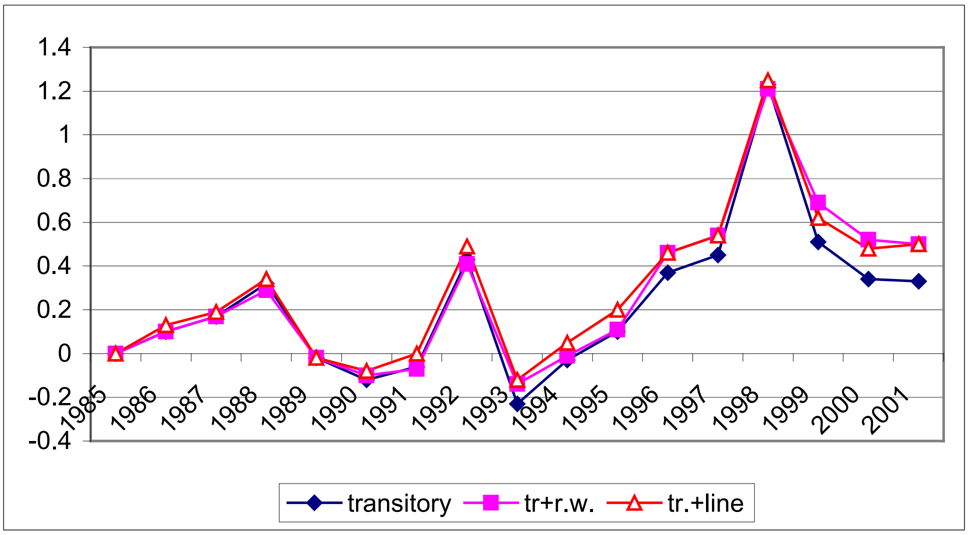
Notation:
S = spring
A = autumn
Gl = glim indices
R = raw data
tr = transitory variations,
rw = random walk + transitory variations
T = linear trend + transitory variations
L = likelihood function
stock = total biomass 2001 in 1000 tonnes

	cod			haddock			saithe	
	ln(L)	stock		ln(L)	stock		ln(L)	stock
S,Gl,tr	0	730		0	96		0	173
S,Gl,rw	2.1	681		2.8	90		0.7	144
S,Gl,T	1.8	690		0.1	96		2.3	137
A,Gl,tr	0	757		0	96		0	227
A,Gl,rw	10.7	678		2.3	90		-1.7*	161
A,Gl,T	11.0	635		0.0	96		1.3	173
S,R,tr	0	704		0	101		0	200
S,R,rw	4.0	662		0	101		1.8	144
S,R,T	4.2	678		0	101		6.1	133
A,R,tr	0	720		0	94		0	235
A,R,rw	10.3	642		8.5	86		0.3	149
A,R,T	5.6	649		0.9	98		4.3	152

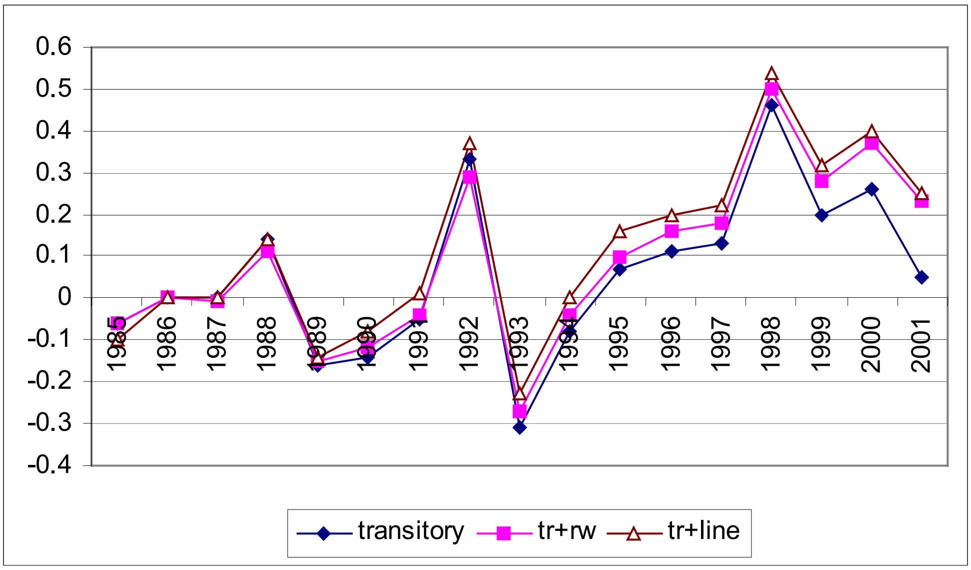
*the value of δ_{7t} was fixed as 0

Icelandic cod

Catchability in trawl fishing January-May



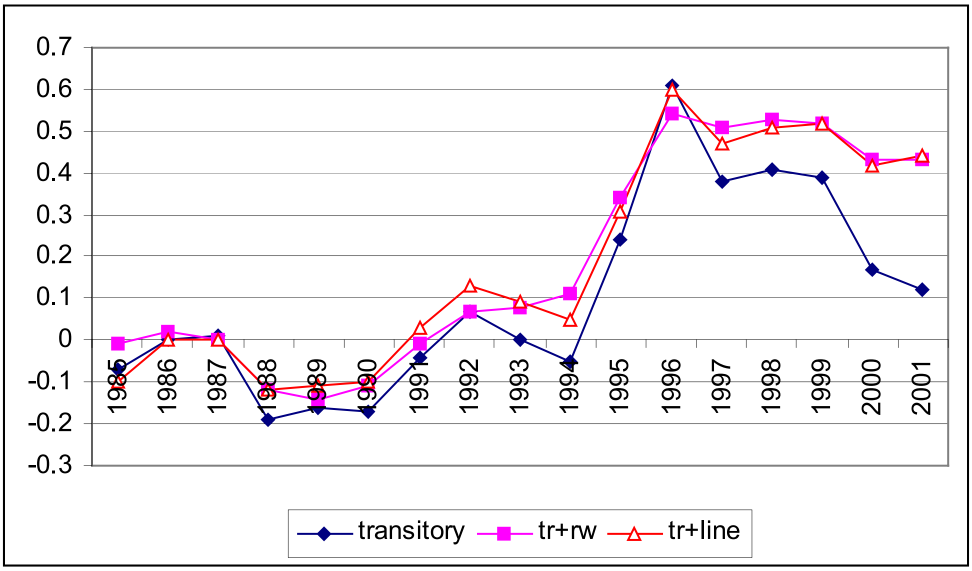
Raw indices, ln-scale



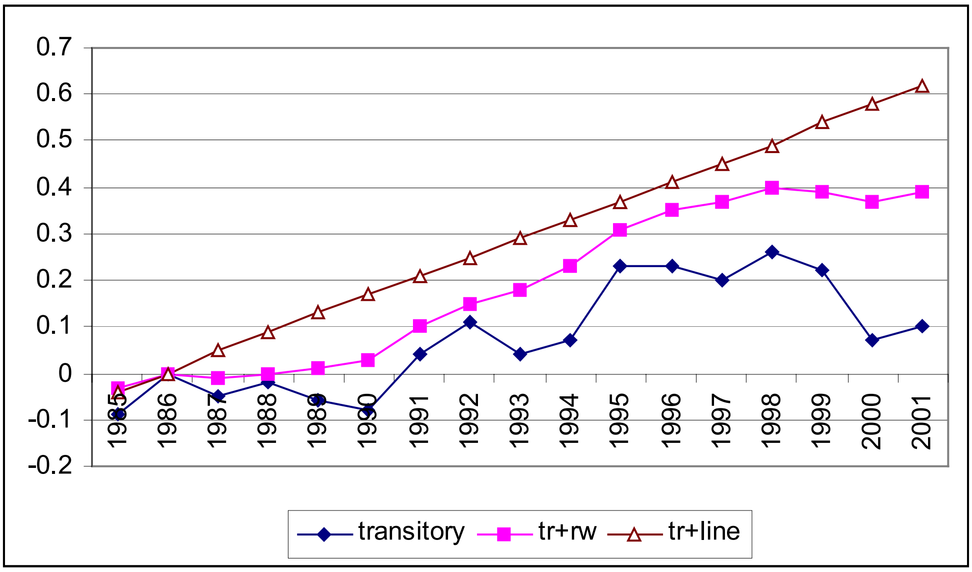
Glim indices, ln-scale

Icelandic cod

Catchability in trawl fishing June-December



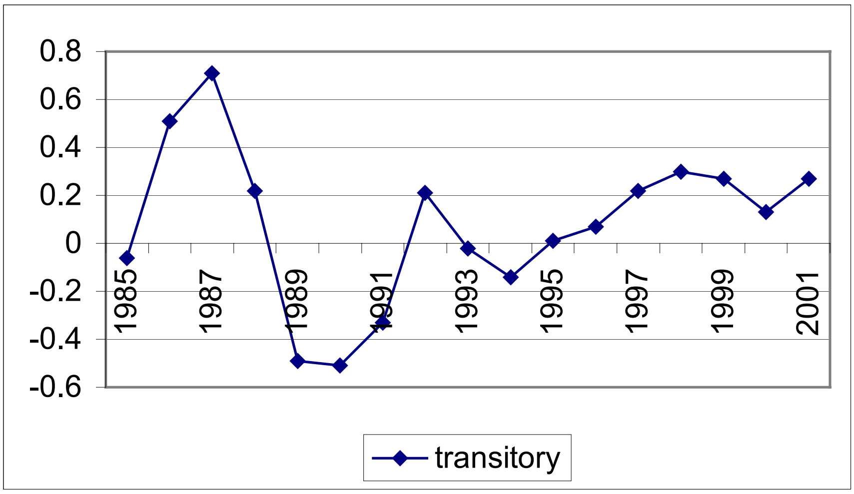
Raw indices, ln-scale



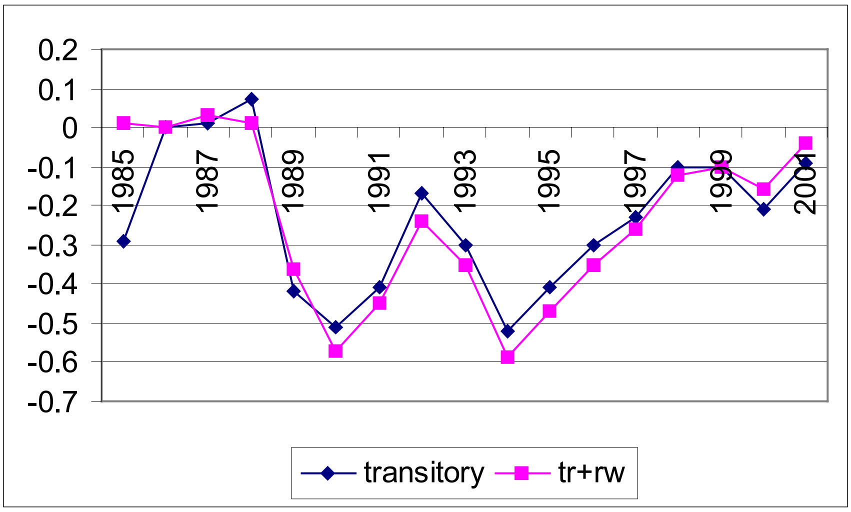
Glim indices, ln-scale

Icelandic Haddock

Catchability in trawl fishing January-May



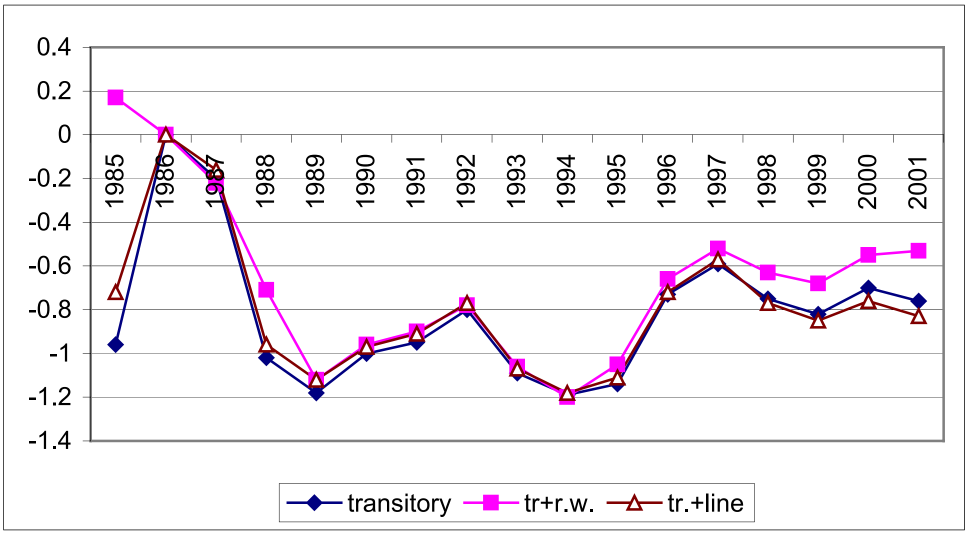
Raw indices, ln-scale



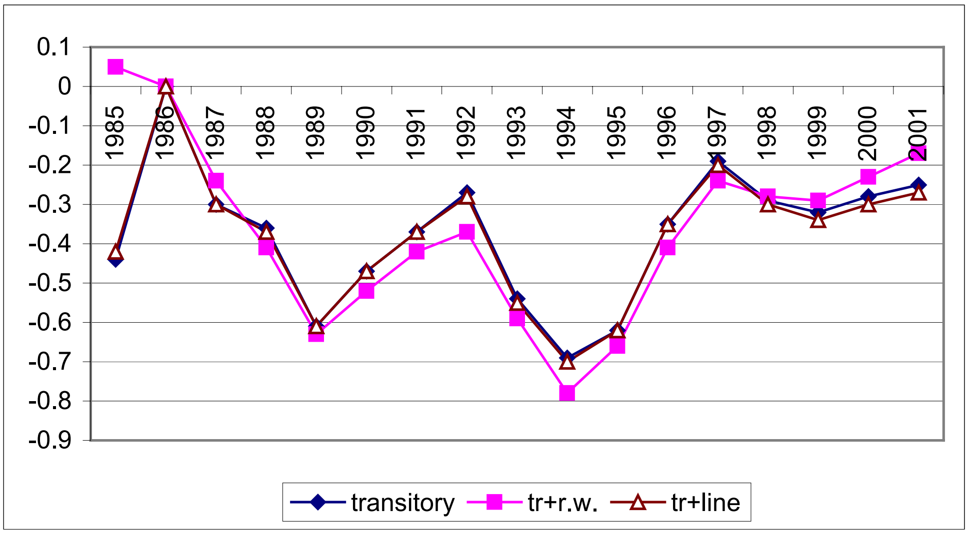
Glim indices ln-scale

Icelandic Haddock

Catchability in trawl fishing June-December



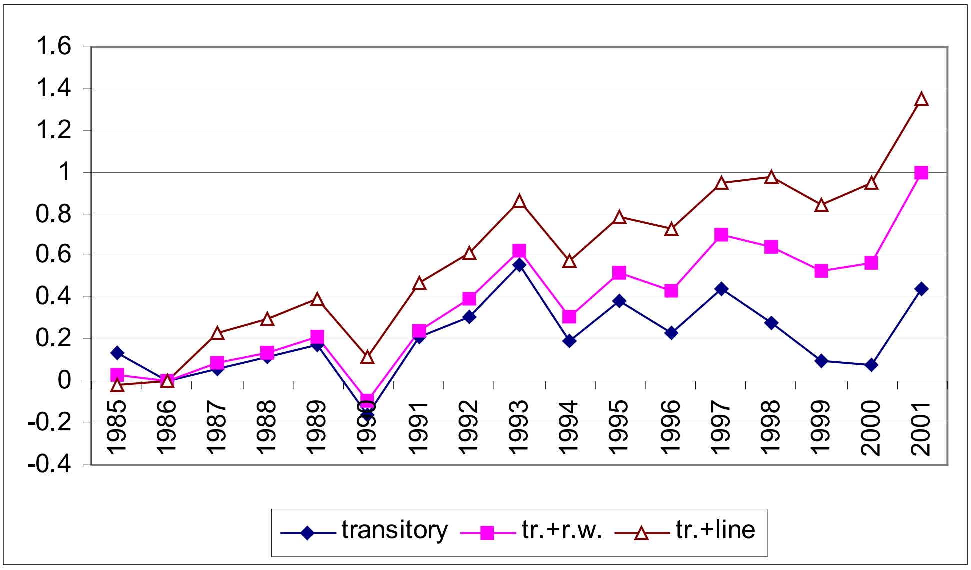
Raw indices, ln-scale



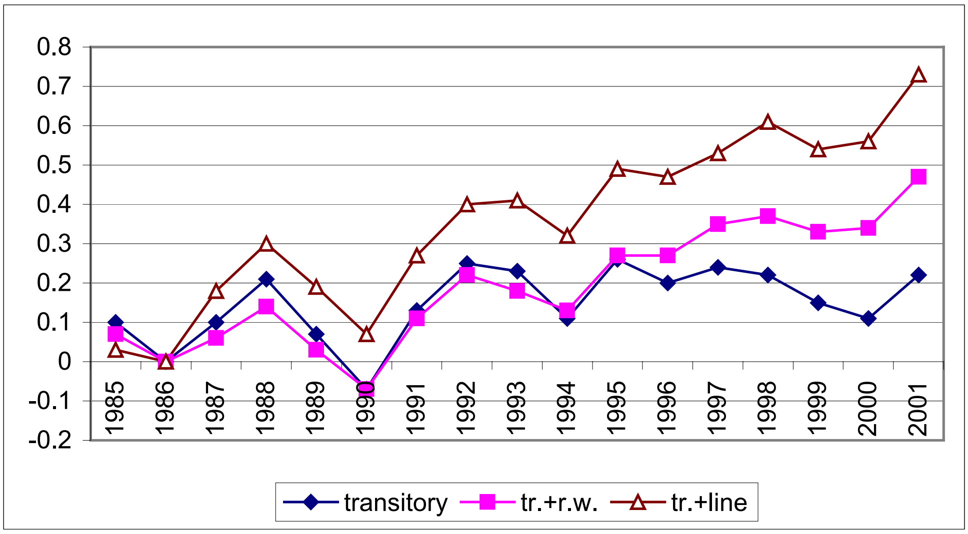
Glim indices, ln-scale

Icelandic Saithe

Catchability in trawl fishing Jan.-May



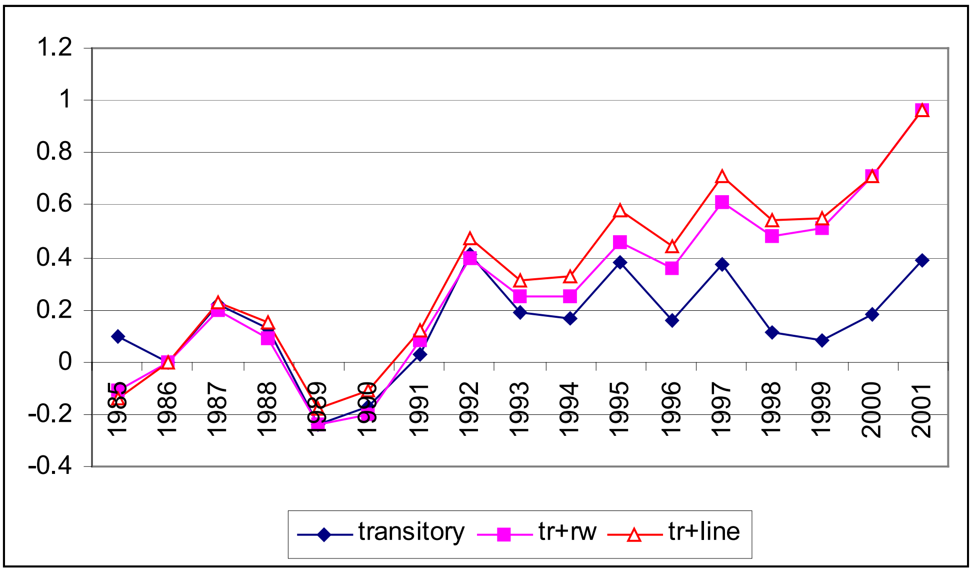
Raw indices, ln-scale



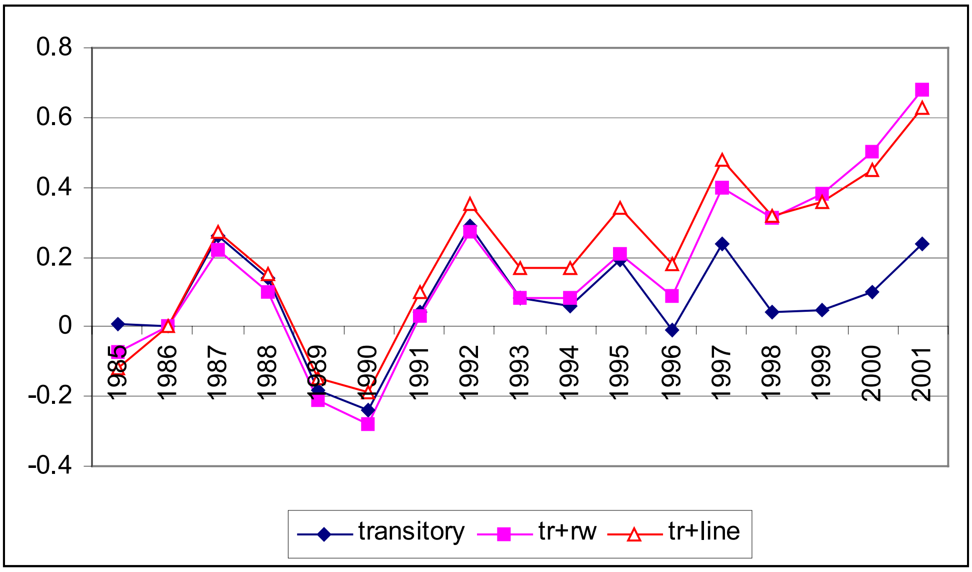
Glim indices, ln-scale

Icelandic Saithe

Catchability in trawl fishing June-December



Raw indices, ln-scale



Glim indices, ln-scale