

# Coastwide analysis of forestry impacts on BC Pacific Salmon

Apr. 2024

## Overview

This short document provides some details on initial models fit and inferential outputs. It can be treated as a living appendix of sorts, and can be added to and polished over time.

Code and data to reproduce the analyses summarized in this document can be found in this repository which is private for now in case there is anything in the ECA dataset that is not suitable for public consumption. Access can be granted by sending Dan or Brendan your github username.

The first set of models we fit includes a covariate for ECA alone (logit transformed and standardized) which is modeled hierarchically down to CU-level for ECA effects and to the individual river (subscript  $r$ ) level for productivity. We test 3 models for the structure of density dependence: either a Ricker (model 1), Beverton-Holt (model 2), or Cushing type (model 3) spawner-recruitment relationship. The stan models themselves are in the github repo as `m1_ricker.stan`, `m1_bh.stan`, `m1_cush.stan`.

## Models

Ricker formulation:

$$\log(R_{t,r}/S_{t,r}) = \alpha_r - \beta_r * S_{t,r} + \beta_{eca,c} * ECA_{t,r} + w_{t,r}$$

Where residual productivity is autocorrelated by 1-year:

$$w_{1,r} \sim N(0, \sigma_r)$$

$$w_{t,r} \sim N(\rho_r * w_{t-1,r}, \sigma_r * \sqrt{(1 - \rho_r^2)})$$

$$\rho \sim U(-1, 1)$$

And stock-specific parameters are drawn hierarchically at the River-level for productivity and CU-level for forestry effects:

$$\alpha_r \sim N(\alpha_c, \sigma_{ar}^2)$$

$$\alpha_c \sim N(\alpha, \sigma_{ac}^2)$$

$$\alpha \sim N(1.5, 2)$$

$$\beta_{eca,c} \sim N(\beta_{eca}, \sigma_{eca})$$

$$\beta_{eca} \sim N(0, 1)$$

$$\sigma_{eca} \sim N[0, 0.5)$$

$$\sigma_r \sim N(\sigma_c, \sigma_{\sigma,r})$$

$$\sigma_c \sim N(\sigma, \sigma_{\sigma,c})$$

$$\sigma \sim N[0.5, 0.5)$$

Stock-specific within brood year density-dependence is estimated independently at the river level, but with informative priors for  $S_{max}$  ( $=1/\beta$ ; density where total predicted recruitment is maximized) based on observed spawner counts ( $S_r$ ):

$$\beta \sim \text{lognormal}(0.5 * \max(S_r), \max(S_r))$$

The Beverton Holt form of this model was the linearized as:

$$\log(R_{t,r}/S_{t,r}) = \alpha_r - \log(1 + (e^{\alpha_r}/R_{k,r}) * S_{t,r}) + \beta_{eca,c} * ECA_{t,r} + w_{t,r}$$

Where the new parameter  $R_{k,r}$  is the stock-specific equilibrium recruitment, sampled with informative priors based on observed recruitment ( $R$ ):

$$R_{k,r} \sim \text{lognormal}(0.75 * \max(R_r), \max(R_r))$$

For the Cushing model, the linearized form is:

$$\log(R_{t,r}/S_{t,r}) = \alpha_r + \beta_r * \log(S_{t,r}) + \beta_{eca,c} * ECA_{t,r} + w_{t,r}$$

A version of each model was fit to the Chum dataset. Model summaries can be found in the github repository under 'outs/summary' in the 'stan models' subfolder.

## Model form comparison

Overall model likelihood across the 3 alternative model (model 1: Ricker, model 2: BH, model 3: Cushing) forms assessed by approximate leave-one-out cross-validation, is:

##	elpd_diff	se_diff	elpd_loo	se_elpd_loo	p_loo	se_p_loo
## model2	0.000	0.00000	-12590.08	82.87004	851.6476	19.15519
## model11	-2601.199	82.57776	-15191.28	90.19241	763.8891	18.50376
## model13	-4627.793	93.88754	-17217.87	83.63883	420.8408	11.47561

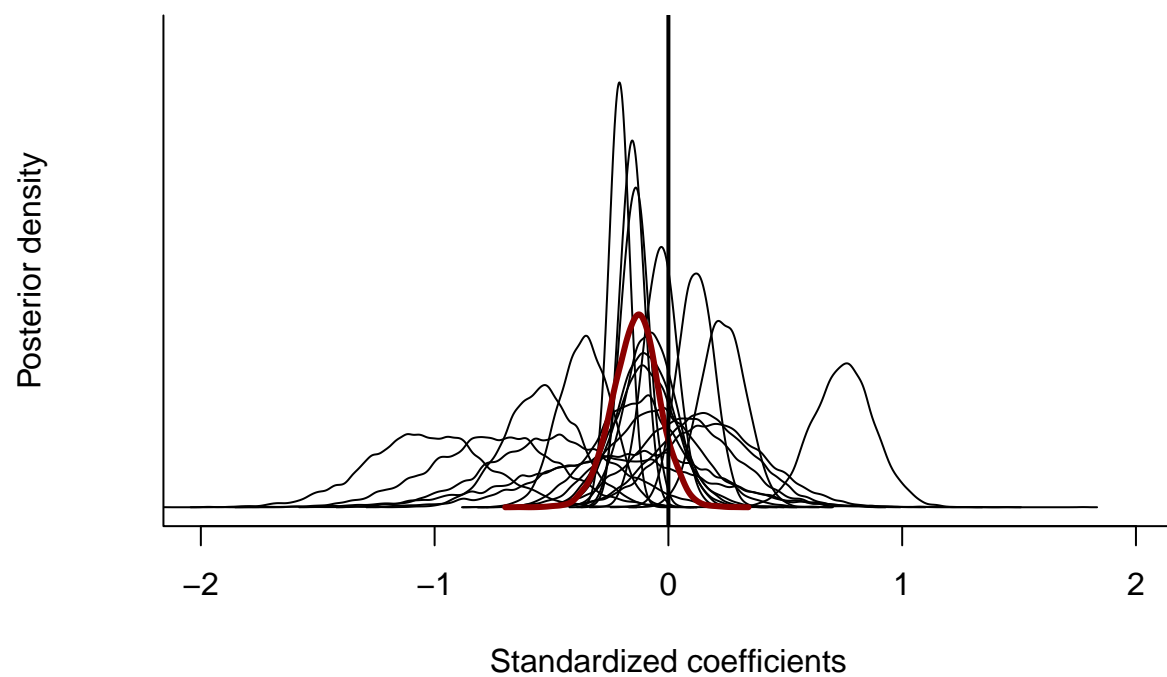
From this the Beverton-Holt model appears to have substantially better predictive performance compared to the Ricker/Cushing model forms. We will proceed with results for both BH/Ricker however.

## Forestry effects

The overall among population effect size (b\_ECA) for ECA, and varying effects of ECA by CU (b\_ECA\_cu), from the Beverton-Holt fit. The plot shows density of effect sizes among CUs and the red line indicates the global effect:

##	variable	mean	sd	q5	q95	rhat
## 1	b_ECA	-0.13879772	0.10085593	-0.305988750	0.02639130	1.002367
## 2	b_ECA_cu[1]	-0.21034937	0.04033780	-0.277363750	-0.14382020	1.000624
## 3	b_ECA_cu[2]	-0.09972521	0.12092379	-0.297617800	0.09747117	1.001087
## 4	b_ECA_cu[3]	0.19622800	0.22661923	-0.167274050	0.57906645	1.002111
## 5	b_ECA_cu[4]	-1.03350397	0.25522140	-1.456413000	-0.60827685	1.000835
## 6	b_ECA_cu[5]	0.11607719	0.07602802	-0.009585427	0.23857715	1.000795
## 7	b_ECA_cu[6]	-0.10243741	0.13561212	-0.327632500	0.11879520	1.000805
## 8	b_ECA_cu[7]	0.23370864	0.09635575	0.076933600	0.39103720	1.000977
## 9	b_ECA_cu[8]	-0.07994321	0.10497158	-0.254018800	0.09110415	1.001313
## 10	b_ECA_cu[9]	0.74839562	0.13196956	0.532932750	0.96647380	1.001664
## 11	b_ECA_cu[10]	-0.15521445	0.04754386	-0.232677850	-0.07622366	1.002234
## 12	b_ECA_cu[11]	-0.03501775	0.06997465	-0.152214700	0.07918511	1.001014
## 13	b_ECA_cu[12]	-0.14445076	0.05564470	-0.235724300	-0.05264579	1.000711
## 14	b_ECA_cu[13]	-0.35739594	0.10904456	-0.534152750	-0.18085810	1.001660
## 15	b_ECA_cu[14]	0.07363328	0.21558917	-0.276502550	0.43280385	1.000320
## 16	b_ECA_cu[15]	-0.25473382	0.41069973	-0.951373550	0.39580490	1.002172
## 17	b_ECA_cu[16]	-0.06430381	0.19514377	-0.385830600	0.25831465	1.000671
## 18	b_ECA_cu[17]	0.15162132	0.20856538	-0.187642600	0.49681865	1.000894
## 19	b_ECA_cu[18]	-0.75204648	0.26747251	-1.207662500	-0.32893680	1.001349
## 20	b_ECA_cu[19]	-0.54249877	0.15995007	-0.804557650	-0.27771420	1.002582
## 21	b_ECA_cu[20]	-0.16421068	0.35021556	-0.736258250	0.40618440	1.000095
## 22	b_ECA_cu[21]	-0.14361452	0.17376956	-0.436148200	0.13583375	1.001410
## 23	b_ECA_cu[22]	-0.49528788	0.27566849	-0.952325950	-0.04610943	1.001660

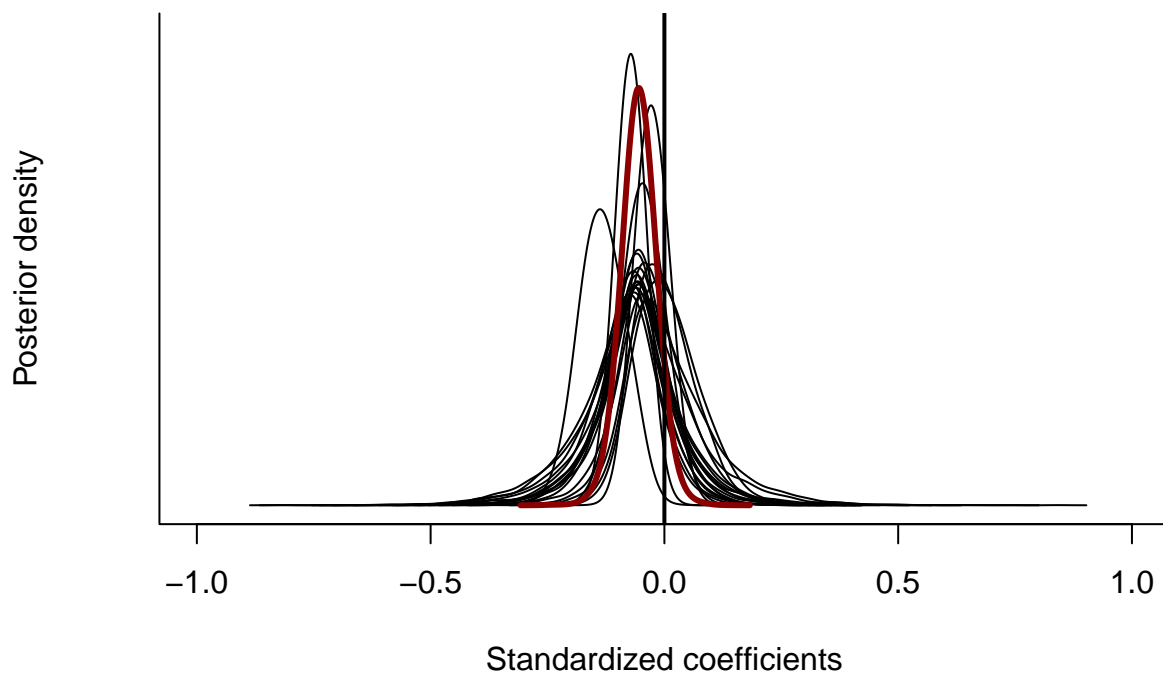
### ECA effect sizes by CU (BH)



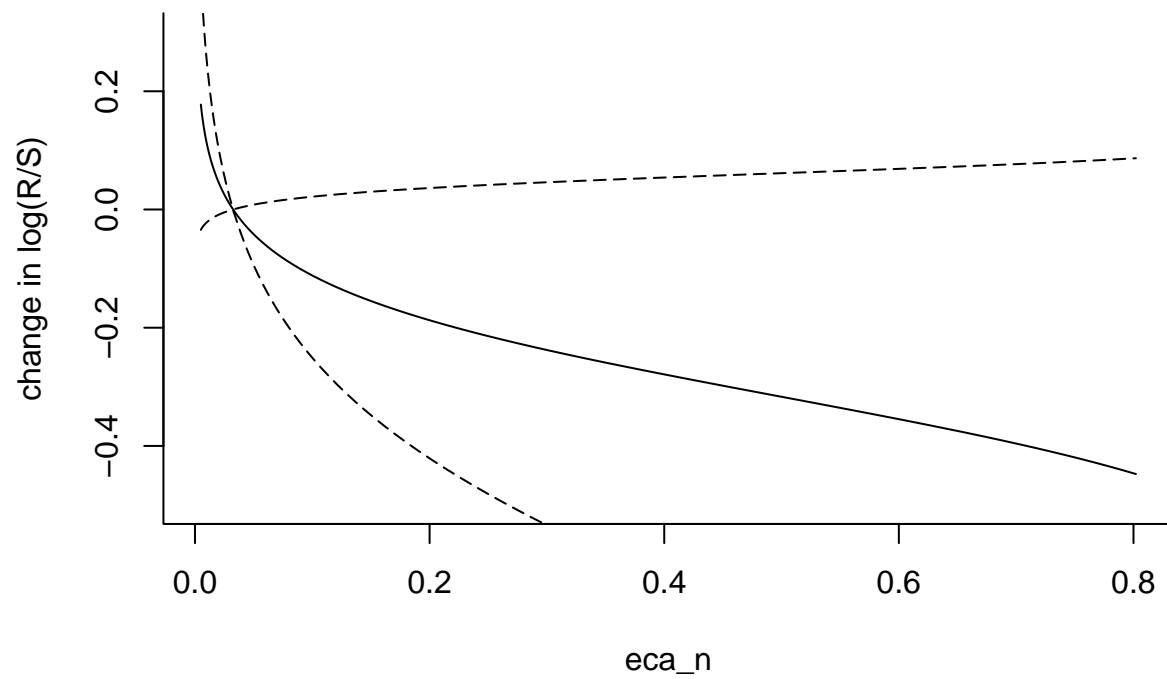
and alternatively with the Ricker model form:

##	variable	mean	sd	q5	q95	rhat
## 1	b_ECA	-0.054333662	0.03459698	-0.10966230	0.0009919693	1.002793
## 2	b_ECA_cu[1]	-0.072371922	0.02884070	-0.12057840	-0.0253834200	1.000183
## 3	b_ECA_cu[2]	-0.024131374	0.07169905	-0.12915355	0.1030647500	1.001175
## 4	b_ECA_cu[3]	-0.013897533	0.10056040	-0.14976155	0.1717358500	1.002141
## 5	b_ECA_cu[4]	-0.090058266	0.09535613	-0.26322540	0.0449054600	1.005591
## 6	b_ECA_cu[5]	-0.004070840	0.06455412	-0.10048495	0.1079735000	1.004470
## 7	b_ECA_cu[6]	0.007319455	0.06895826	-0.09297971	0.1308671500	1.003829
## 8	b_ECA_cu[7]	-0.059914191	0.08566169	-0.20472390	0.0772574600	1.004292
## 9	b_ECA_cu[8]	-0.056094021	0.07861854	-0.18859355	0.0755901250	1.004899
## 10	b_ECA_cu[9]	0.009591035	0.09721453	-0.11468455	0.1948060500	1.002496
## 11	b_ECA_cu[10]	-0.026344081	0.03335694	-0.07978288	0.0291210200	1.002066
## 12	b_ECA_cu[11]	-0.044957400	0.04561646	-0.12039335	0.0312637600	1.003401
## 13	b_ECA_cu[12]	-0.132912620	0.04813456	-0.21127420	-0.0528107300	1.008975
## 14	b_ECA_cu[13]	-0.106682990	0.09551370	-0.28825595	0.0222931100	1.004217
## 15	b_ECA_cu[14]	-0.078974193	0.07892060	-0.21791705	0.0412813600	1.003187
## 16	b_ECA_cu[15]	-0.057971053	0.09890730	-0.21759945	0.0977015650	1.004827
## 17	b_ECA_cu[16]	-0.059188685	0.09123195	-0.21024190	0.0877996050	1.004137
## 18	b_ECA_cu[17]	-0.051800878	0.09374111	-0.19829310	0.1009114000	1.004657
## 19	b_ECA_cu[18]	-0.098816039	0.09492052	-0.27070260	0.0310442400	1.006573
## 20	b_ECA_cu[19]	-0.063649378	0.07187560	-0.18260235	0.0520365550	1.002750
## 21	b_ECA_cu[20]	-0.044413909	0.09518136	-0.19415205	0.1157807000	1.003376
## 22	b_ECA_cu[21]	-0.057618487	0.06848823	-0.17194800	0.0558957350	1.005447
## 23	b_ECA_cu[22]	-0.076366171	0.09784881	-0.24623830	0.0635329850	1.003332

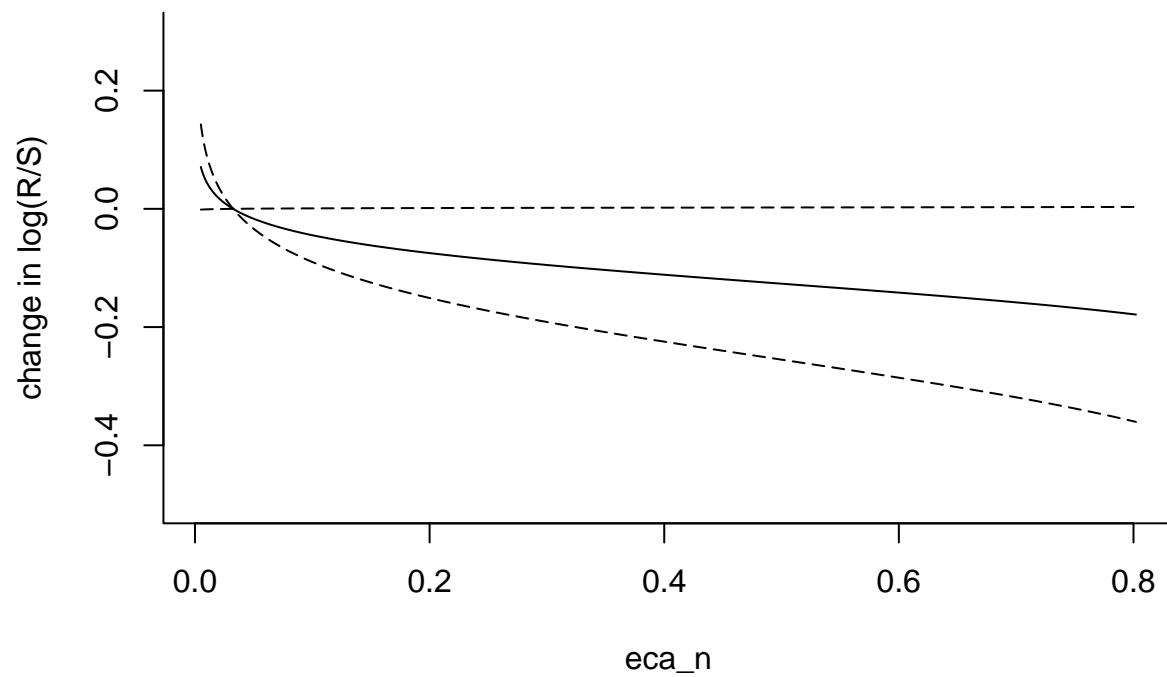
### ECA effect sizes by CU (Ricker)



Visualized (back converted from logit scale to original ECA) for the Beverton-Holt model:



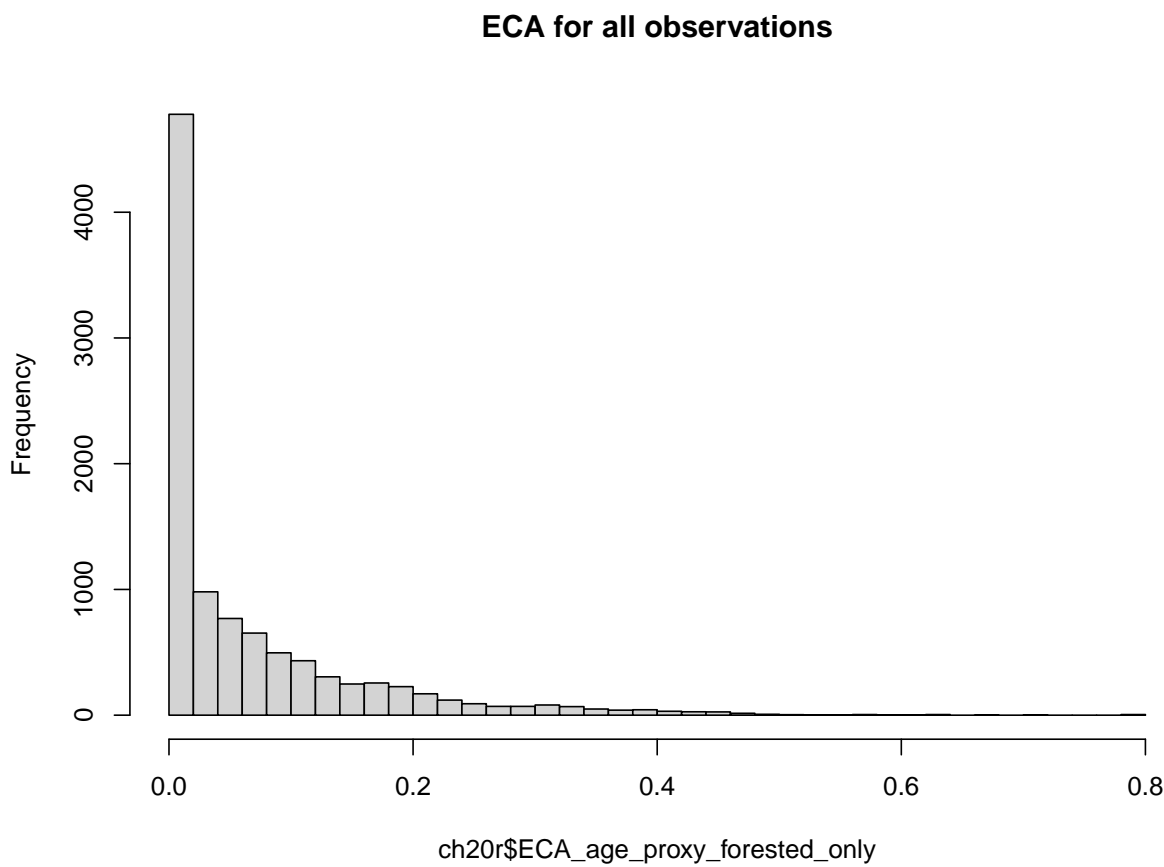
And Ricker model:



Proposed to do/future tweaks:

1. Shared year effects or shared latent productivity trends
2. Watershed area & interaction with ECA
3. non-linear function for ECA?

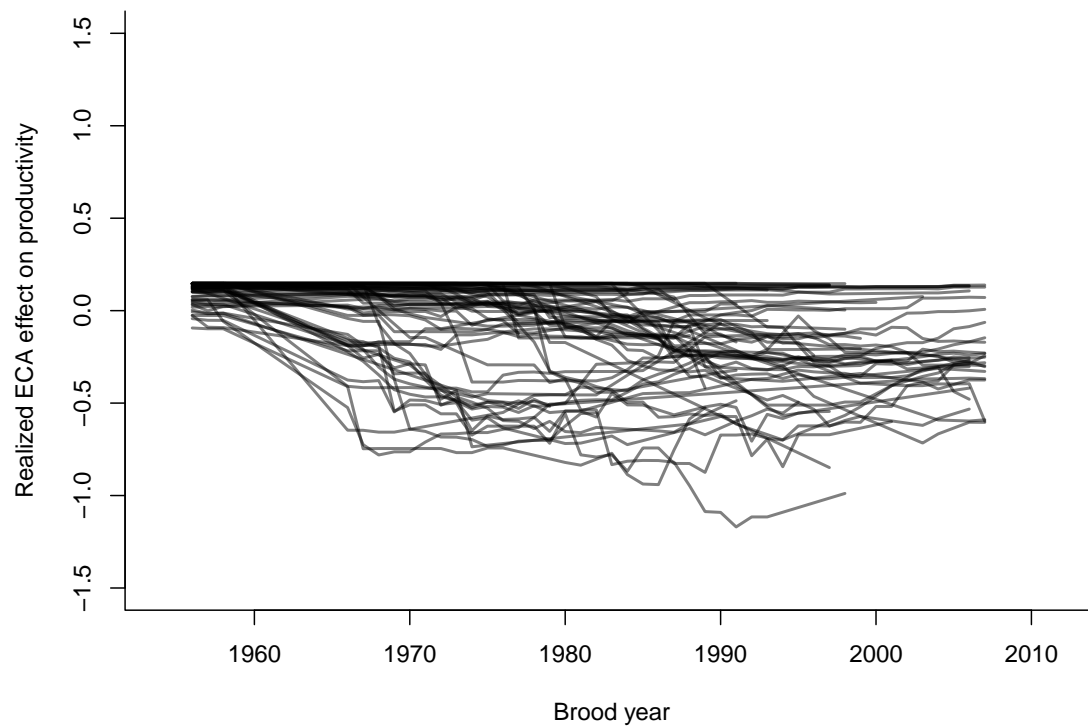
Overall distribution of ECA among all observations:



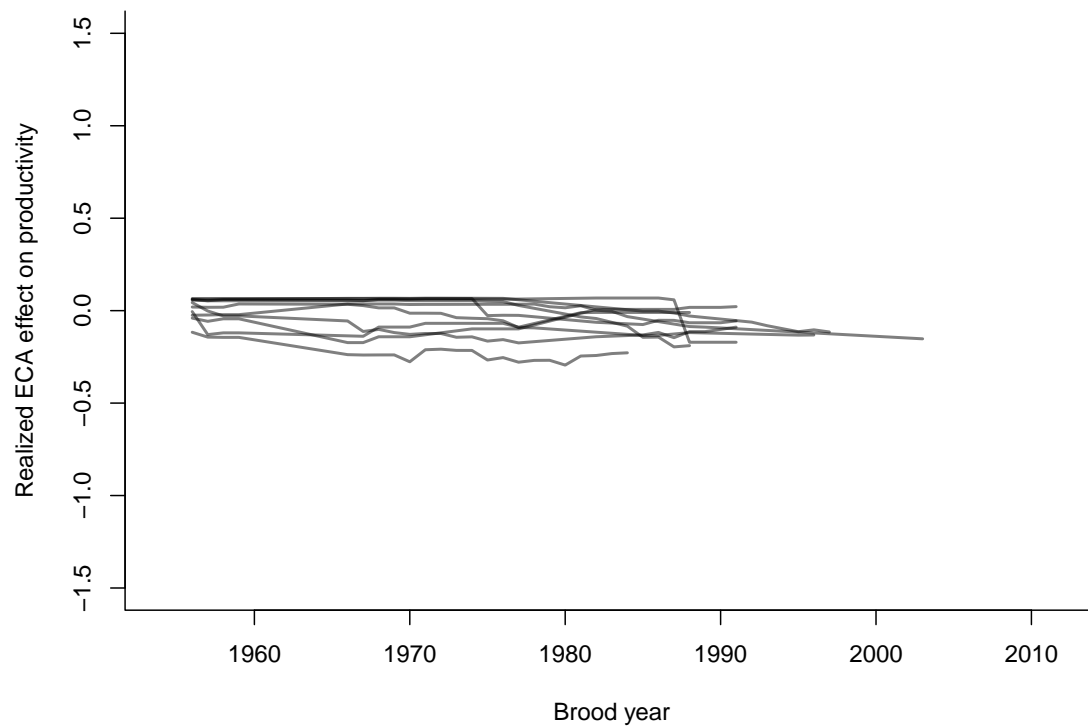
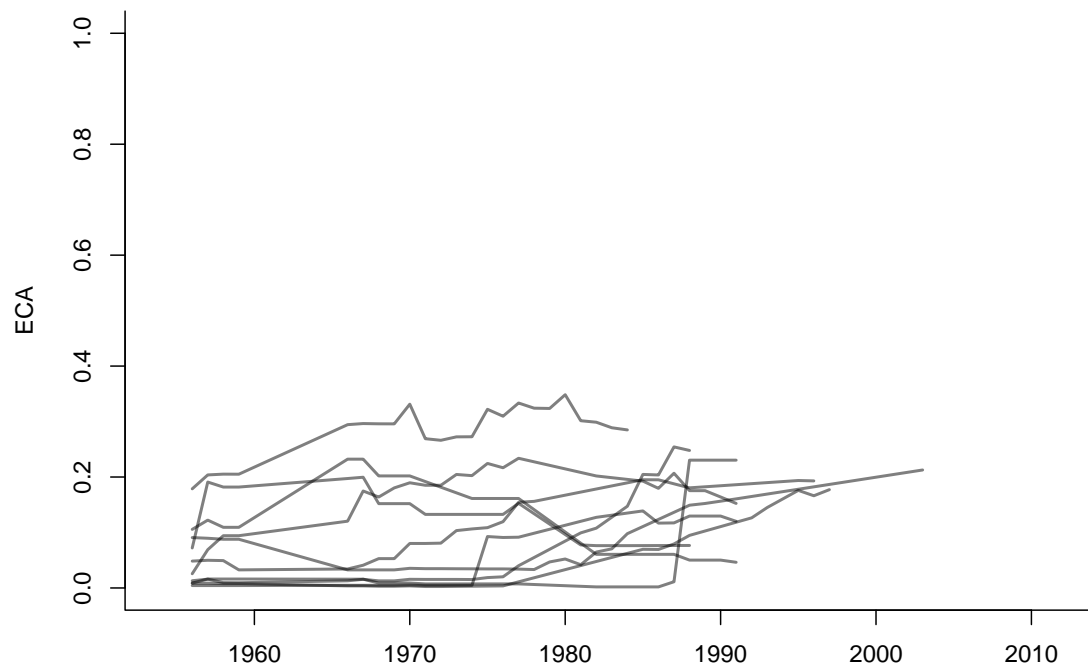


River-level ECA and effect on productivity through time by CU (BH model):

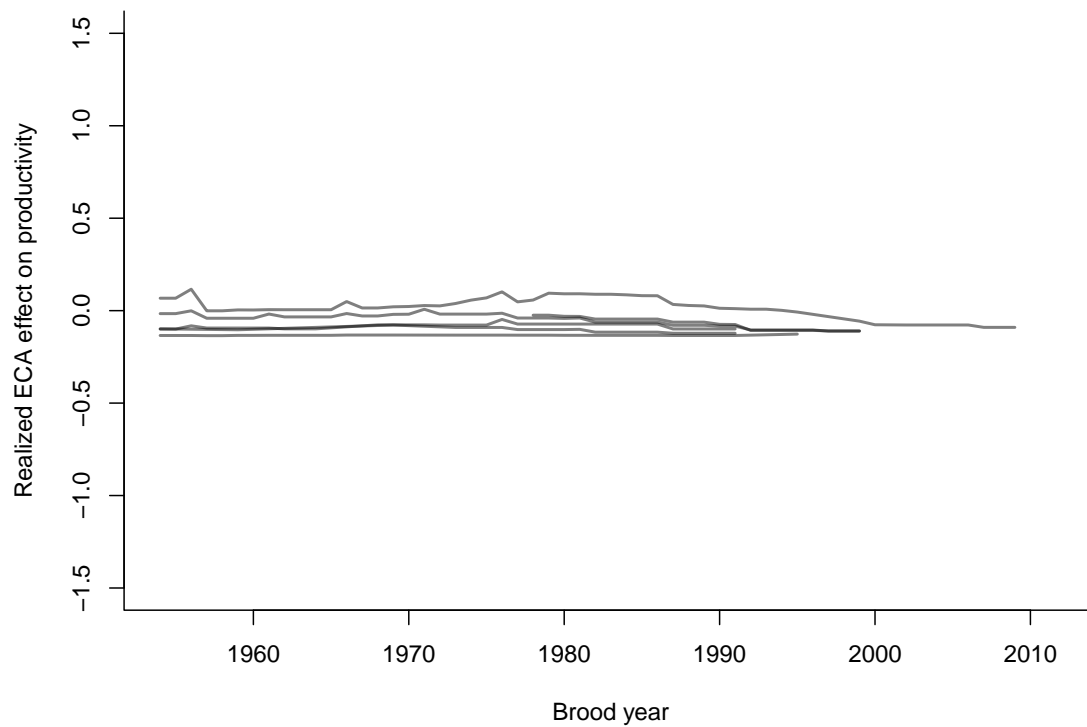
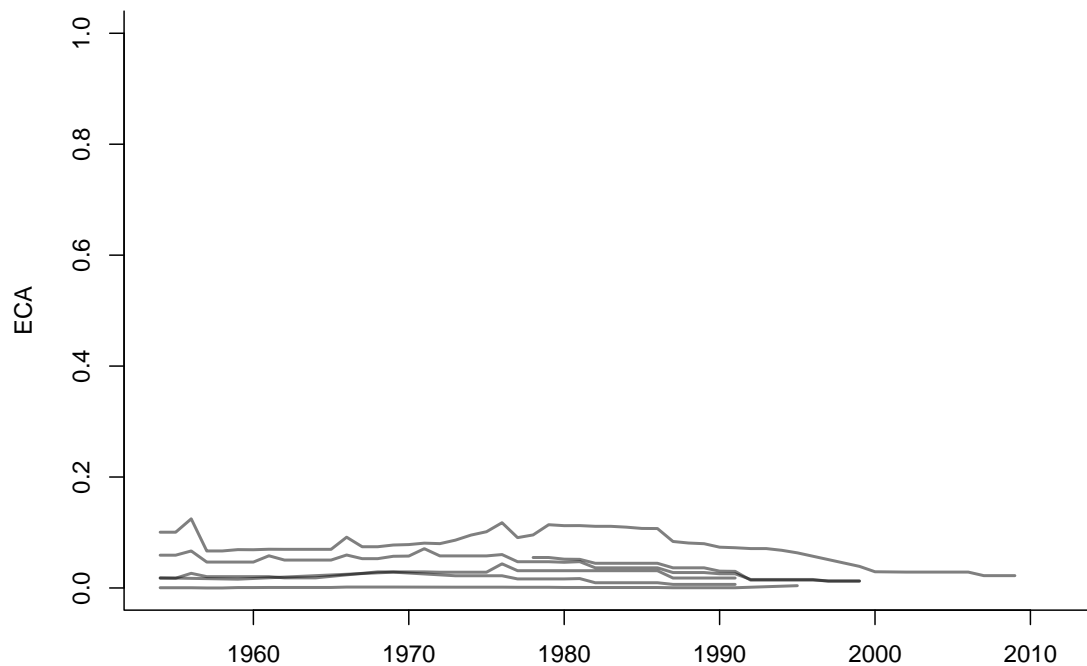
CM-10



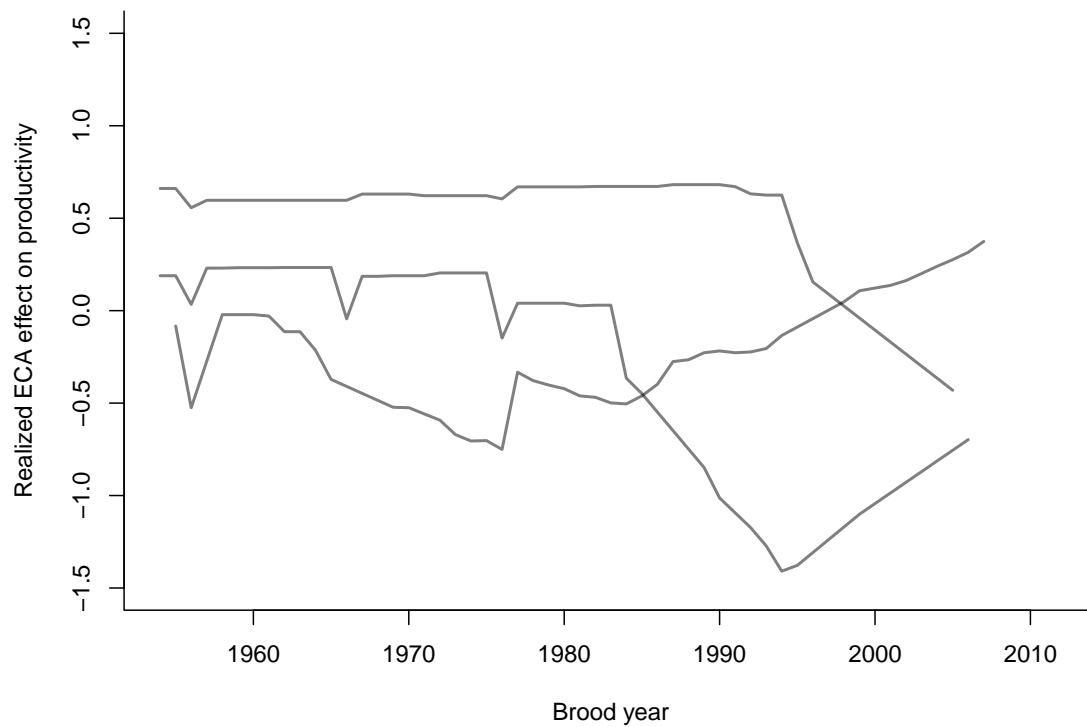
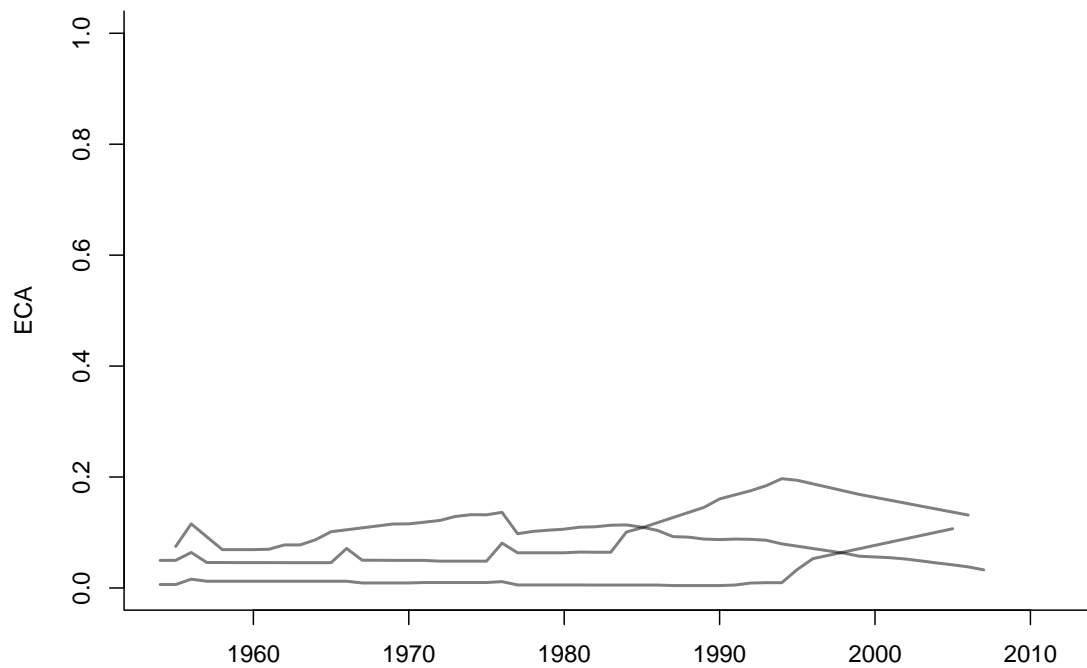
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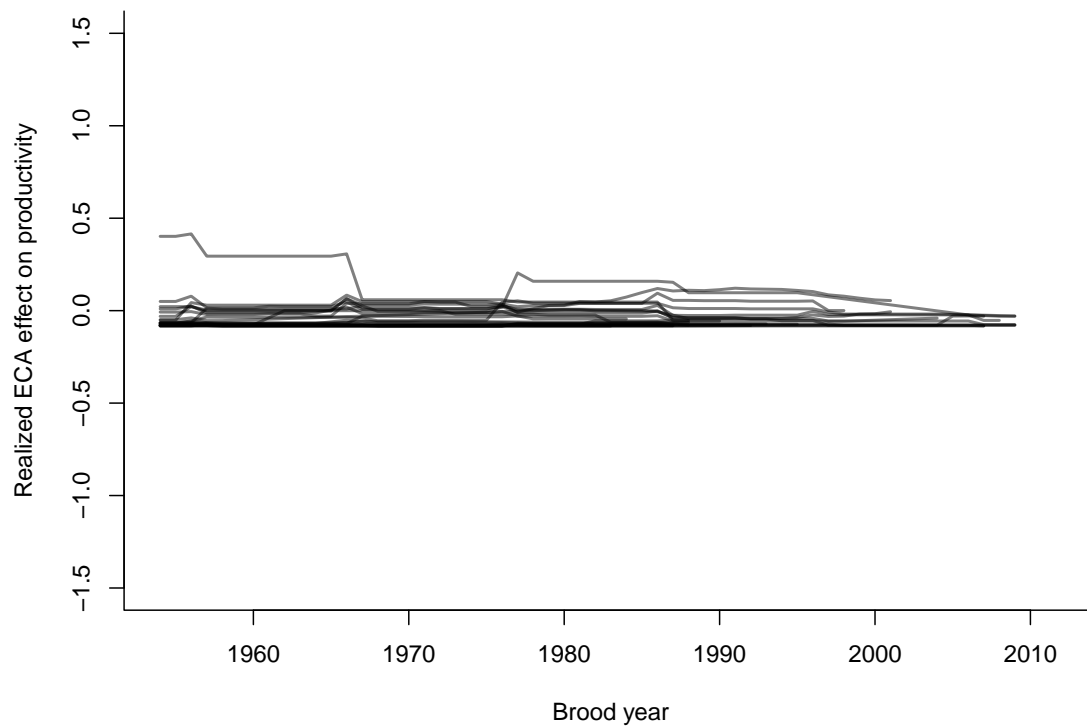
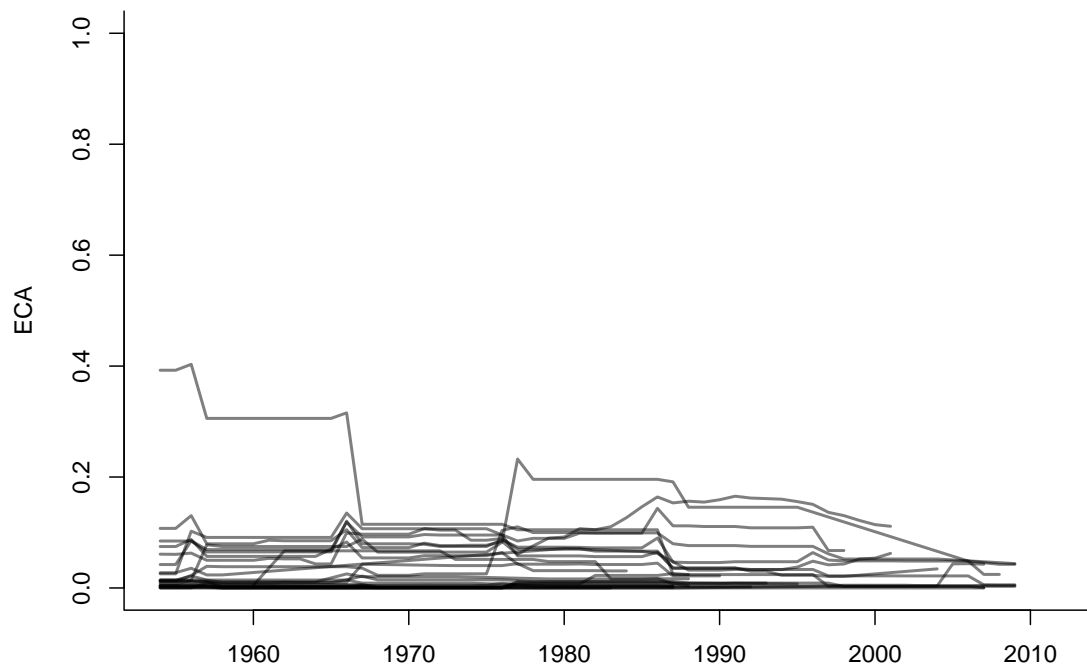
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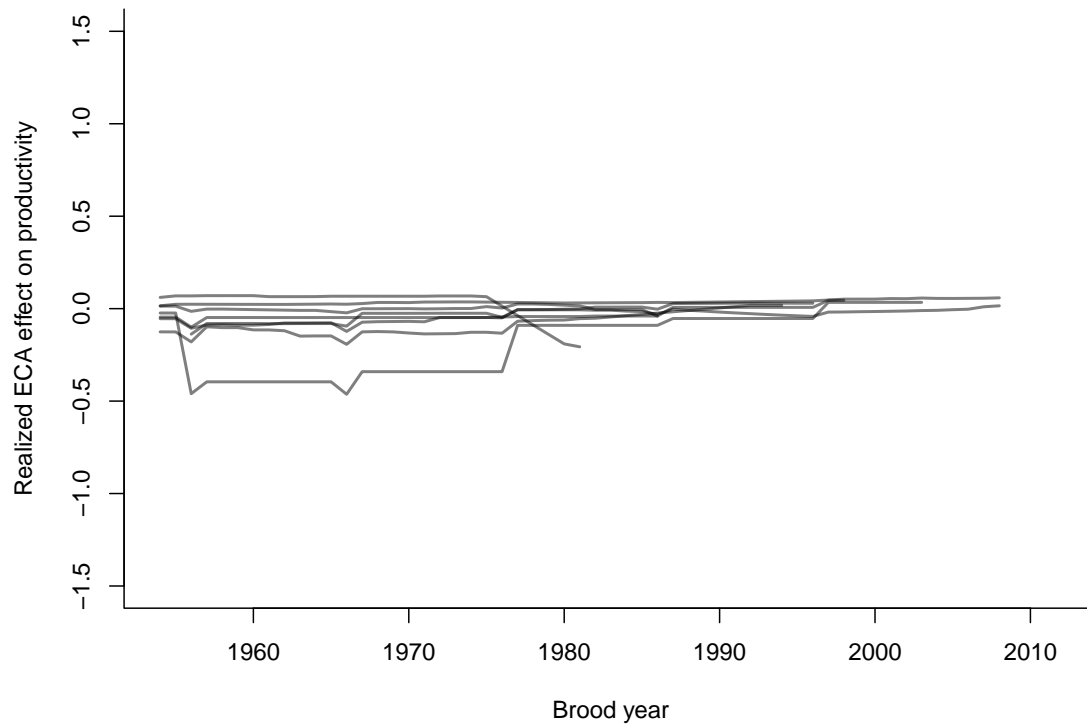
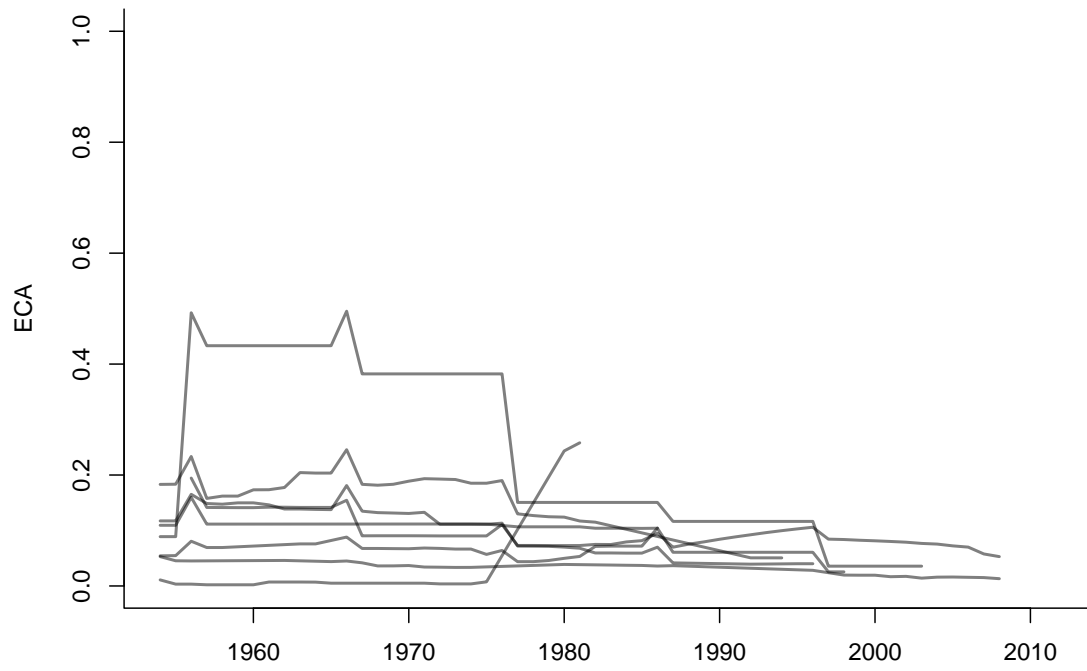
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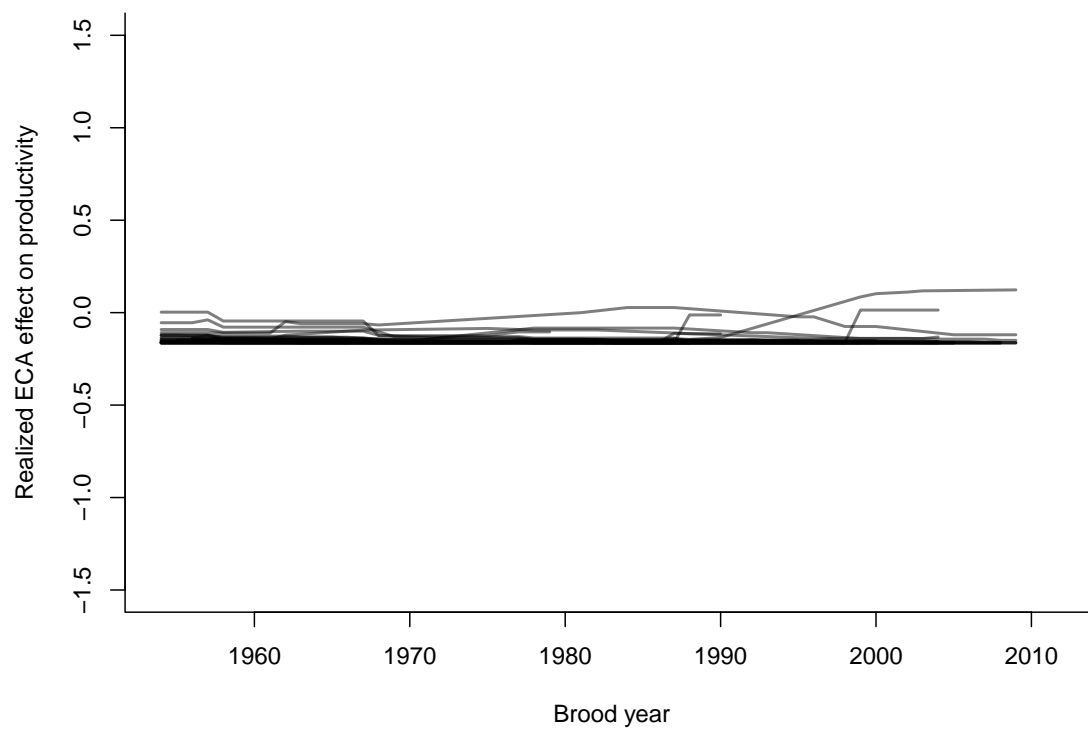
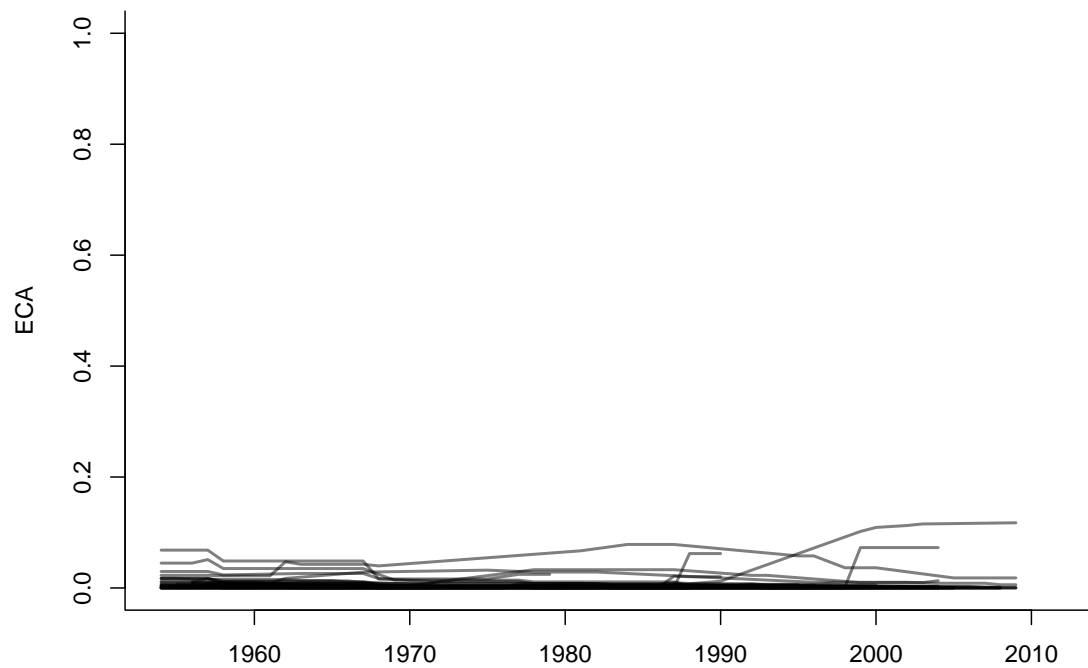
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CM-16

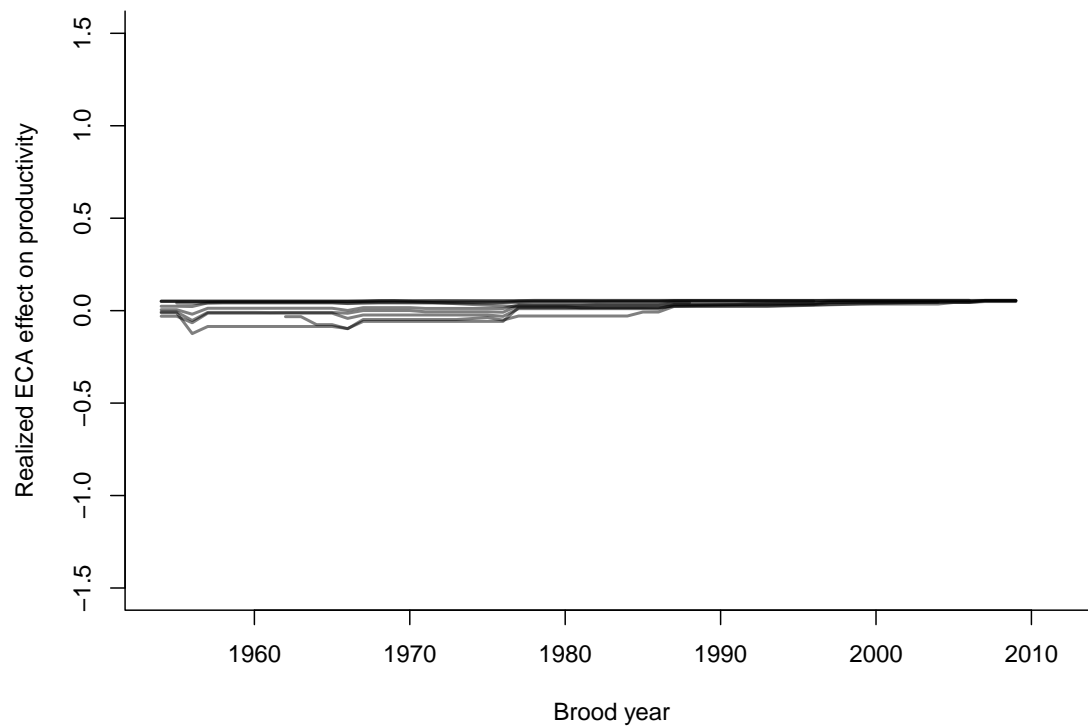
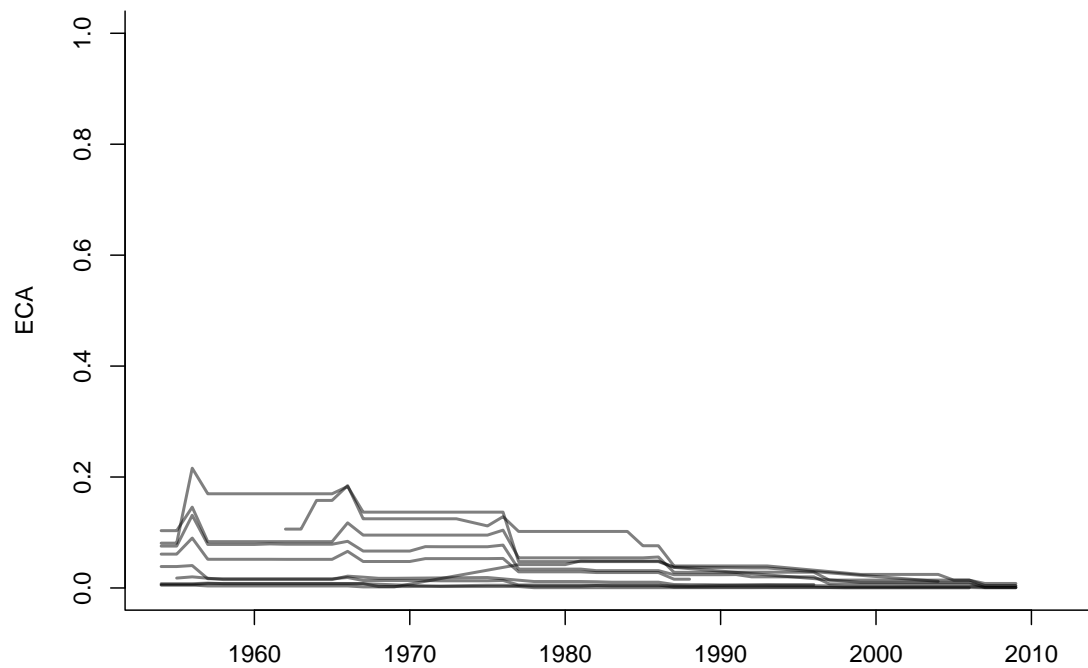


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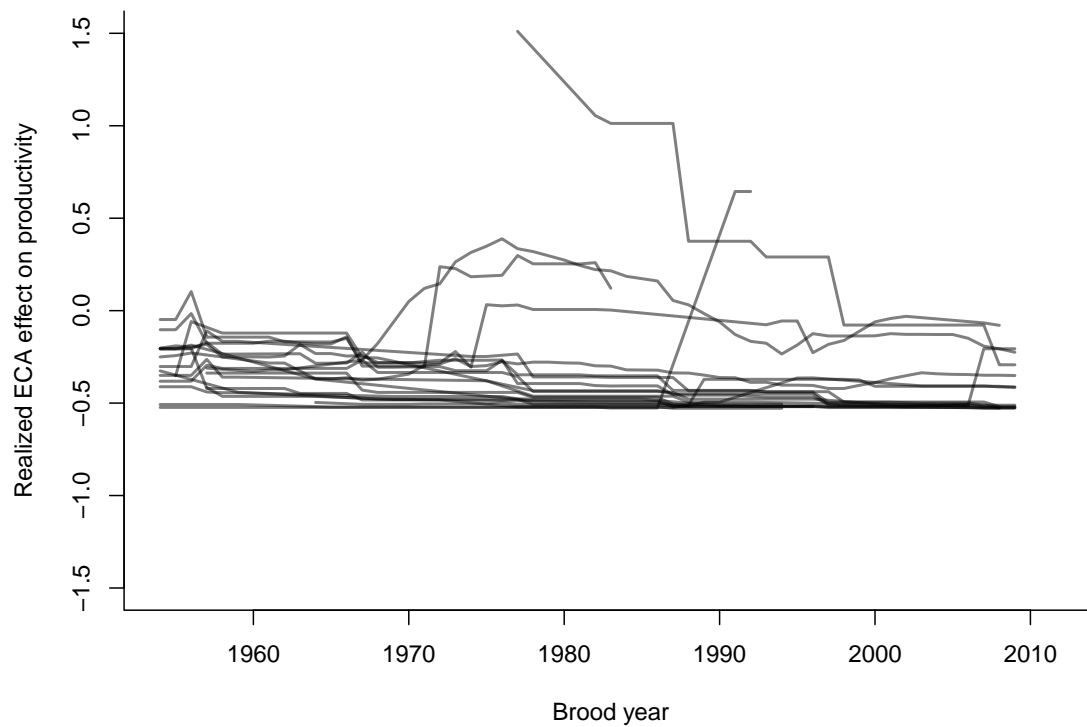




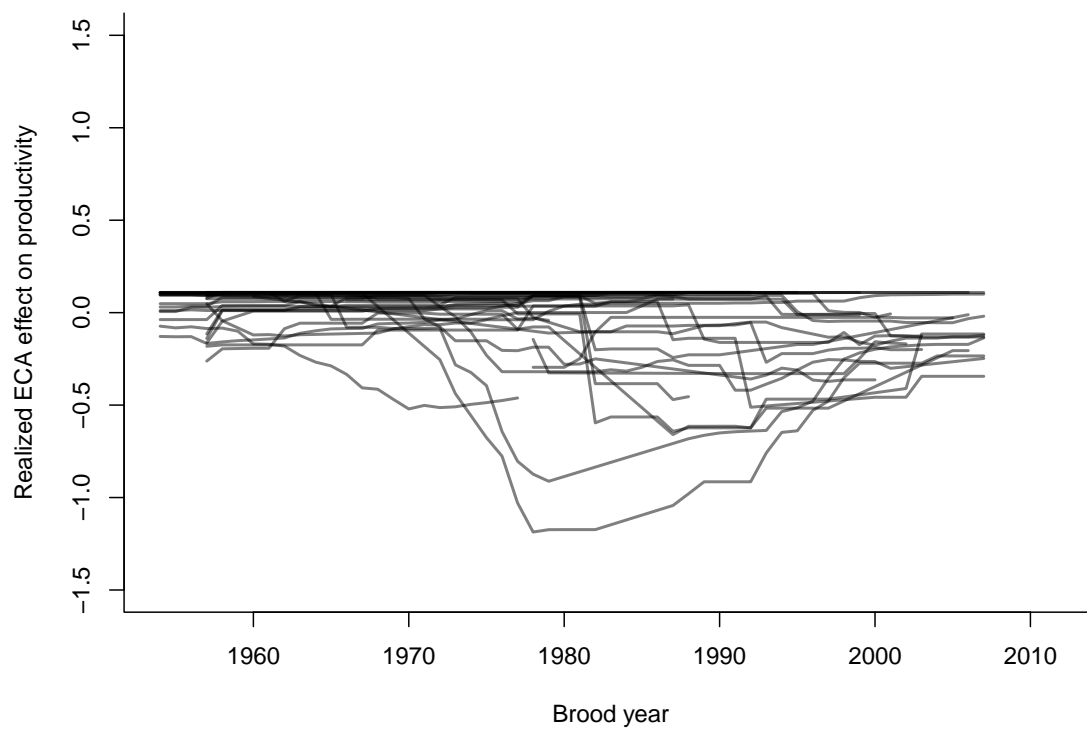
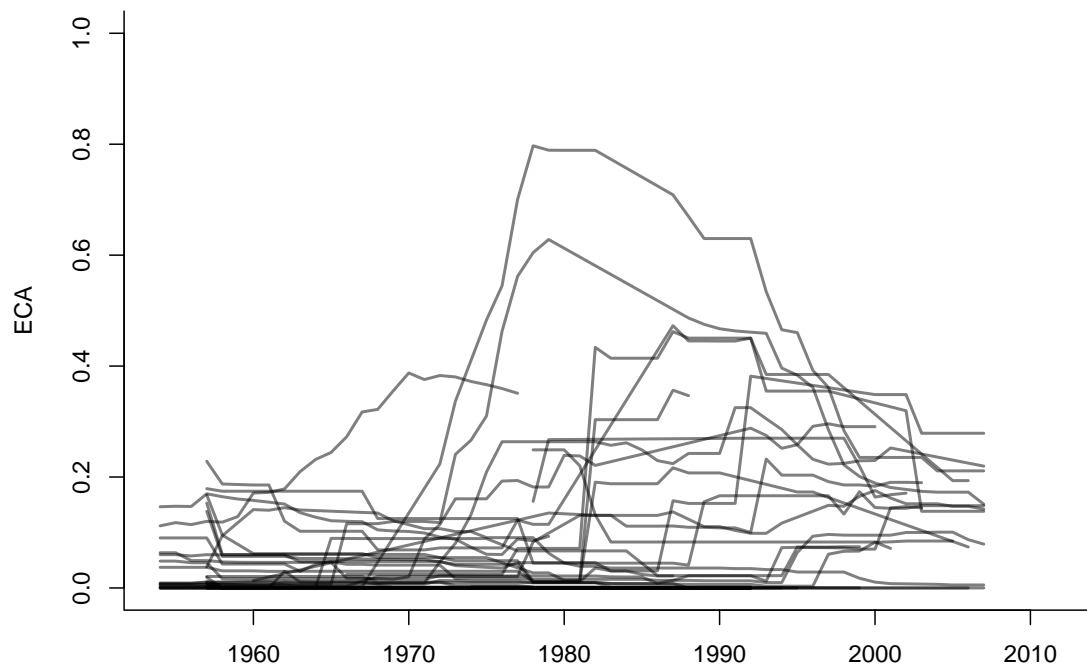
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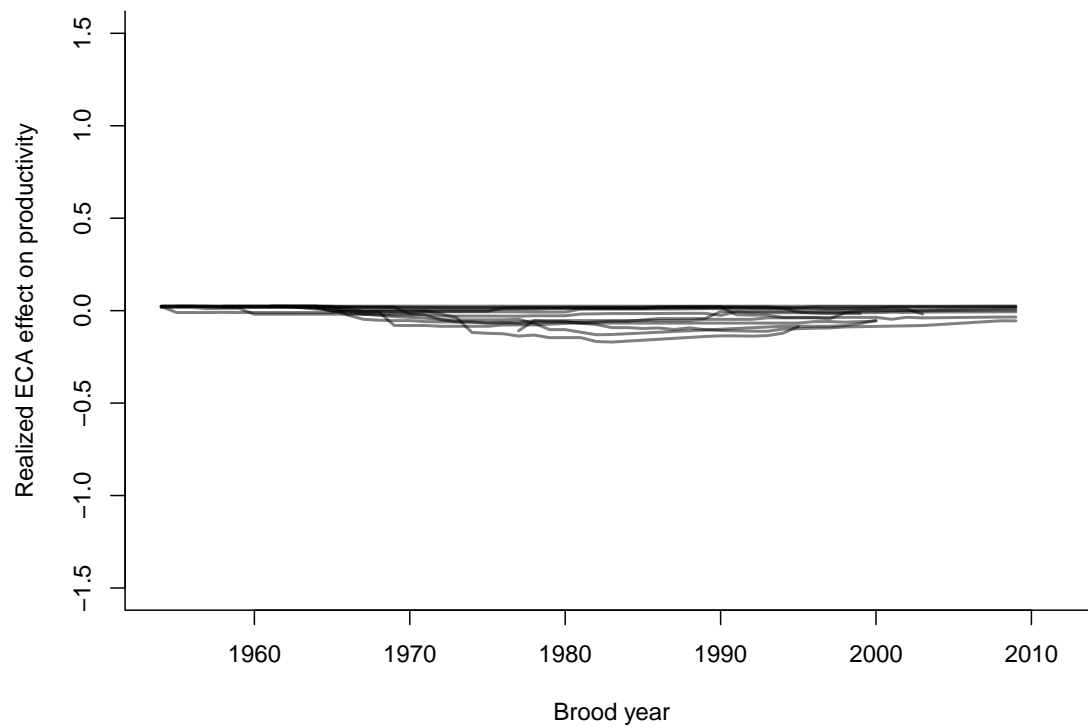
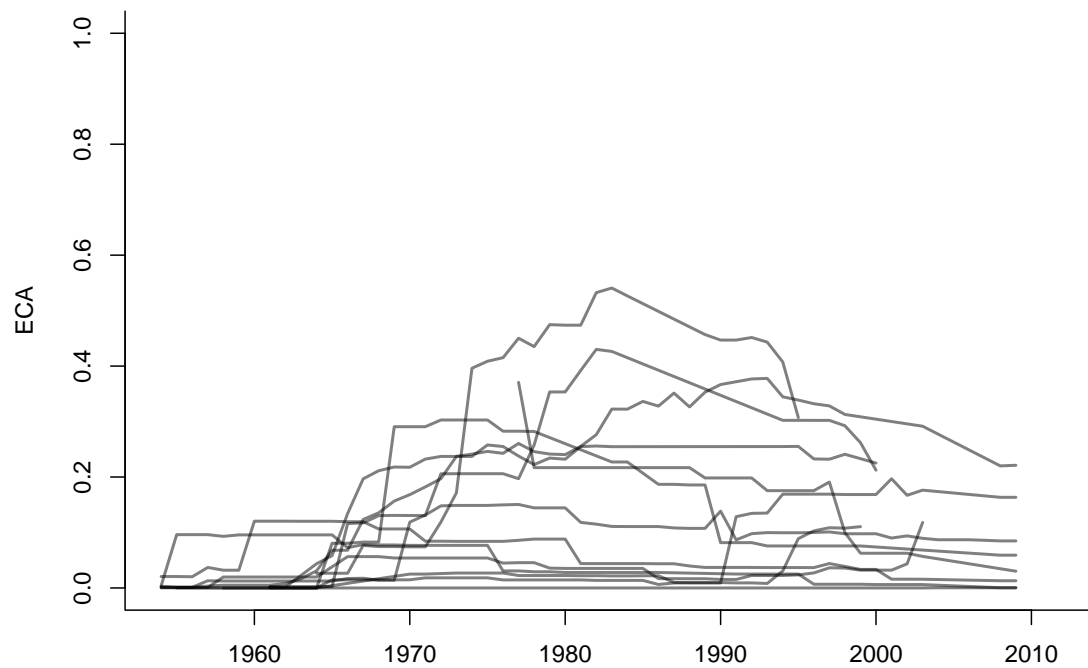
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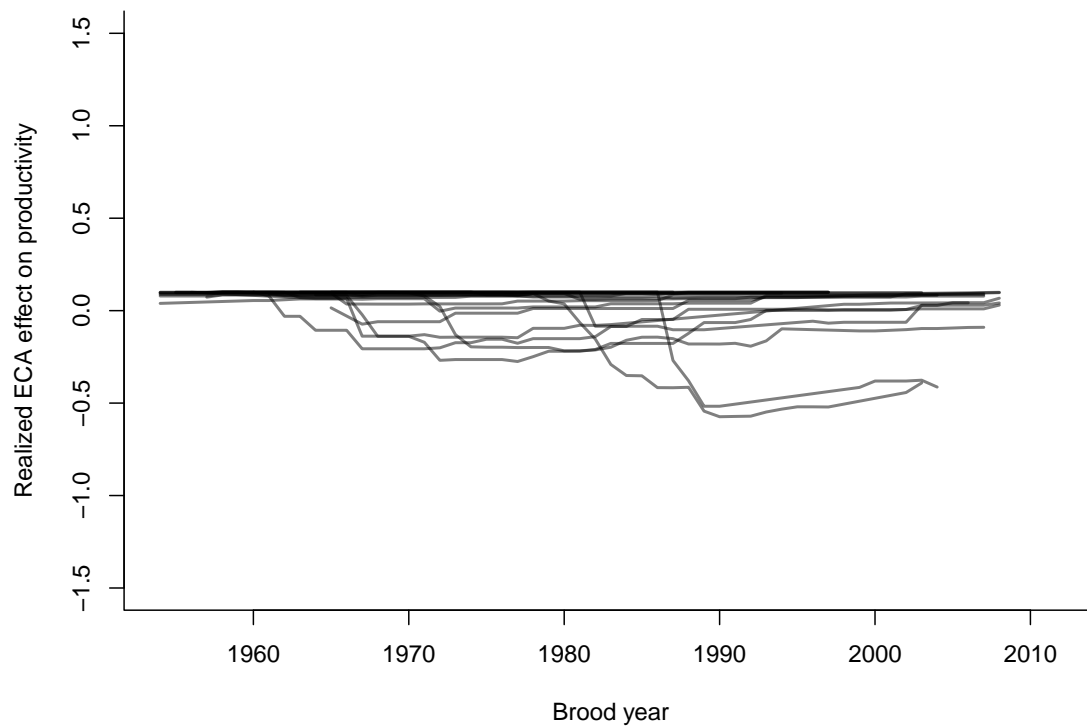
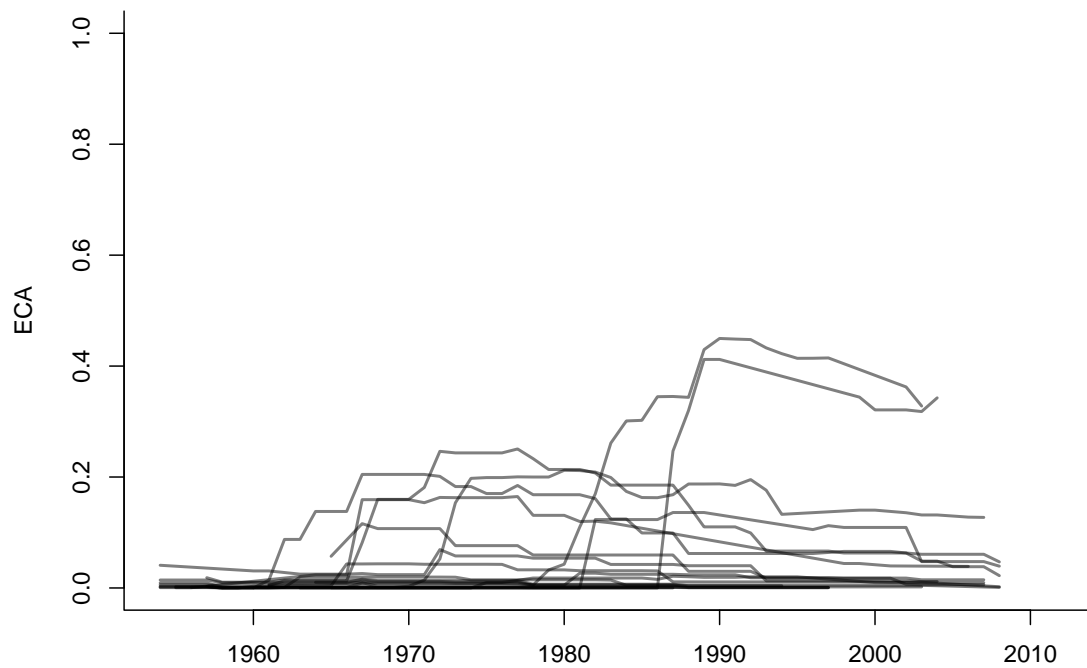
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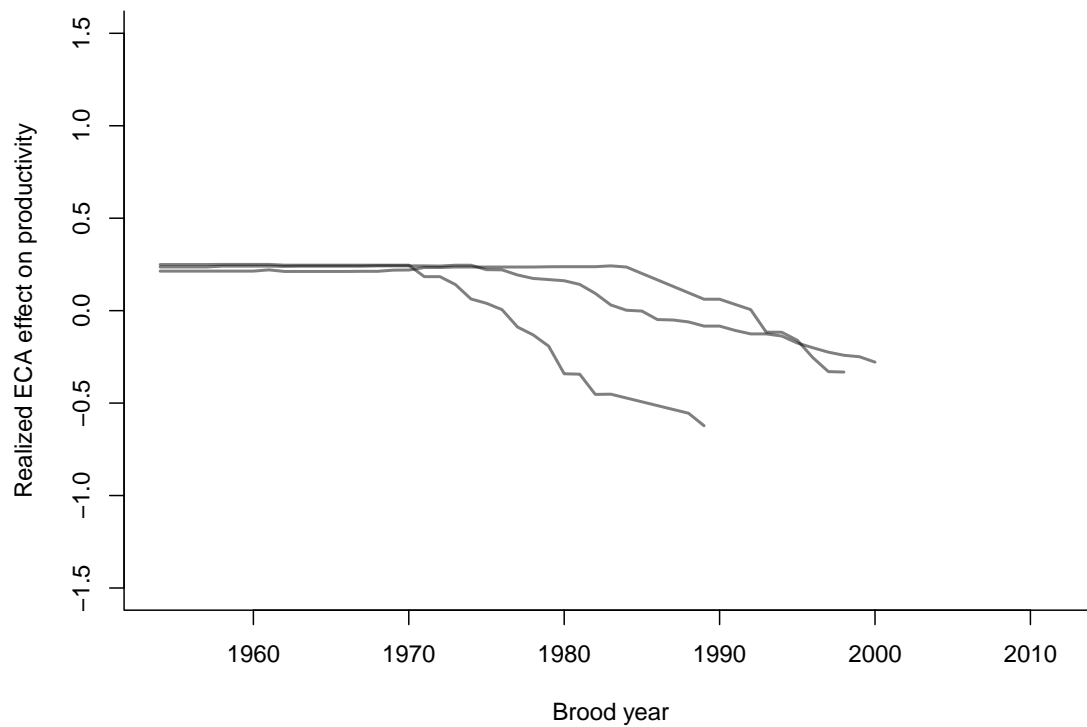
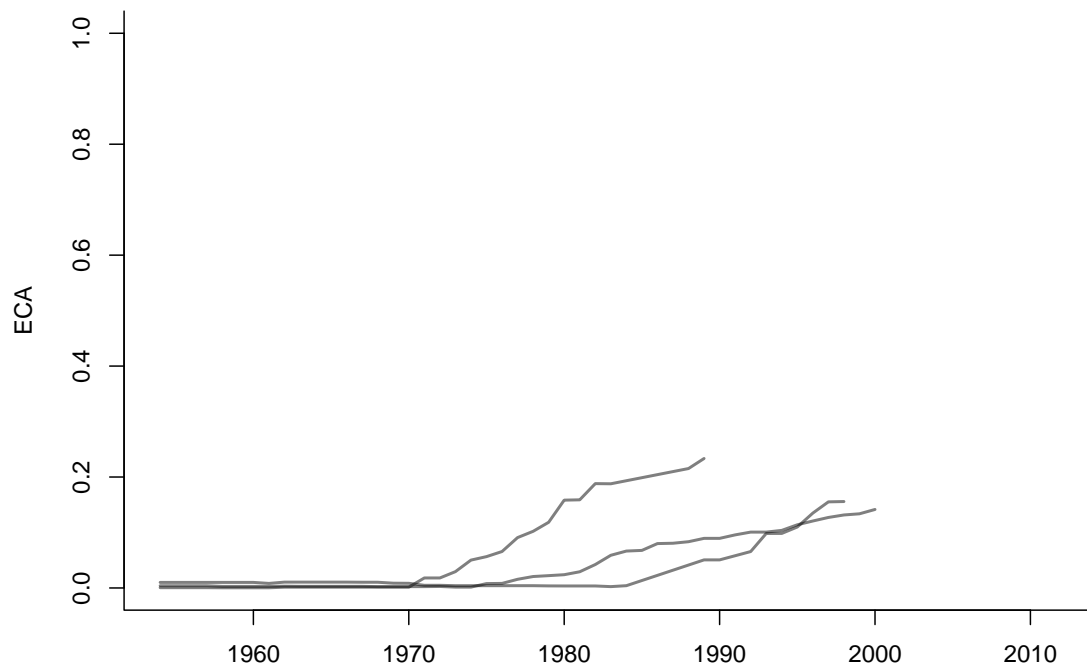
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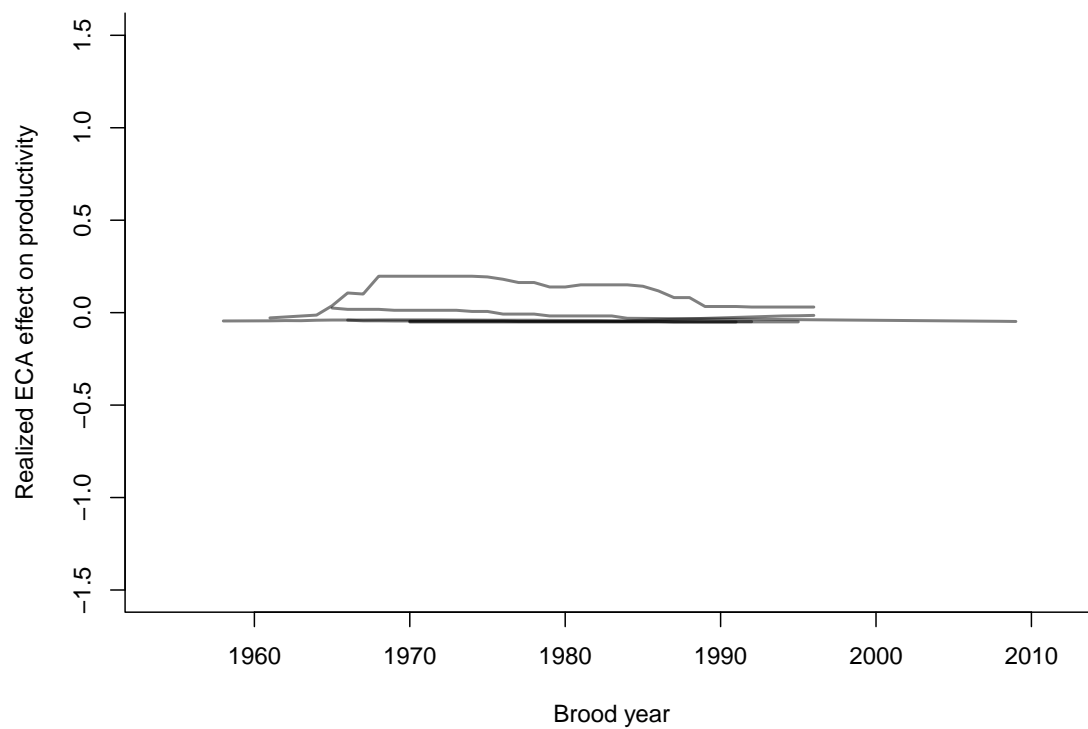
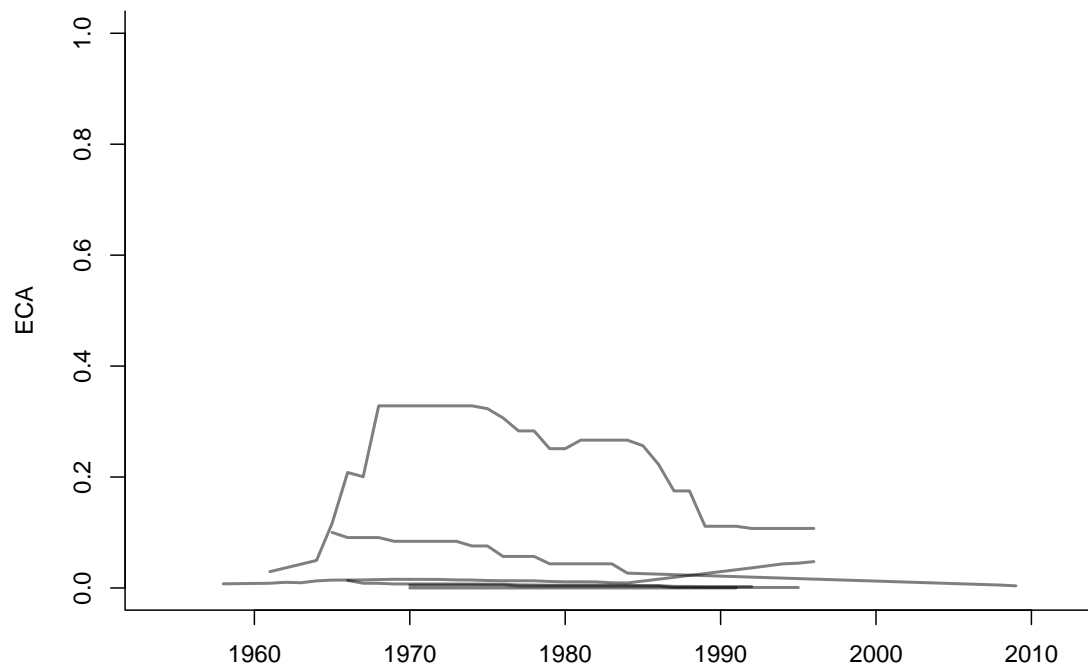
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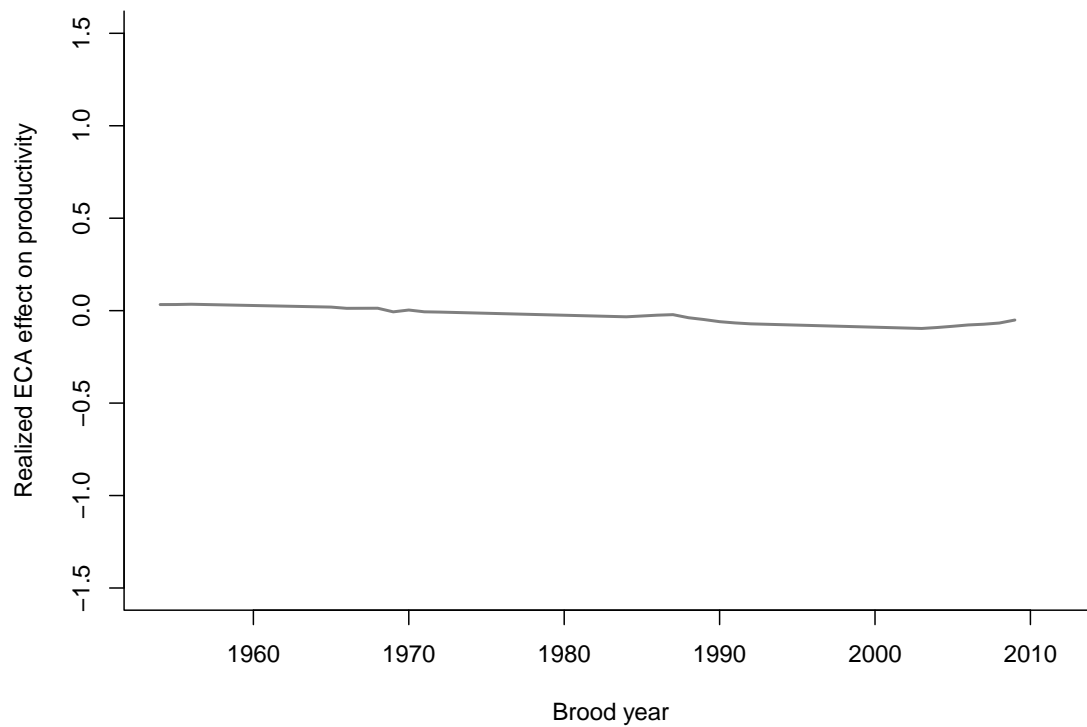
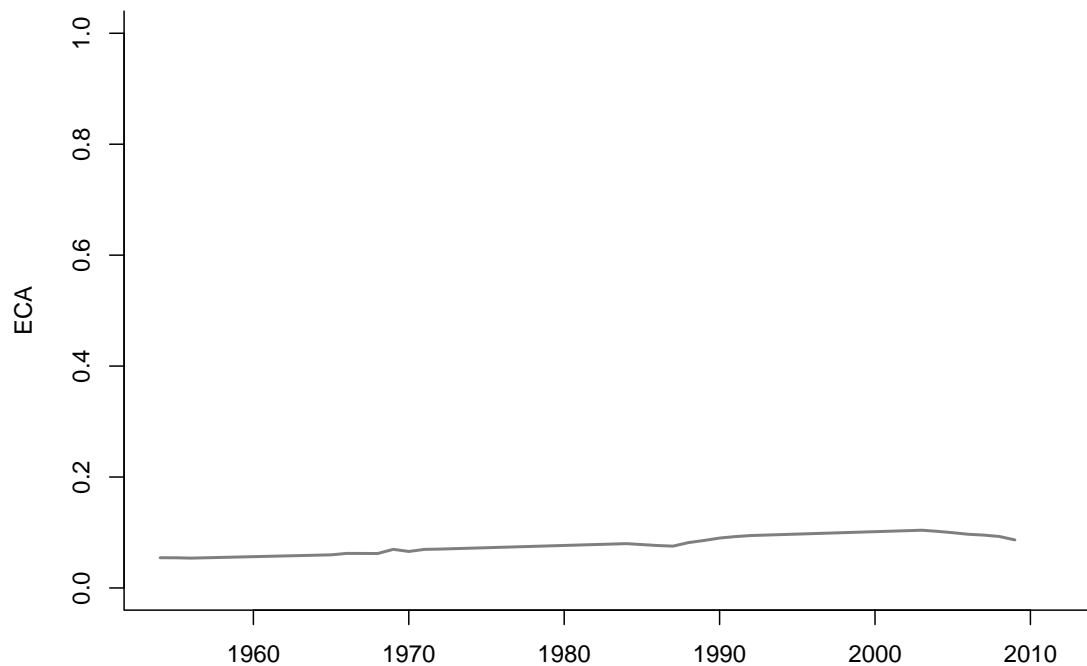
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CM-27

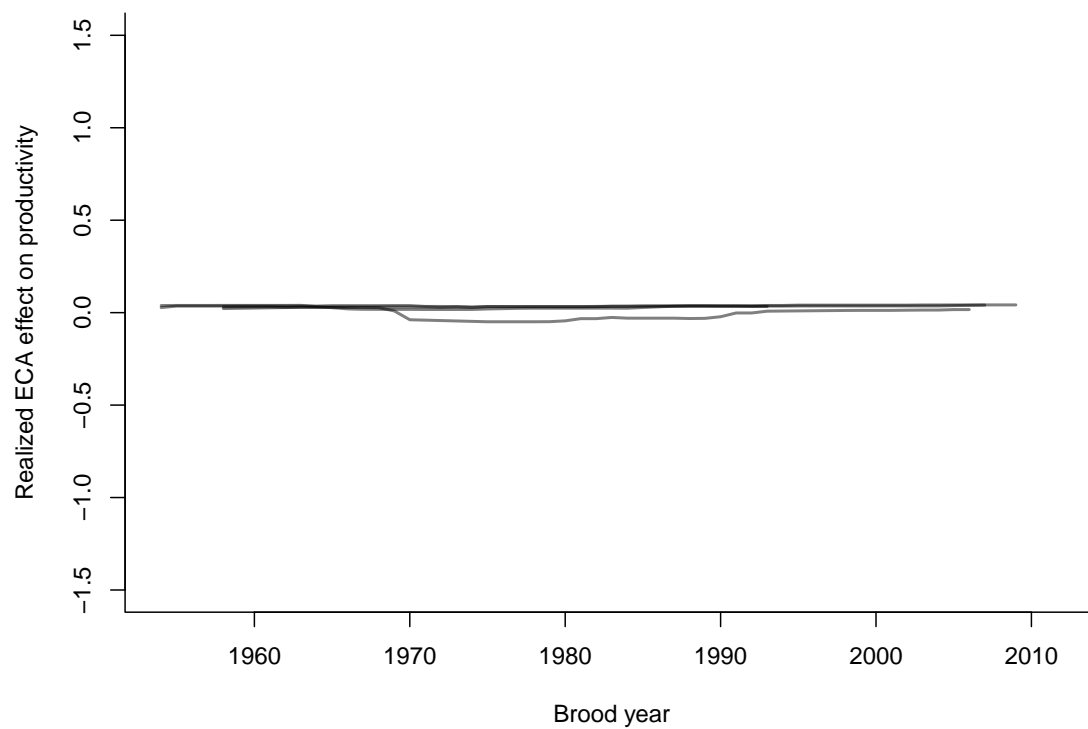
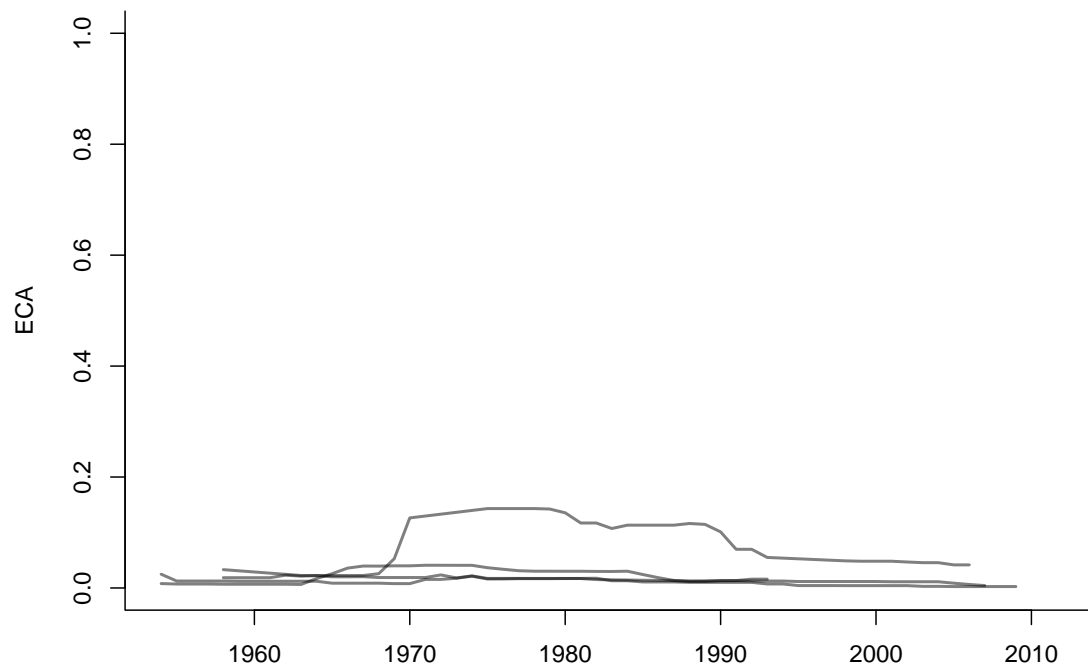


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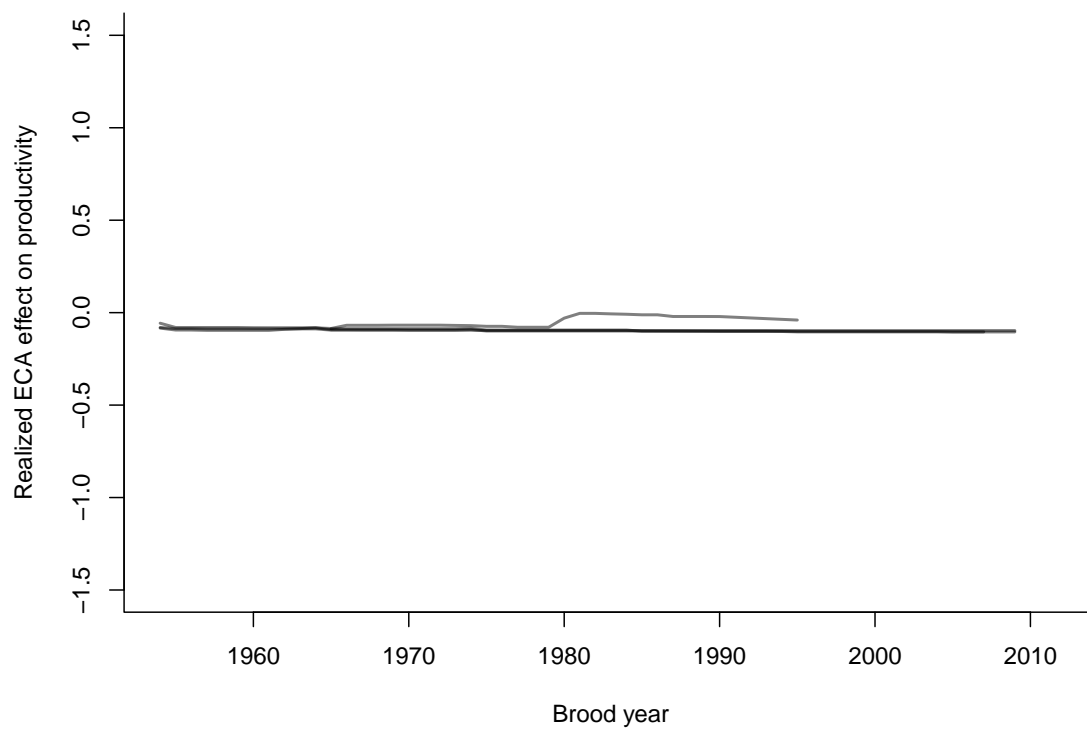




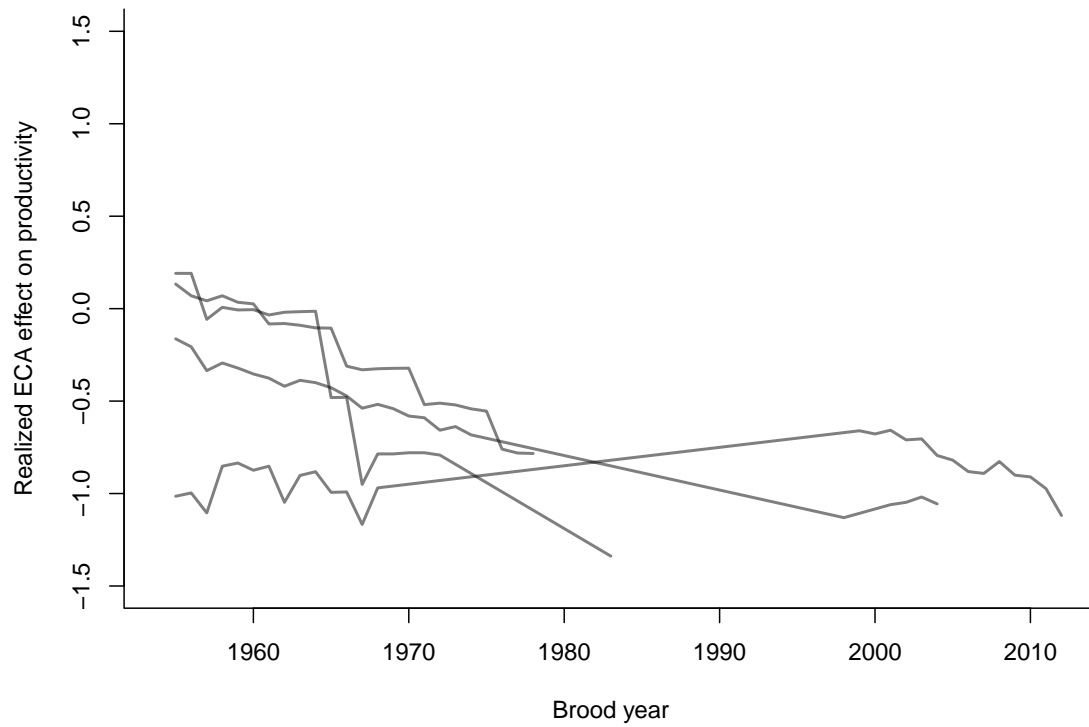
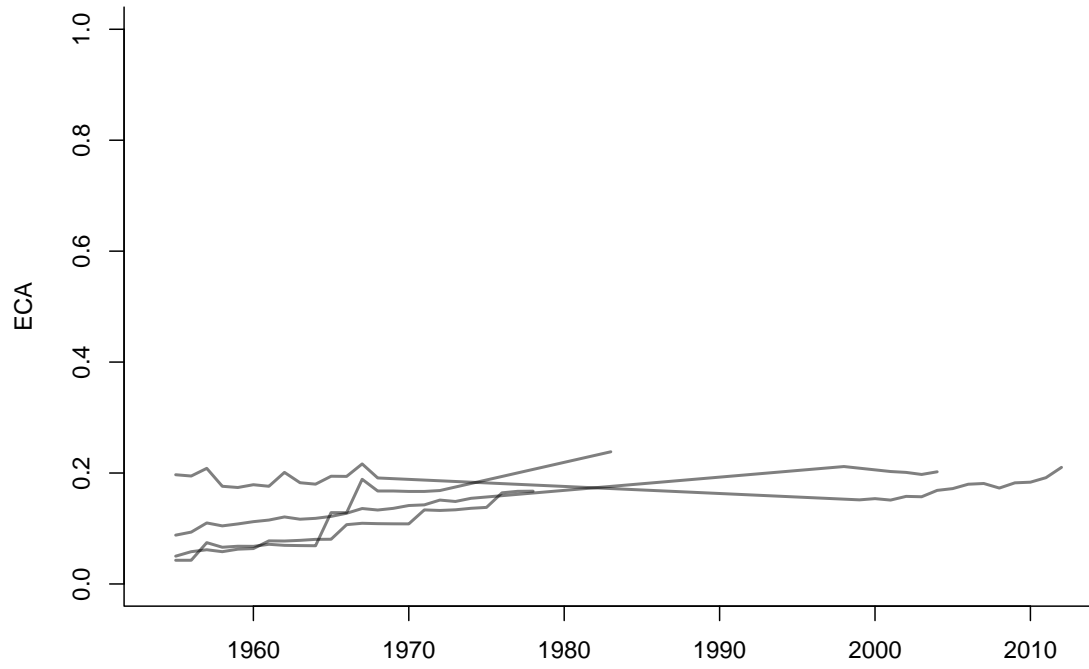
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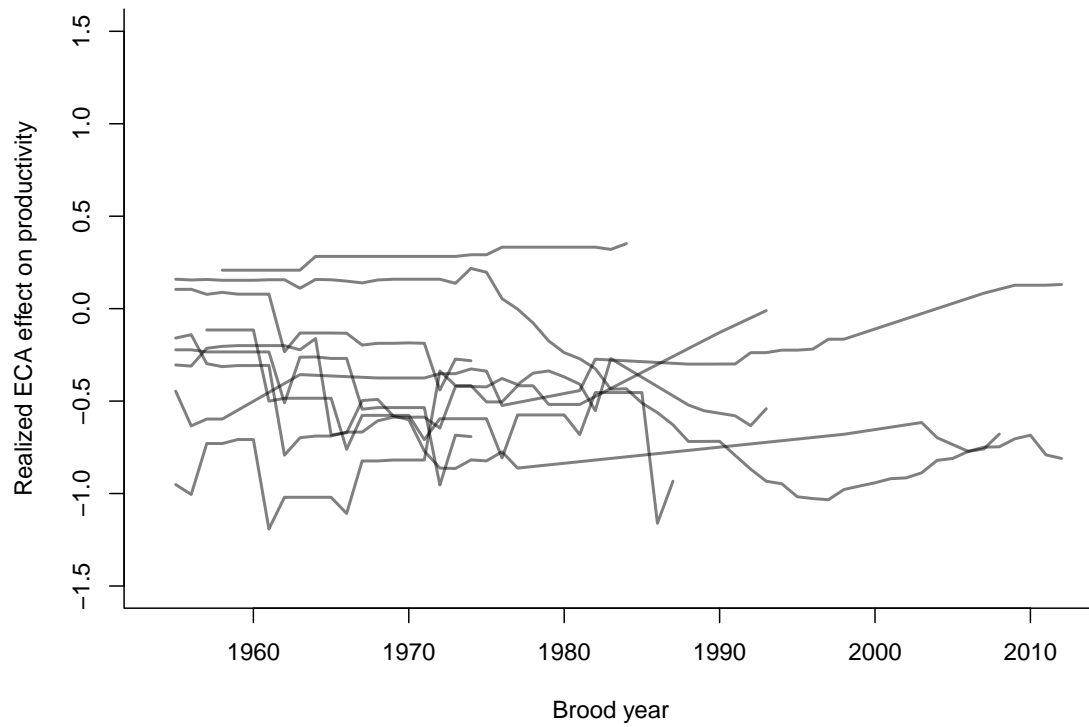
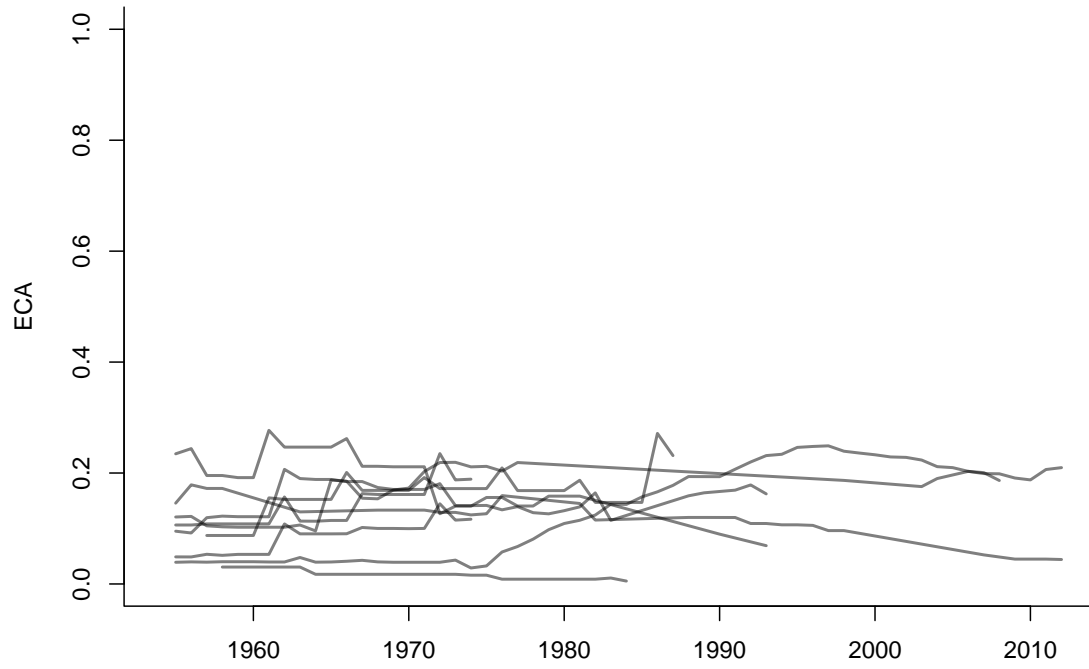
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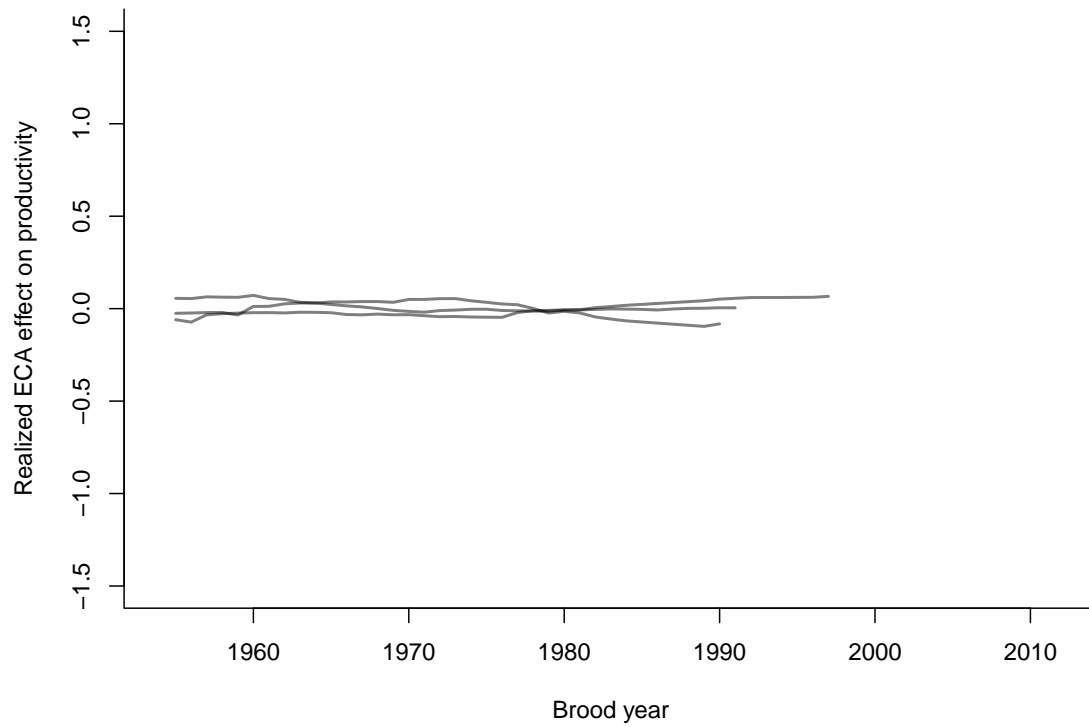
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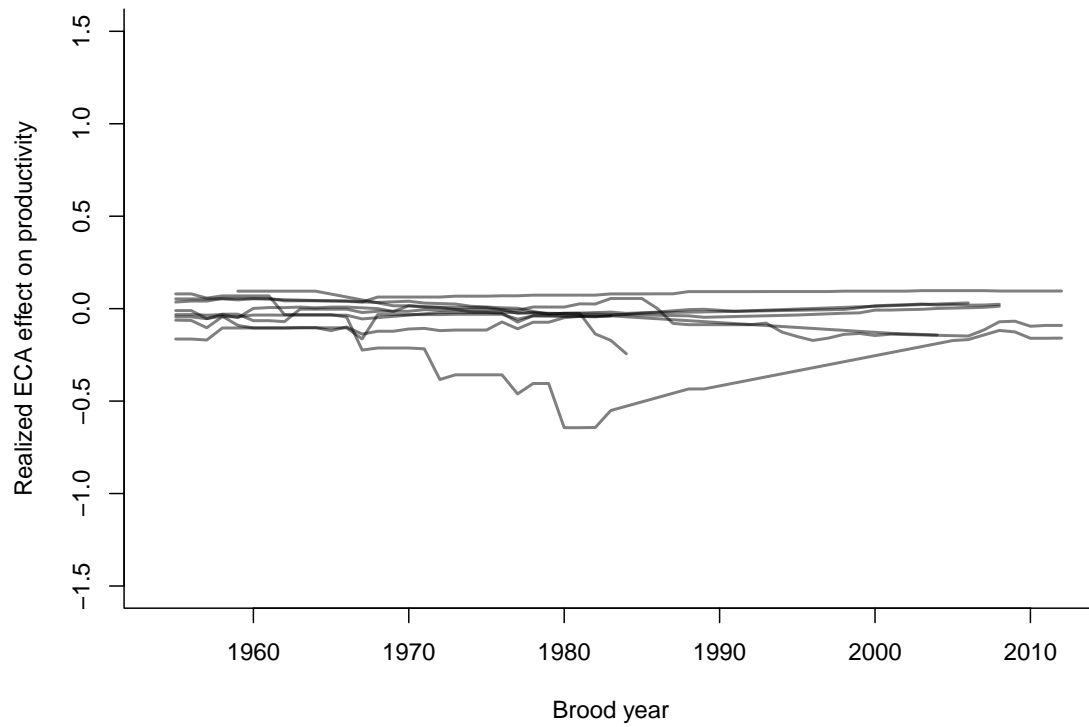
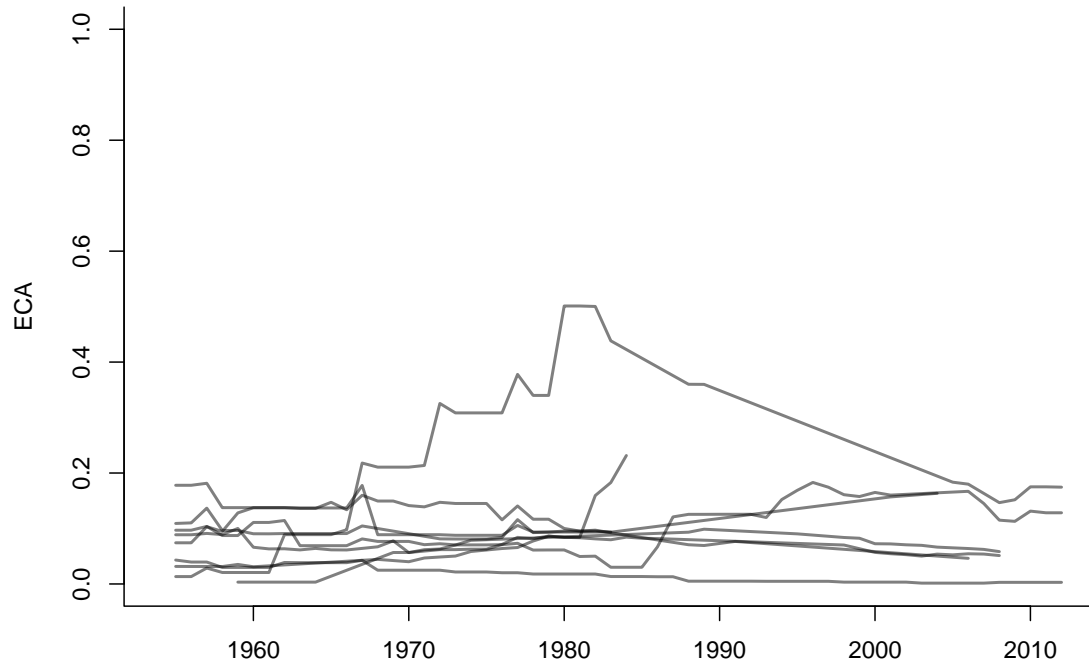
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# CM-8



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