SCRS/1992/171 Col.Vol.Sci.Pap. ICCAT, 40 (2) : 383-390 (1993)

SOME COMMENTS ON THE APPROACHES USED TO ASSESS SOUTH ATLANTIC ALBACORE

Punt, A. E.
Department of Applied Mathematics, University of Cape Town, Rondebosch 7700, South Africa

SUMMARY

The use of two alternative estimation approaches (the generalized production model and a dynamic production model) for the stock of albacore in the south Atlantic is investigated. The generalized production model approach is found to be able to provide apparently well determined estimates of management-related quantities even if catch and effort are unrelated. This is clearly an undesirable property. Monte Carlo simulation is used to compare the estimation performance of the two approaches. The estimates of MSY and E_{MSY} provided by the generalized production model are positively biased to a substantial extent (typically 100 percent), whereas those provided by the dynamic production model are very much less so. While the estimates provided by the dynamic production model are rather imprecise, it is still to be preferred to the generalized production model.

RESUME

Le présent document examine l'utilité de deux alternatives (le modèle de production généralisé et un modèle dynamique de production) pour aborder l'estimation du stock de germon dans l'Atlantique sud. Il est observé que la méthode du modèle de production généralisé fournit apparemment des estimation bien définies du volume associé à la gestion, même si la prise et l'effort ne sont pas corrélés. Il s'agit clairement d'une caractéristique peu souhaitable. La simulation de Monte Carlo est utilisée pour comparer la performance de l'estimation par les deux méthodes. Les estimations de la PME et de E_{PME} fournies par le modèle de production généralisé sont affectées d'un biais positif substantiel (typiquement 100 %), alors que celles qui découlent du modèle dynamique de production le sont bien moins. Bien que les estimations fournies par le modèle dynamique de production soient assez peu précises, il est encore préférable au modèle de production généralisé.

RESUMEN

Se investiga el uso práctico de dos enfoques de estimación alternativos (el modelo de producción generalizado y un modelo de producción dinámico) para el stock de atún blanco en el Atlántico sur. El enfoque del modelo de producción generalizado parece poder facilitar estimaciones aparentemente bien determinadas de las cantidades relacionadas con la gestión, incluso si la captura y el esfuerzo no están relacionados. Claramente, no es una propiedad deseable. Se utiliza la simulación de Monte Carlo para comparar la ejecución de estimación de los dos enfoques. Las estimaciones de RMS y de E_{RMS} que aporta el modelo de producción generalizado están positivamente sesgados de forma importante (típicamente, 100%), mientras que los que aporta el modelo de producción dinámico son muy inferiores. Mientras las estimaciones facilitadas por modelo de producción dinámico son más bien imprecisos, se le prefiere, no obstante al modelo de producción generalizado.

INTRODUCTION

At its 1991 meeting, the ICCAT (International Commission for the Conservation of Atlantic Tunas) SCRS (Standing Committee on Research and Statistics) based its assessment of the status of the stock of albacore (*Thunnus alalunga*) in the south Atlantic on the results of two production-model estimation procedures (ICCAT 1992). The first of these (Yeh *et al.* 1991, 1992) consisted of the combination of the Pella-Tomlinson surplus production function (Pella and Tomlinson 1969) and an estimation procedure comprising an effort-averaging procedure coupled with the continuous equilibrium assumption (Fox 1975). The other approach (Punt *et al.* 1992) was based on an age-structured model and used an observation error estimator to obtain estimates for the model parameters. For consistency with ICCAT nomenclature, the Yeh *et al.* (op. cit) approach is henceforth referred to as the generalized production-model and is detailed in Appendix A.

The estimation method used by Yeh *et al.* (op. cit.) has been questioned many times in the scientific literature. Roff and Fairbairn (1980) criticize it because effort appears in both the independent and dependent variables in the regression of CPUE against a moving average of effort; this automatically introduces a negative correlation between the variables. Polacheck and Hilborn (1987) censure the approach because it provides estimates of management quantities which may appear reasonable even though they clearly cannot be estimated from the data, while Butterworth and Andrew (1984) and Punt (1988) show that estimated quantities may be substantially biased by failure to take account of the resource dynamics.

This paper examines each of these problems in turn, and illustrates their effects for the stock of albacore in the south Atlantic.

THE CORRELATION IMPLICIT IN EFFORT-AVERAGING PROCEDURES

Equations (A.2) to (A.4) involve regressing CPUE against a weighted moving average of annual effort. As the effort for year y appears on both sides of Equation (A.2), this approach necessarily results in a negative correlation between the "independent" and "dependent" variables (even if catch and effort are in reality unrelated). To illustrate this effect, the Equation (A.2) to (A.4) approach was applied to 500 sets of pseudo catch-effort data. Each pseudo data set consisted of catch and effort data for a 20-year period and each data point was drawn at random from a uniform distribution between 0 and 1: U[0,1]. For simplicity, the Pella-Tomlinson shape parameter, m, was set to 2 for these calculations (equivalent to the Schaefer form of the surplus production function) and the weighting factor in Equation (A.3) was ignored.

Table 1 contains the median and 90% distribution limits (across the 500 simulations) of the estimates of the Maximum Sustainable Yield (MSY) and the effort level at which MSY will be achieved (E_{MSY}). Results are presented for four choices of the period over which effort is averaged (k=1,2,3 and 5). The estimate of MSY almost always lies outside of the range of "observed" data (in all cases the median MSY is larger than 1.2). Were these results to be interpreted in a management context, the resource would be assessed to be underexploited because annual catches have never exceeded MSY. While the confidence intervals for MSY are very wide and skew, those for E_{MSY} are reasonably symmetrical and narrow. Those narrow confidence intervals imply that the Equation (A.3) approach provides estimates of E_{MSY} which are quite precise. Not bad performance for a procedure using random numbers (with NO information content) for input!

It is possible to remove the implicit correlation between the "independent" and "dependent" variables by multiplying both sides of Equation (A.2) by effort (before averaging) - see Equation (A.5). The results of applying the Equation (A.5) approach (for k = 1,2,3 and 5) to the 500 pseudo data sets are also given in Table 1. In this case MSY almost always (a probability less than 5%) lies within the range of the "observed" data - the obvious outliers evident in Table 1(a) have now vanished. For the Equation (A.3) and (A.5) approaches, there is a widening of the distributions of the results as the number of years over which effort is averaged is increased. This is a consequence of the reduction of the number of data points used in the regression.

These results illustrate the point made by Polacheck and Hilborn (1987), that apparently reasonable estimates of management-related quantities can be provided by the generalized production-model approach, even if the data cannot support their estimation.

ESTIMATION OF BIASES

While the results in Table 1 are certainly disconcerting, it does not necessarily follow that the generalized production-model approach cannot provide reliable results. Monte-Carlo simulation has therefore been used to investigate the performances of the effort-averaging approach and a dynamic production-model approach (see Appendix B). The testing process involves the construction of a model of the resource dynamics (often referred to as the "operating model"), generation of a large number (100 in this case) of data sets based on the model, application of each candidate approach to each data set, and the comparison of the estimates provided by the estimators with their true values (known by the operating model). This process is illustrated in Figure 1. The dynamic approach of Appendix B and the generalized production-model are essentially based on the following model:

$$
\begin{aligned}
B_{y+1} &= [B_y + G(B_y)]\, e^{\varepsilon_y} - C_y + \eta_y K \\
(C/E)_y &= q(B_y + B_{y+1})/2\, e^{\phi_y} + v_y q K
\end{aligned}
\qquad (1)
$$

where B_y is the biomass at the start of year y,

$G(B)$ is surplus production as a function of biomass,

q is the catchability coefficient, and

ε_y, η_y, ϕ_y and v_y are normally distributed random variables with mean zero and standard deviations σ_ε, σ_η, σ_ϕ and σ_v respectively.

The dynamic model of Appendix B corresponds to the choice $\sigma_\varepsilon=\sigma_\eta=\sigma_v=0$. In order to test the two approaches adequately, five parameterizations of model (1) are considered. All five set r=0.166, q=0.185 and K=404.1. These values are obtained by fitting the dynamic model to the catch-effort data in Table 2 - the generalized production-model is unable to provide estimates of r, q, and K. The five parameterizations differ in how the error variances are specified:

a) $\sigma_\varepsilon = 0.13$; $\sigma_\eta = 0$; $\sigma_\phi = 0$; $\sigma_v = 0$
b) $\sigma_\varepsilon = 0$; $\sigma_\eta = 0.13$; $\sigma_\phi = 0$; $\sigma_v = 0$
c) $\sigma_\varepsilon = 0$; $\sigma_\eta = 0$; $\sigma_\phi = 0.13$; $\sigma_v = 0$
d) $\sigma_\varepsilon = 0$; $\sigma_\eta = 0$; $\sigma_\phi = 0$; $\sigma_v = 0.13$
e) $\sigma_\varepsilon = 0.07$; $\sigma_\eta = 0.07$; $\sigma_\phi = 0.07$; $\sigma_v = 0.07$

Note that when generating the data sets, it is assumed that $B_1=B_{1956}=K$, and that the catches are those given in Table 2. CPUE data are generated for each year for which they are available in the actual data set (i.e. 1967-1990).

In order to keep this presentation reasonably consise, only three management-related quantities (MSY, E_{MSY} and B_{1990}/K) have been considered. Figures 2(a) - 2(e) provide relative error distributions for the three management quantities for the five parameterizations of model (1) and for five estimation procedures [the dynamic production-model of Appendix B, and four variants of the generalized production-model approach]. In order to summarize the results further, Table 3 provides the medians of the distributions of the absolute values of the relative (proportional) error for each estimation procedure, paramerization of model (1) and management-related quantity.

From Figure 2, it is obvious that the generalized production-model approach provides estimates of MSY and E_{MSY} which are subject to substantial positive bias (typically 100%). The performance of these approaches in terms of bias for B_{1990}/K is far more satisfactory. In contrast, the dynamic production-model approach provides estimates of all three quantities with far less bias in all cases. Of the generalized production-model approaches considered, those based on m=2 perform better than those based on m=1.001. In general, the dynamic production-model results are less precise than those of the generalized production-model. Nevertheless, consideration of the medians of the distributions of the absolute values of the relative errors (which reflect bias to some extent as well as precision) shows that for MSY and E_{MSY}, the dynamic production-model approach is far preferable to the generalized production-model approaches (Table 3). The results for B_{1990}/K do not readily distinguish between the relative merits of the approaches. However, even when the dynamic production-model approach is not the best for this quantity, it is also never substantially worse than the other approaches.

Not surprisingly, the performance of the dynamic production-model is best when the error structure of the operating model is identical to that of the estimator [Figure 2(c); Table 3(c)]. The poorest performance occurs when all the error is the population dynamics equation (i.e process error) and is absolute rather than relative (i.e. σ_n=0.13) [Figure 2(b); Table 3(b)]. Under this parameterization of model (1), the biomass of the resource can change substantially from one year to the next (95% distribution range for the change is [-0.26K, 0.26K]). While the performance of the procedure for this case is not very good for MSY and E_{MSY}, it quite satisfactory for B_{1990}/K [Table 3(b)].

These results show that the conclusions of Butterworth and Andrew (1984) and Punt (1988) that the generalized production-model provides estimates with substantial positive bias applies to the stock of albacore in the south Atlantic. They also show clearly that the use of a dynamic production-model approach is preferable to the use of the generalized production-model approach.

CONCLUSIONS

- The generalized production-model approach with its associated effort-averaging estimator provides estimates of management related quantities for the stock of Albacore in the south Atlantic which are positively biased to a substantial extent.
- A dynamic production-model-estimation procedure is able to outperform the generalized production-model approach markedly for this stock.
- Use of the generalized production-model approach is to be avoided, and estimators taking account of the dynamics of the stock should be applied instead.

ACKNOWLEDGEMENTS

This work was undertaken as part of the Benguela Ecology Programme (FRD, South Africa), and funded also by a contract with the South African Sea Fisheries Research Institute. Prof. D.S. Butterworth (Department of Applied Mathematics, University of Cape Town) is thanked for his comments on an earlier draft of this paper.

REFERENCES

BUTTERWORTH, D.S. and P.A. ANDREW. 1984. Dynamic catch-effort models for the hake stocks in ICSEAF Divisions 1.3 to 2.2. *Colln scient. Pap. int. Commn SE. Atl. Fish.* 11(1): 29-58.

BUTTERWORTH, D.S. and P.A. ANDREW. 1987. Further results from the application of dynamic catch-effort models to the hake stocks in the ICSEAF Convention Area. *Colln scient. Pap. int. Commn SE. Atl. Fish.* 14(1): 109-160.

BUCKLAND, S.T. 1984. Monte Carlo confidence intervals. *Biometrics* 40: 811-817.

FOX, W.W. 1975. Fitting the generalized stock production model by least-squares and equilibrium approximation. *Fish. Bull.* 73(1): 23-37.

ICCAT. 1990. Report of the 1989 ICCAT albacore workshop, 19-28 September 1989, Madrid. *Colln. Vol. Sci. Pap. ICCAT.* 33: 171pp.

ICCAT. 1992. Report of the ICCAT SCRS, ?-? November 1991, Madrid. *Colln. Vol. Sci. Pap. ICCAT.* 34: 170pp.

PELLA, J.J. and P.K. TOMLINSON. 1969. A generalized stock production model. *Inter-Am. Trop. Tuna Commn Bull.* 13: 421-496.

POLACHECK, T. and R. HILBORN. 1987. A proposal to abandon the use of equilibrium models for surplus production models. *ICSEAF document SAC/87/Doc/20.* (11pp) (mimeo).

PUNT, A.E. 1988. Model selection for the dynamics of southern African hake resources. *Rep. Benguela Ecol. Progm. S. Afr. 15:* [vii] + 395pp.

PUNT, A.E. and D.S. BUTTERWORTH. 1991. On an approach for comparing the implications of alternative fish stock assessments, with application to the stock of Cape hake off northern Namibia. *S. Afr. J. mar. Sci.* 10: 219-240.

PUNT, A.E., PENNEY, A.J. and C.G. WILKE. 1992. Stock assessment of South Atlantic albacore using an age-structured production model. *ICCAT Document SCRS/91/84* (18pp).

ROFF, D.A. and D.J. FAIRBAIRN. 1980. An evaluation of Gulland's method for fitting the Schaefer model. *Can. J. Fish. Aquat. Sci.* 37: 1229-1235.

YEH, S-Y., T-S. TSOU and H-C. LIU. 1991. Assessment of the south Atlantic albacore resource by using surplus production models, 1976-1988. *Colln. Vol. Sci. Pap. ICCAT.* 34: 166-170.

YEH, S-Y. ??? 1992.

Table 1 : Medians and 90% distribution ranges (in parenthesis) for MSY and E_{MSY} obtained by applying various versions of two effort-averaging approaches to 500 pseudo catch-effort data series.

(a) The Equation (A.3) approach

Value of k	Quantity MSY	E_{MSY}
1	1.231 (0.601; 8.047)	0.400 (0.314; 0.546)
2	1.297 (0.623; 8.145)	0.376 (0.287; 0.509)
3	1.312 (0.621; 8.696)	0.368 (0.278; 0.543)
5	1.414 (0.601;10.625)	0.355 (0.260; 0.685)

(b) The Equation (A.5) approach

Value of k	Quantity MSY	E_{MSY}
1	0.615 (0.467; 0.786)	0.591 (0.478; 0.949)
2	0.590 (0.451; 0.787)	0.552 (0.424; 1.145)
3	0.577 (0.441; 0.811)	0.525 (0.389; 1.178)
5	0.569 (0.311; 0.880)	0.495 (0.316; 1.391)

Table 2 : Catch and effort statistics for the stock of albacore in the south Atlantic.

YEAR	CATCH ('000t)	TAIWANESE LONGLINE CPUE (kg / 100 hooks)
1957	0.7	
1958	1.0	
1959	4.8	
1960	10.5	
1961	10.8	
1962	18.9	
1963	17.3	
1964	25.9	
1965	29.8	
1966	27.3	
1967	15.9	61.9
1968	25.7	79.0
1969	28.4	55.6
1970	23.6	44.6
1971	25.0	57.1
1972	33.4	38.3
1973	28.2	33.8
1974	19.7	36.1
1975	17.6	41.9
1976	19.3	36.6
1977	21.6	36.3
1978	23.0	38.8
1979	22.5	34.3
1980	22.6	37.6
1981	23.5	34.0
1982	29.0	32.2
1983	14.5	26.9
1984	13.1	36.6
1985	28.3	30.1
1986	35.1	30.7
1987	38.2	23.4
1988	27.6	22.4
1989	25.3	21.9
1990	22.5	

Sources : 1957 - 1960 catches - ICCAT (1990)
1961 - 1990 catches - ICCAT (1992)
CPUE - Yeh *et al.* (1992)

Table 3 : Medians of the absolute values of the relative errors for five estimation procedures, five parameterizations (a)-(e) of the operating model, and three management-related quantities.

i) MSY

OP MODEL	ESTIMATION PROCEDURE (I)	(II)	(III)	(IV)	(V)
(a)					
(a)	32.86	80.47	95.29	78.80	95.35
(b)	59.00	84.82	90.58	80.53	91.09
(c)	11.51	81.81	93.83	75.70	89.74
(d)	22.87	97.56	101.37	90.88	94.66
(e)	52.12	83.51	97.32	86.08	99.28

ii) E_{MSY}

OP MODEL	ESTIMATION PROCEDURE (I)	(II)	(III)	(IV)	(V)
(a)	30.29	99.55	108.24	136.08	155.12
(b)	67.48	78.29	87.19	114.48	121.49
(c)	9.47	147.77	155.01	173.61	194.65
(d)	19.60	158.57	178.40	187.75	217.15
(e)	54.68	98.33	123.39	129.18	170.82

iii) B_{1990}/K

OP MODEL	ESTIMATION PROCEDURE (I)	(II)	(III)	(IV)	(V)
(a)	26.02	26.08	24.88	29.57	24.75
(b)	25.26	17.09	17.17	23.86	22.76
(c)	14.53	47.44	44.23	24.79	24.57
(d)	39.10	51.71	58.55	48.29	51.71
(e)	23.91	20.67	22.45	25.88	24.32

Estimation procedures:
- I) Dynamic production-model
- II) Generalized production-model - Equation (A.3) with m = 2
- III) Generalized production-model - Equation (A.3) with m = 1.001
- IV) Generalized production-model - Equation (A.5) with m = 2
- V) Generalized production-model - Equation (A.5) with m = 1.001

Operating model parameterizations:
- a) $\sigma_\varepsilon = 0.13$; $\sigma_\eta = 0$; $\sigma_\phi = 0$; $\sigma_v = 0$
- b) $\sigma_\varepsilon = 0$; $\sigma_\eta = 0.13$; $\sigma_\phi = 0$; $\sigma_v = 0$
- c) $\sigma_\varepsilon = 0$; $\sigma_\eta = 0$; $\sigma_\phi = 0.13$; $\sigma_v = 0$
- d) $\sigma_\varepsilon = 0$; $\sigma_\eta = 0$; $\sigma_\phi = 0$; $\sigma_v = 0.13$
- e) $\sigma_\varepsilon = 0.07$; $\sigma_\eta = 0.07$; $\sigma_\phi = 0.07$; $\sigma_v = 0.07$

APPENDIX A : THE GENERALIZED PRODUCTION-MODEL APPROACH

If the dynamics of a resource are governed by the Pella-Tomlinson (1969) equation:

$$\frac{dB}{dt} = rB(1 - (B/K)^m) - C \qquad (A.1)$$

where r is the intrinsic growth rate parameter,

K is the average biomass level prior to exploitation,

q is the catchability coefficient,

B is the resource biomass,

m is the Pella-Tomlinson shape parameter, and

E is fishing effort,

the resource is in equilibrium (i.e. dB/dt = 0), and CPUE is proportional to biomass (i.e. C/E = qB), then CPUE can be shown to be related to effort according to the following equation:

$$(C/E)_y = (\alpha + \beta E_y)^{1/m} \qquad (A.2)$$

where $\alpha = (qK)^m$, and

$\beta = q^{m+1}K^m/r$.

Fox (1975) suggested that estimates of the parameters α and β (and hence MSY and E_{MSY}) could be obtained by minimizing the quantity:

$$SS = \sum_y \widehat{(C/E)}_y^{-2} [(C/E)_y - \widehat{(C/E)}_y]^2 \qquad (A.3)$$

where $(C/E)_y$ is the observed CPUE for year y, and

$\widehat{(C/E)}_y$ is the CPUE predicted for year y using Equation (A.2).

When minimizing Equation (A.3), (E_y) on the RHS of Equation (A.2) is replaced by:

$$\bar{E}_y = \sum_{i=0}^{k-1} (k-i)\, E_{y-i} \Big/ \sum_{j=0}^{k-1} (k-j) \qquad (A.4)$$

where k is the number of year-classes contributing substantially to the catch in year y [Yeh *et al.* (1991, 1992) chose a value of 3 for k].

The above formalism can, quite justifiably, be criticized because effort for year y appears on both sides of Equation (A.2). An alternative fitting procedure which overcomes this problem is to minimize the following function instead:

$$SS = \sum_y \widehat{(C/E)}_y^{-2} [C_y - \hat{C}_y]^2 \qquad (A.5)$$

where

$$\hat{C}_y = \bar{E}_y (\alpha + \beta \bar{E}_y)^{1/m}$$

APPENDIX B : THE BUTTERWORTH-ANDREW (B_1=K) OBSERVATION ERROR ESTIMATOR [Butterworth and Andrew 1984, Punt and Butterworth 1991]

The fishery is modelled as follows:

$$B_{y+1} = B_y + g(B_y) - C_y \qquad (B.1)$$

$$(C/E)_y = q\left(\frac{B_y + B_{y+1}}{2}\right) e^{v_y} \qquad v_y \sim N(0;\sigma_v^2) \qquad (B.2)$$

where B_y is the biomass at the start of year y, and B_1 = K,

$g(B)$ is surplus production as a function of biomass, and here $g(B) = rB(1 - B/K)$

r is the intrinsic growth rate parameter,

q is the catchability coefficient,

K is the average biomass level prior to exploitation,

C_y is the catch during year y,

$(C/E)_y$ is the CPUE for year y, and

σ_v^2 is the variance of the log of the observation error.

Estimates of the parameter values are obtained by minimizing the quantity:

$$SS = \sum_y{}' [\ln(C/E)_y - \ln\widehat{(C/E)}_y]^2 \qquad (B.3)$$

where Σ' is summation over all years (y) for which CPUE data are available,

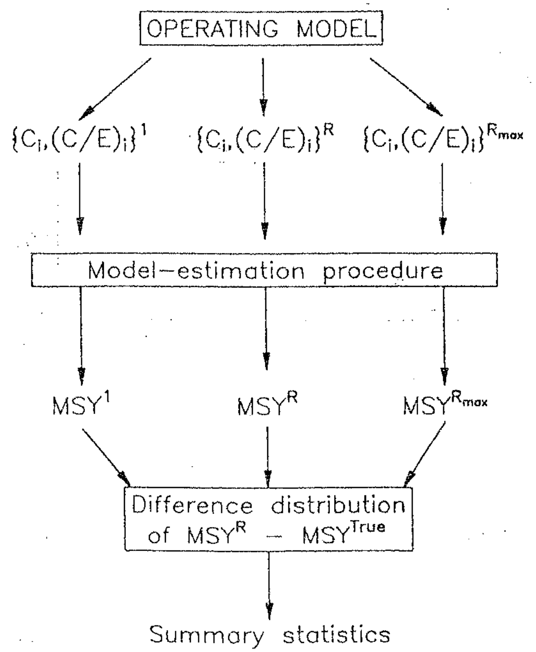

Figure 1 : Flowchart of the method used to determine the ability of a model-estimation procedure to estimate a management-related quantity (such as MSY, as considered here).

Figure 2(a)

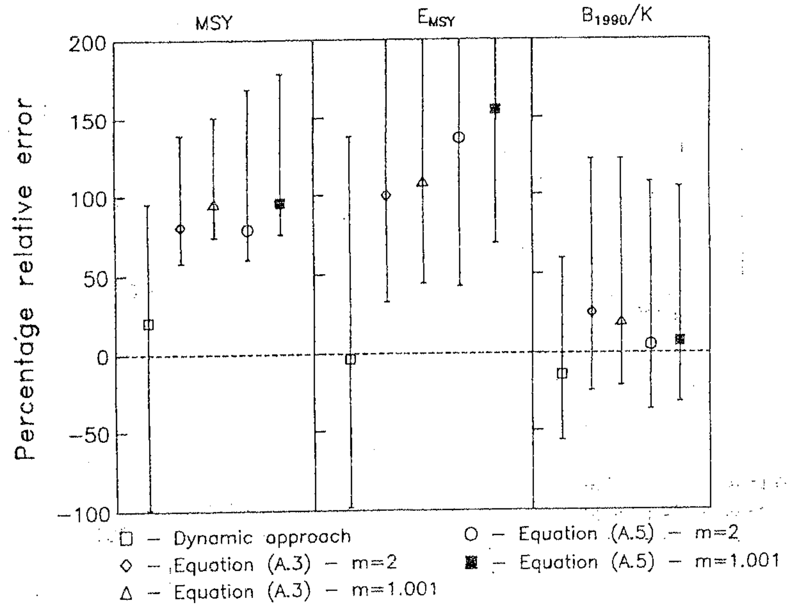

Figure 2 : Comparison of the estimation performance of five production-model approaches. "Dynamic model" refers to the Appendix B approach, and "Equations (A.3) and (A.5)" refer to variants of the generalized production-model approach. Medians and 90% intervals are shown. Plots a) to e) correspond to the five different error parameterizations detailed in the text.

Figure 2(b)

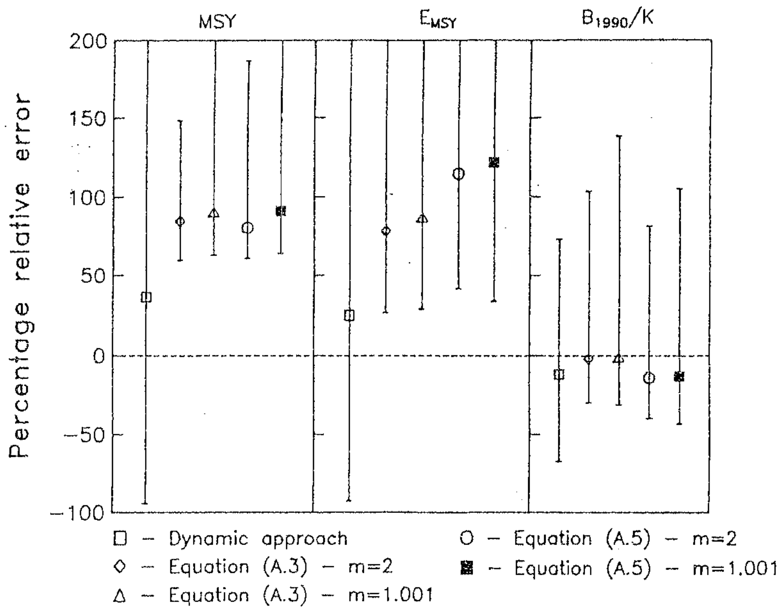

Figure 2(c)

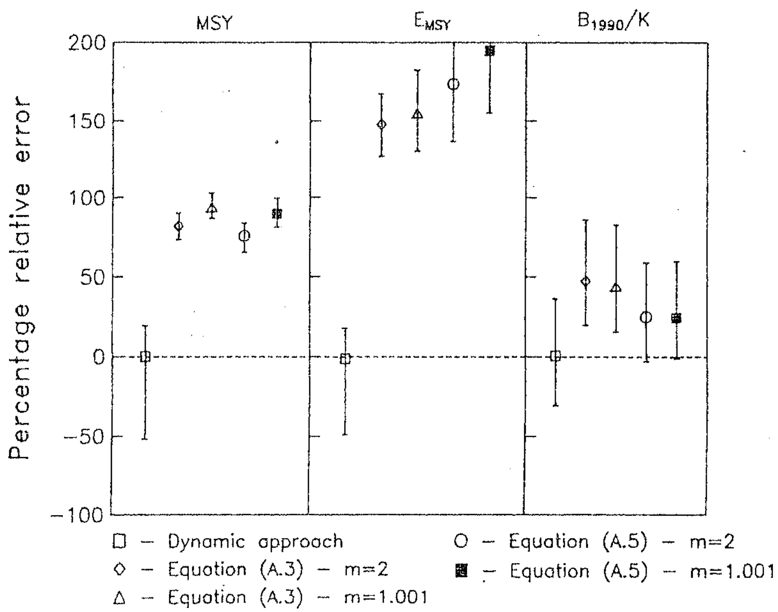

Figure 2(d)

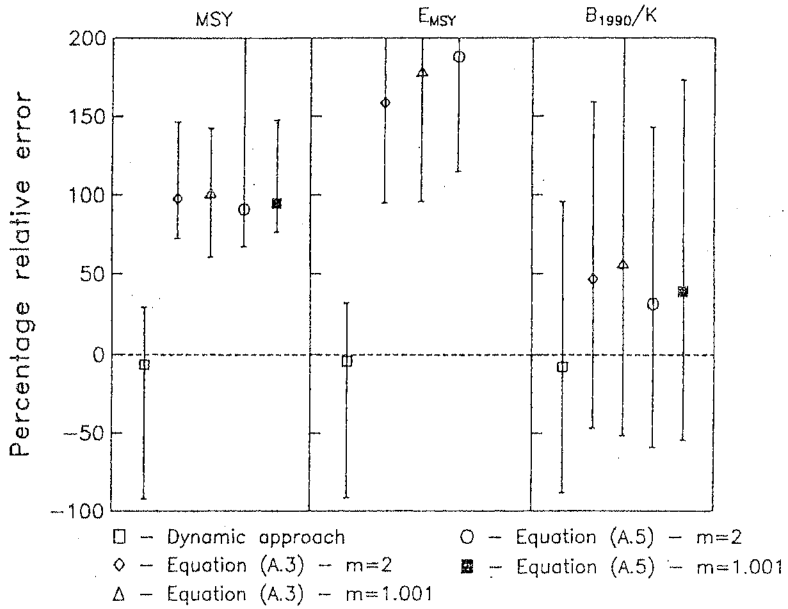

Figure 2(e)