

Kissimmee River Eutrophication Abatement Project

Optimization Leader: Steve Rust, Battelle

Statistician: Steve Rust, Battelle

Project Code: KREA

Type: Type II

Mandate or Permit:

- Lake Okeechobee Protection Plan Act (LOPA)
- Florida Watershed Restoration Act

Project Start Date: 1986

Division Manager: Okeechobee Division: Susan Gray

Program Manager: Brad Jones

Points of Contact: Brad Jones, Gary Ritter, Steffany Gornak, Joyce Zhang, Patrick Davis

Field Point of Contact: Patrick Davis

Spatial Description

Sampling locations for Project KREA are located in Polk and Okeechobee counties along many of the tributaries of the Kissimmee River from Lake Kissimmee to Lake Okeechobee. Many of these tributaries drain dairy and agricultural areas. Best Management Practices (BMPs) have been implemented in this watershed for the Works of the District Program as well as the Dairy Rule and the Rural Clean Waters Program. Twenty-three locations are sampled for this project and are located on the Kissimmee River and tributaries that drain the S-65A, S-65BC, S-65D, S-65E, S-154 and S-191 drainage basins. The LOWA Project also collects samples in this watershed; however, it is important to note that there is no duplication of effort with Project KREA. Ten stations that are now sampled as part of Project LOWA should also be considered in the optimization of Project KREA. These ten stations include (KREA07, KREA08, KREA10D, KREA33, KREA40A, KREA43A, KREA44, KREA44C, KREA49, and KREA 49A. Due to the nature of LOWA sampling (i.e., focus on one specific basin and then move and focus on a different basin), these ten stations may be incorporated back into Project KREA in the near future.

Project Purpose, Goals and Objectives

The primary purpose of Project KREA is to provide baseline and assessment data for Lake Okeechobee watershed restoration and enhancement projects. Specific objectives of the project are to:

- A. Inventory the water quality in tributaries discharging into pools A-E of C-38 and in the S154 basin entering Lake Okeechobee south of pool E
- B. Provide monitoring data to assess the efficacy of Best Management Practices (BMPs) for reducing phosphorous in surface discharge from dairies
- C. Monitor phosphorous contributions from each tributary
- D. Estimate phosphorous loads leaving Lake Okeechobee watershed basins
- E. Identifying high episodic phosphorous events and locating corresponding source areas

Sampling Frequency and Parameters Sampled

Samples are collected on a bi-weekly basis via grab samples at 13 stations: KREA 01, KREA 04, KREA 17A, KREA 20, KREA 22, KREA 23, KREA 25, KREA 28, KREA 30A, KREA 06A, KREA 14, KREA 19, and KREA 41A. Samples from the first nine stations are analyzed for DO, H2OT, PH, SCOND, NH4, TKN, NO2, NOX, TPO4, OPO4, and CL. Samples from the last four stations are analyzed for DO, H2OT, PH, SCOND, TKN, and TPO4.

Samples are collected on a monthly basis via grab samples at eight stations: KREA 79, KREA 91, KREA 92, KREA 93, KREA 94, KREA 95, KREA 97, and KREA 98. These samples are analyzed for DO, H2OT, PH, SCOND, CHLA, CHLA2, PHAEO, TSS, TURB, COLOR, ALKA, DOC, TOC, NH4, TKN, NO2, NOX, TPO4, OPO4, and CL. In addition, on a quarterly basis, the samples are analyzed for CA, K, MG, and NA.

Station locations are illustrated on the map in Figure 1. Sampling frequencies for KREA station-parameter combinations are reported in Table 1. The KREA stations are listed below by group and basin.

TRIBUTARY STATIONS

S154 Basin

- KREA 20
- KREA 25
- KREA 28
- KREA 30A

S65D Basin

- KREA 01
- KREA 04
- KREA 06A
- KREA 22
- KREA 23

S65E Basin

- KREA 14
- KREA 17A
- KREA 19
- KREA 41A

RIVER CHANNEL STATIONS

S65A Basin

- KREA 79
- KREA 91
- KREA 92
- KREA 97

S65C Basin

- KREA 93
- KREA 94
- KREA 95
- KREA 98

The tributary stations are sampled by vehicle trips. The river channel in the S65C basin is collected by boat from restored Kissimmee River channels. The river channel stations in the S65A basin are collected by boat from unrestored Kissimmee River channels and the primary purpose of these stations is to act as control sites for the restored river channel stations in the S65C basin.

Early on in the optimization project, District staff indicated that relevant data may be collected under the LOWA project at the following stations: KREA 07, KREA 08, KREA 10D, KREA 33, KREA 40A, KREA 43A, KREA 44, KREA 44C, KREA 49, and KREA 49A. After consultation

with District staff while finalizing the KREA data set, it was determined that the LOWA data would not be employed in the KREA optimization analyses performed.

District staff questioned the use of the in situ measurements and suggested that a quarterly deployment of a data sonde for a continuous 4 day period may provide more useful information than measurements taken at single point in time during grab sample collection. District staff also mentioned that the capability to monitor episodic events is critical in this region and is currently not addressed by this project or others in the Kissimmee River watershed.

Current and Future Data Uses

The KREA data are used in several District reports including the South Florida Environmental Report, and reports pertaining to the Kissimmee River Restoration. The Lake Okeechobee watershed modeling activities (CREAMS and FHANTM models) also use this information and the information is included in the Lake Okeechobee Annual Basin Assessment Reports.

In the future, this data will be used for TMDL development in cooperation with DEP (for nitrogen and phosphorus). Additionally, this information will be critical for the CERP watershed critical projects, Taylor Creek and Nubbin Slough STAs.

Optimization Analyses

Perhaps the most significant water quality monitoring objective that motivates KREA monitoring is detection of an increasing or decreasing trend in TPO4 concentrations over time. The Lake Okeechobee Protection Plan (LOPP) calls for a 70% reduction in the TPO4 load to Lake Okeechobee by 2015 and a near-shore TPO4 concentration of less than 40 ppb ($\mu\text{g/L}$). The LOPP also specifies construction projects, management projects, and a myriad of best management practices that are designed to achieve these TPO4 goals. Over the next decade, the District will use its KREA monitoring data and statistical trend analysis procedures to assess the effectiveness of LOPP implementation toward meeting the 2015 TPO4 goals.

A key question related to the KREA monitoring project is whether or not the monitoring data collected will be sufficient to assess the effectiveness of projects and practices implemented to control and improve water quality and determine whether or not sufficient progress is being made toward water quality goals and objectives. One way to address this question is to perform statistical power analyses to determine the smallest water quality trends that will be detectable with high probability based on water quality data collected according to current monitoring plans. Using the resulting detectable trends, District staff will be able to determine whether the trends necessary to achieve long-term goals will be discernable from trends that fail to achieve the long-term goals. The same statistical power analysis procedures can be used to identify detectable water quality trends for alternatives to the current monitoring design. With power analysis results for both the current and alternative monitoring designs in hand, District staff will be able to optimize the KREA monitoring design for achievement of long-term goals and objectives.

Optimization Analysis Procedures

Four primary parameters were selected for which to perform KREA optimization analyses. They are DO, TKN, TPO4 and CL with DBHYDRO codes 8, 21, 25, and 32, respectively. For the river channel stations, optimization analyses were also performed for TURB and CHLA2. Power analyses for each station-parameter combination were performed by carrying out the following power analysis steps:

- Fit a statistical model to the water quality parameter data in order to have a basis for generating simulated data to support a Monte Carlo based power analysis procedure

- Generate multiple replicate simulated water quality time series data sets; for all power analyses reported here, each time series generated was for a 5-year monitoring period
- Perform a Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) for each simulated time series data set; in particular, obtain a point estimate of the slope vs. time for the log-transformed water quality parameter values
- Estimate the *annual proportion change* (APC) in water quality parameter values that is detectable with 80% power using a simple two-sided test based on the Seasonal Kendall's Tau slope estimate performed at a 5% significance level

Parameter values were natural log-transformed for statistical modeling because the log-transformed data was more nearly normally distributed than were the untransformed data. The fitted statistical model contains the following components:

- Fixed seasonal effects that repeat themselves in an annual cycle
- A long-term linear trend in the log-transformed parameter concentrations; this corresponds to a fixed percentage increase or decrease in the water quality parameter each year
- A random error term representing temporal variability in true water quality parameter values; these error terms are allowed to be correlated from one time point to the next in order to capture any serial autocorrelation that is present in the monitoring data
- A random error term representing sampling and chemical analysis variability; these error terms are assumed to be stochastically independent from one time point to the next

The fitted statistical model is used to perform a Monte Carlo simulation analysis in which multiple TPO4 time series data sets are simulated and used to determine the anticipated statistical properties of trend detection procedures that will be used by the District. All statistical trend analyses performed on the simulated data were based on the Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) preferred by the District.

In the course of performing the power analyses for the District, it was determined that the basic Seasonal Kendall's Tau trend detection procedures do not necessarily control the true significance level of the hypothesis test for trend when there is serial autocorrelation exhibited in the data. This was found to be true even for procedures that attempt to correct for serial autocorrelation. For this reason, all power analysis results reported here are for a simple hypothesis test procedure based on the median slope estimator that accompanies the Seasonal Kendall's Tau test procedure. The median slope estimator is assumed to follow a normal distribution and power results are obtained by performing a simple z-test with this estimator.

Power analyses were attempted for each of 52 tributary station-parameter combinations. However, there was insufficient CL data for stations 06A, 14, 19, and 41A. Therefore, power analyses were completed for only 48 tributary station-parameter combinations. For each combination, an attempt was made to simulate the following three monitoring designs:

- The current monitoring frequency of semi-monthly samples (24 samples per year)

- An alternative reduced sampling design of monthly samples (12 samples per year)
- A second alternative increased sampling design of weekly samples (52 samples per year)

Because of high proportions of no bottle samples for stations 20, 25, and 30A, it was not possible to complete power analyses at these stations for a sampling frequency of 12 samples per year. In total, 132 station-parameter-design combinations were explored for tributary stations.

Power analyses were successfully performed for each of 48 river channel station-parameter combinations. For each combination, an attempt was made to simulate the following three monitoring designs:

- The current monitoring frequency of monthly samples (12 samples per year)
- An alternative reduced sampling design of bi-monthly samples (6 samples per year)
- A second alternative increased sampling design of semi-monthly samples (24 samples per year)

In total, 144 station-parameter-design combinations were explored for river channel stations.

For each station-parameter-design combination analyzed, an estimate was obtained of the minimum annual percentage change (APC) in parameter value that is detectable with 80% power using the median slope estimator z-test procedure performed at a two-sided significance level of 0.05.

Analysis of the data from DBHYDRO indicates that it was sometimes not possible to obtain one of the weekly autosamples called for by the current monitoring design. By analyzing TPO4 records from DBHYDRO along with “No Bottle Sample” records, it was possible to estimate the proportion of attempted sampling occasions for which no sample was obtained. This procedure was carried out for sampling dates during the period from January 1, 2000 through September 30, 2004 in order to estimate the proportion of the time that no sample was obtained. In the Monte Carlo procedure used to generate simulated monitoring data, sampling results were set equal to missing values with probability equal to the proportion of “No Bottle Samples”.

Rust (2005) describes the power analysis procedure and underlying statistical model employed here in detail. Rust (2005) also documents the SAS program used to carry out the power analyses for which results are reported here.

Optimization Analysis Results

Appendix A contains a figure corresponding to each of the time series data sets for which power analyses were performed. For the KREA project, that is 48 tributary station-parameter combinations and 48 river channel station-parameter combinations. Table A-1 contains a row identifying each of the 96 figures in Appendix A. The last three columns of Table A-1 identify the following:

- The number of samples per year called for in the current monitoring plan
- The number of seasons assumed in the mixed model fitted to the data and used to simulate monitoring data

- The proportion of “No Bottle Samples” during the period January 1, 2000 through September 30, 2004 which was used as a probability for generating missing data when the Monte Carlo simulation was performed

Each figure in Appendix A displays the actual water quality parameter time series for an individual station as black dots connected by black lines. The plotted values are the natural logarithm of water quality parameter values. The fixed portion of the fitted mixed model is illustrated as a red curve. As illustrated in the figures in Appendix A, tributary station data sets go back as far as 1992 to mid-1996 while river channel data sets go back as far as early-1996 to late-1998.

A summary of the power analysis results are reported in Table B-1. Table B-1 contains a row for each of the 276 power analyses performed. In this case that is usually three power analyses per station-parameter combination. A power analysis was performed for the current sampling frequency. In addition, alternative monitoring designs calling for sampling at half the current rate and double the current rate were also investigated.

For each station, the standard deviation of the monitoring data about the fitted fixed effects model and the correlation coefficient for two measurements taken exactly one month apart are reported. These two quantities are key drivers of the power analysis results. In addition, the number of samples per year simulated and the detectable annual percentage change for that monitoring scenario are reported in the last two columns of Table B-1.

The detectable annual percentage change (detectable APC) is the minimum true percentage change per year that would be consistently detected by the test for trend based on the median slope estimator that accompanies the Seasonal Kendall’s Tau procedure. Consistently detected means that the null hypothesis of no trend would be rejected 80% of the time.

As noted in the footnote to Tables A-1 and B-1, because the estimated autocorrelation coefficient for certain station-parameter combinations is negative, it is suspected that the assumptions underlying the mixed model used in the power analysis procedure are violated for those combinations. For this reason, the detectable APC results for these station-parameter combinations will be largely ignored when drawing conclusions from the power analysis results.

The detectable APC results reported in Table B-1 are illustrated graphically in Figures 2-11. Figures 2-5 are for tributary stations and Figures 6-11 are for river channel stations. The following conclusions related to TPO4 concentrations at tributary stations may be drawn from Figure 5 and the corresponding rows of Table B-1.

- The TPO4 time series data for all stations except stations 04 and 22 exhibit significant serial autocorrelation
- Detectable APC values for stations 20, 25 and 30A are considerable larger than those for other KREA tributary stations; this result is apparently due to the very high incidence of “No Bottle Samples” at these stations
- Detectable APC values for tributary stations other than 20, 25, and 30A at the current monitoring frequency of 24 samples per year are in the range of 21%-50%

- The effect of reduced sampling frequencies on detectable APC values is much smaller than would be expected for independent time series data; if the monitoring data exhibited no serial autocorrelation, one would expect an increase in the sampling frequency to 52 samples per year to cause the detectable APC to decrease by a multiplicative factor of 1.4; in this case, for all tributary stations other than 04, 20, 25 and 30A, the detectable APC values decrease by a multiplicative factor less than 1.2; the smaller effect associated with sample frequency reduction is due the significant autocorrelation exhibited in the TPO4 time series data

The following conclusions related to TPO4 concentrations at river channel stations may be drawn from Figure 10 and the corresponding rows of Table B-1.

- The TPO4 time series data for all stations except station 91 exhibit significant serial autocorrelation
- Detectable APC values for stations 93, 95 and 98 are considerable larger than those for other KREA tributary stations; this result is apparently due to the fact that these stations exhibit the highest levels of variability and serial autocorrelation
- Detectable APC values for river channel stations other than 93, 95 and 98 at the current monitoring frequency of 12 samples per year are in the range of 16%-33%
- The effect of reduced sampling frequencies on detectable APC values is much smaller than would be expected for independent time series data; if the monitoring data exhibited no serial autocorrelation, one would expect an increase in the sampling frequency to 24 samples per year to cause the detectable APC to decrease by a multiplicative factor of 1.4; in this case, for all river channel stations, the detectable APC values decrease by a multiplicative factor less than 1.2; the smaller effect associated with sample frequency reduction is due the significant autocorrelation exhibited in the TPO4 time series data

The following conclusions related to CHLA2, CL, DO, TKN, and TURB water quality values may be drawn from Figures 2-4, 6-9 and 11 and the corresponding rows of Table B-1.

- CHLA2 (river channel stations only): Current sampling frequencies result in detectable APC values in the range 33%-64%; changing the sampling frequency has only a small effect on detectable APC values at 5 stations with high autocorrelation but has a large effect at 3 stations with low autocorrelation
- CL: Insufficient monitoring data is obtained at stations 20, 25 and 30A to have good detectable APC values; for other stations, current sampling frequencies result in detectable APC values in the range 15%-34%; for most stations, changing the sampling frequency has only a small effect on detectable APC values because most CL time series exhibit considerable serial autocorrelation
- DO: Stations 20, 25, 93 and 97 have very large detectable APC values; for other stations, current sampling frequencies result in detectable APC values in the range 20%-49%; changing the sampling frequency has only a small effect on detectable APC values at stations with high autocorrelation but has a large effect at stations with low autocorrelation; the river channel stations exhibit low levels of serial autocorrelation

- TKN: Stations 20, 25, 30A and 91 have very large detectable APC values; for other stations, , current sampling frequencies result in detectable APC values in the range 7%-18%; changing the sampling frequency has only a small effect on detectable APC values at stations with high autocorrelation but has a large effect at stations with low autocorrelation
- TURB (river channel stations only): The restored river channel stations (93, 94, 95 and 98) have detectable APC values greater than or equal to 100% due to extremely high levels of variability and serial autocorrelation which may be due to river channel restoration activities; for the unrestored river channel stations (79, 91, 92, and 98) current sampling frequencies result in detectable APC values in the range 20%-26%; changing the sampling frequency at these stations has a moderate effect due to these stations exhibiting only moderate levels of serial autocorrelation

Recommendations for Current Monitoring Plans

A 70% reduction in TPO4 loads to Lake Okeechobee, if accomplished smoothly over the next decade, would require an 11.3% reduction in phosphorus load each year. In annual percentage change terminology that translates to an APC of 12.7%. For the purposes of evaluating the current and alternative monitoring designs for which power analysis results were generated, it seems reasonable to expect a design to have a detectable APC of 12.7% or smaller. If this requirement is satisfied by a monitoring design, then a smooth 11.3% annual reduction in TPO4 concentrations over a 5-year monitoring period would have an 80% chance of being declared a statistically significant trend.

Requiring a detectable APC of 12.7% is not a very restrictive requirement. Stated another way, the absolute error in estimating the annual percentage change in TPO4 concentrations would be on the order of 7.5%. If there was no change in the average TPO4 concentration over a 5-year monitoring period (observed annual percentage change of 0%), then a 95% confidence interval for the true annual percentage change in TPO4 concentrations would be (-8.1%, +8.8%). Projecting the uncertainty in the annual percentage change over a 10-year time period, the 95% confidence interval for the percentage change over a 10-year time period would be (-57%, +132%). Therefore, a detectable APC of 12.7% still leaves the district in a position of some considerable uncertainty regarding 10-year trends in TPO4 concentrations.

The following recommendations are made regarding the monitoring plans for KREA monitoring stations:

1. Current sampling frequencies at tributary and river channel stations result in detectable APC values that are considerably above the 12.7% target associated with 2015 TPO4 goals; for most stations, even a doubling of the number of samples per year does not move the detectable APC close to 12.7%; because there does not seem to be a simple monitoring change that will result in achievement of the target detectable APC, it is recommended that the District
 - A. Investigate alternative more sophisticated methods for analyzing the TPO4 concentration data in an attempt to better explain the systematic variations over time and produce more precise estimates of trend, and/or
 - B. Investigate methods of data aggregation that will result in more precise estimates of long-term trends

2. In general, detectable APC values for TKN concentrations are better than those for TPO4; therefore, it is concluded that any monitoring plan that produces precise enough estimates of TPO4 trends will at the same time produce even more precise estimates of TKN trends, allowing precise estimates of trends in TPO4 to TKN ratios to be determined as well; therefore, separate optimization recommendations for TKN will not be required
3. In general, detectable APC values for CHLA2, CL, DO, and TURB exceed 20% indicating that the ability to detect trends in these parameters is somewhat limited; no separate recommendation is made regarding changes in monitoring plans targeted at these parameters since it is likely that steps taken to improve TPO4 trend estimation would also result in improvements for these parameters
4. It is recommended that the data sets with potential model violations and potential outliers be re-analyzed to produce robust power analysis results for these data sets; however, it is doubtful that such re-analyses would change the general recommendations just offered above.

References

- Reckhow KH, Kepford K, and Hicks WW (1993). Methods for the Analysis of Lake Water Quality Trends. EPA 841-R-93-003.
- Rust SW (2005). Power Analysis Procedure for Trend Detection with Accompanying SAS Software. Battelle Report to South Florida Water Management District, November 2005.



Table 1. Parameters Measured In Situ and from Grab Samples for Project KREA

| Station | D O | TEMP | P H | SCOND | CHLA | CHLA2 | PHAE0 | TSS | TURBI | COLOR | ALKA | TDORC | TORGC | NH4 | TKN | NO2 | NOX | TP04 | 0P04 | C L | C A | K | M G | N A |
|----------|-----|------|-----|-------|------|-------|-------|-----|-------|-------|------|-------|-------|-----|-----|-----|-----|------|------|-----|-----|-----|-----|-----|
| KREA 01 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 04 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 17A | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 20 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 22 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 23 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 25 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 28 | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 30A | bw | bw | bw | bw | | | | | | | | | | bw | bw | bw | bw | bw | bw | bw | | | | |
| KREA 06A | bw | bw | bw | bw | | | | | | | | | | | bw | | | bw | | | | | | |
| KREA 14 | bw | bw | bw | bw | | | | | | | | | | | bw | | | bw | | | | | | |
| KREA 19 | bw | bw | bw | bw | | | | | | | | | | | bw | | | bw | | | | | | |
| KREA 41A | bw | bw | bw | bw | | | | | | | | | | | bw | | | bw | | | | | | |
| KREA 79 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 91 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 92 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 93 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 94 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 95 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 97 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |
| KREA 98 | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | m | qtr | qtr | qtr | qtr |

bw = bi-weekly; m = monthly; qtr = quarterly

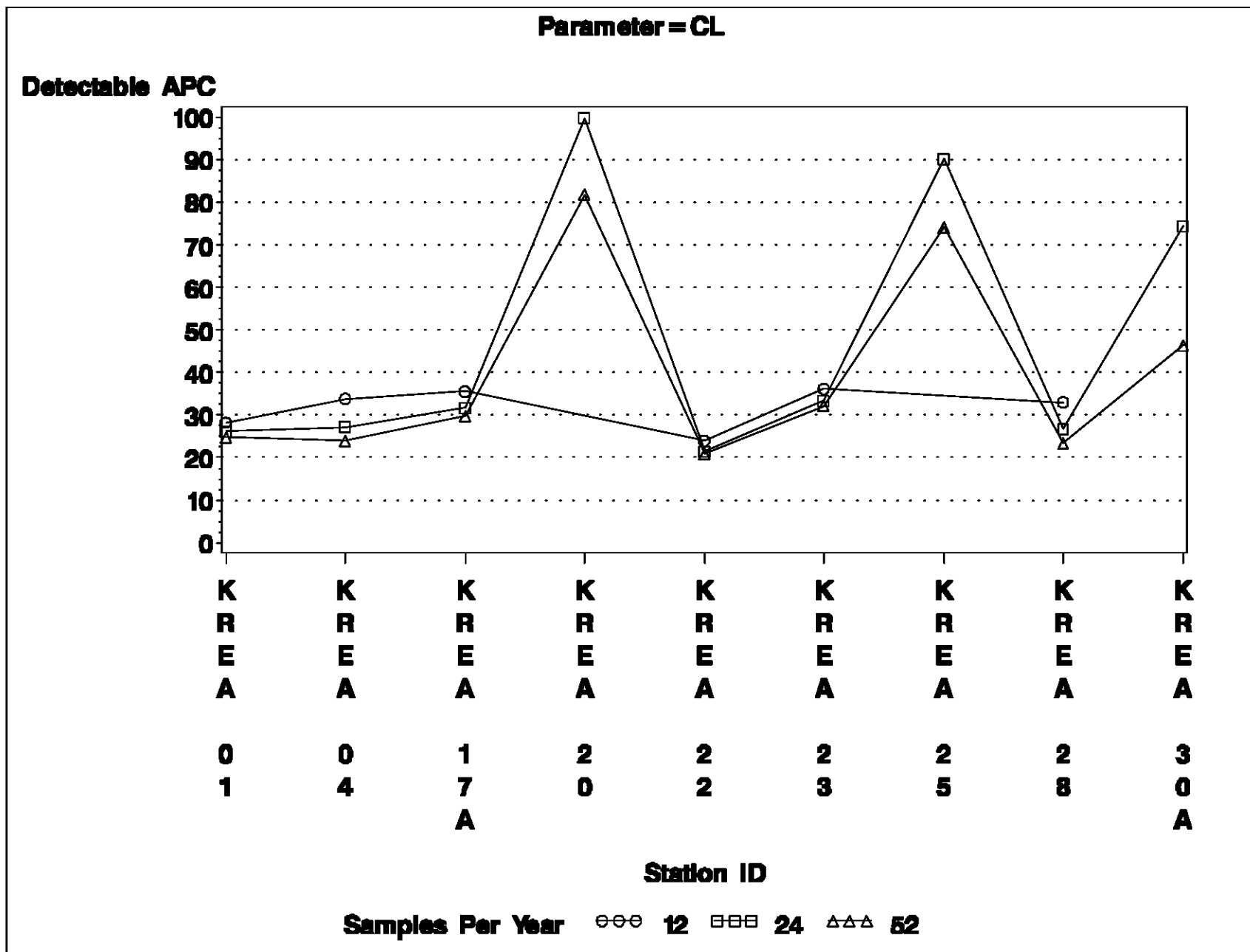


Figure 2

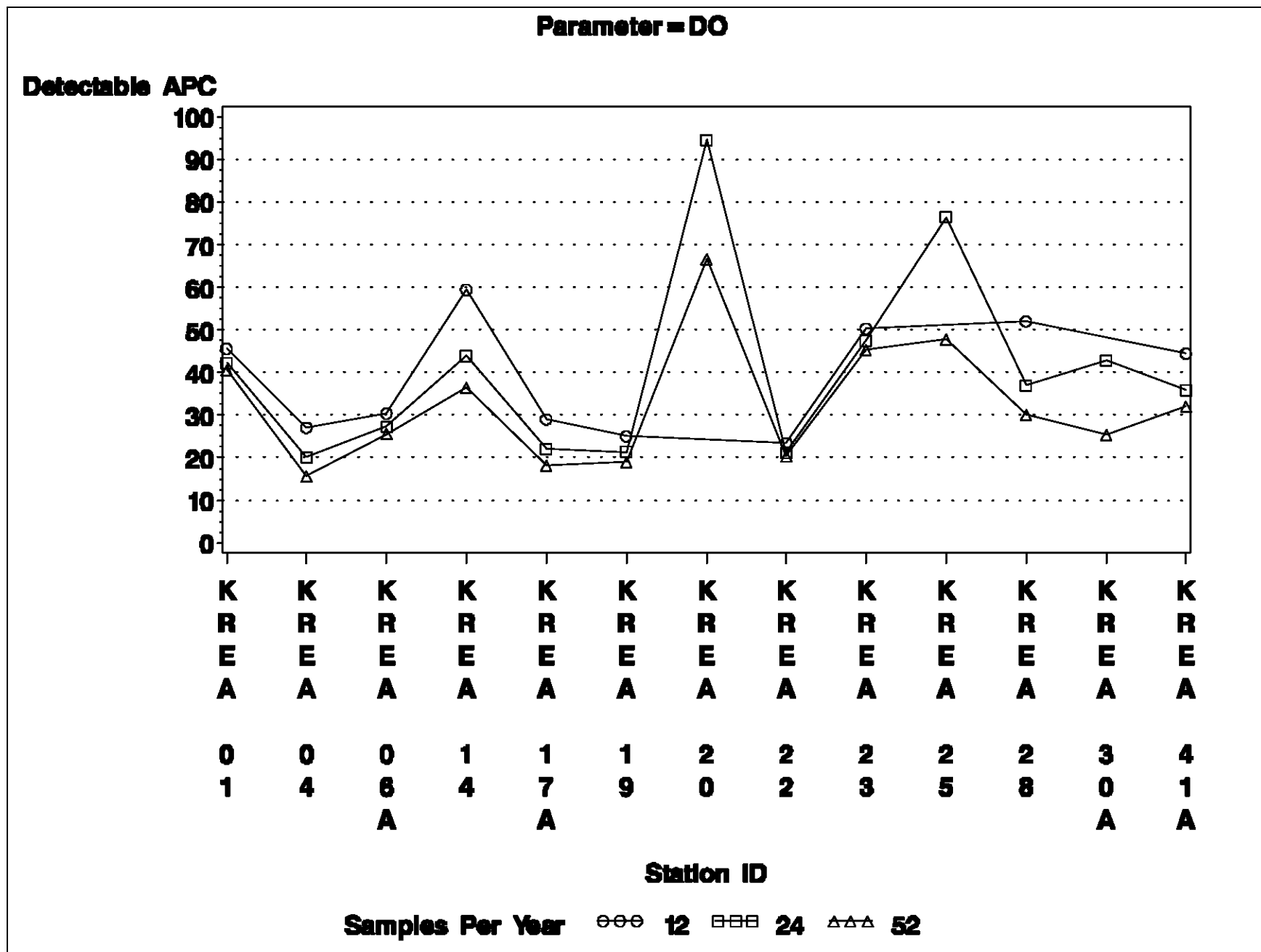


Figure 3

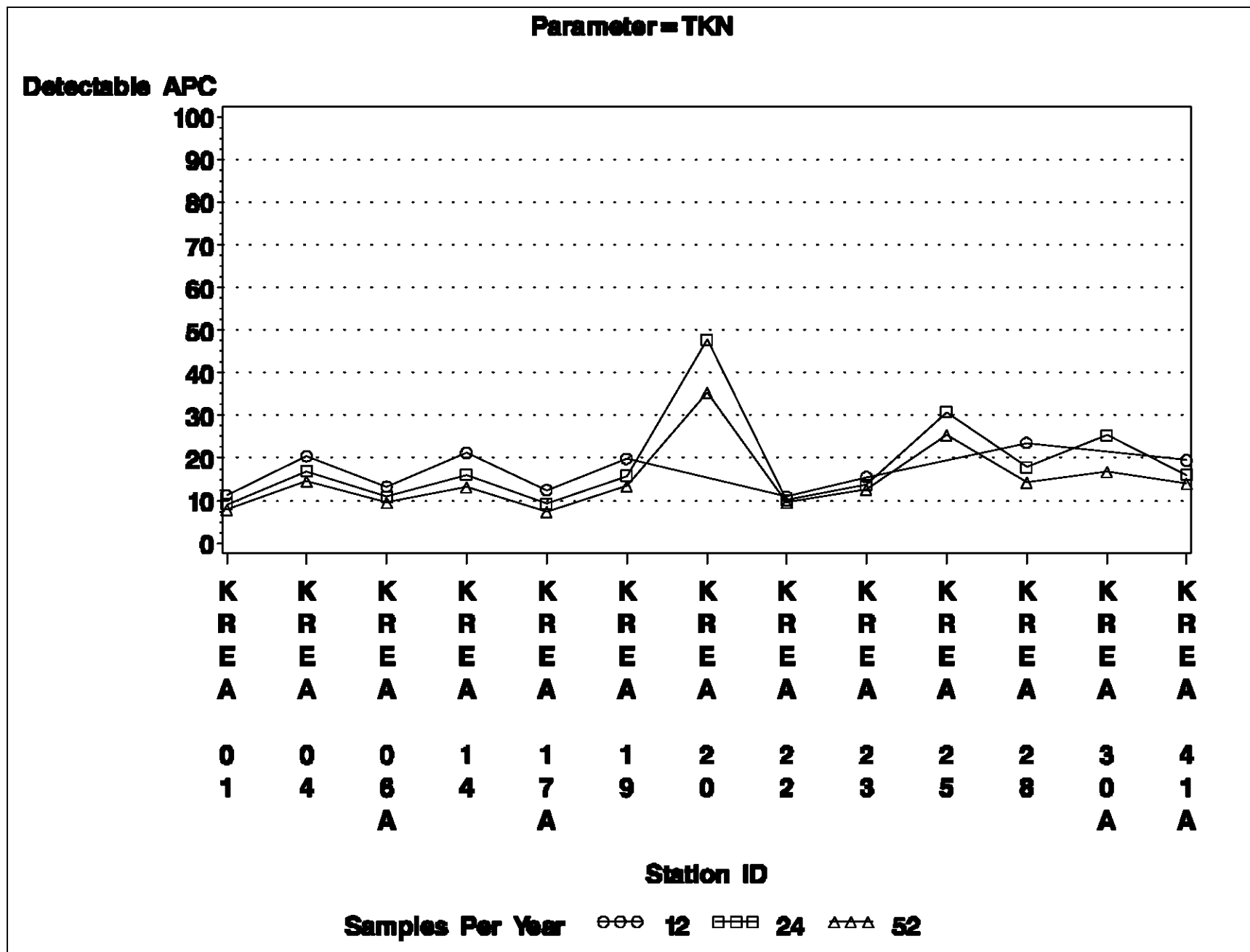
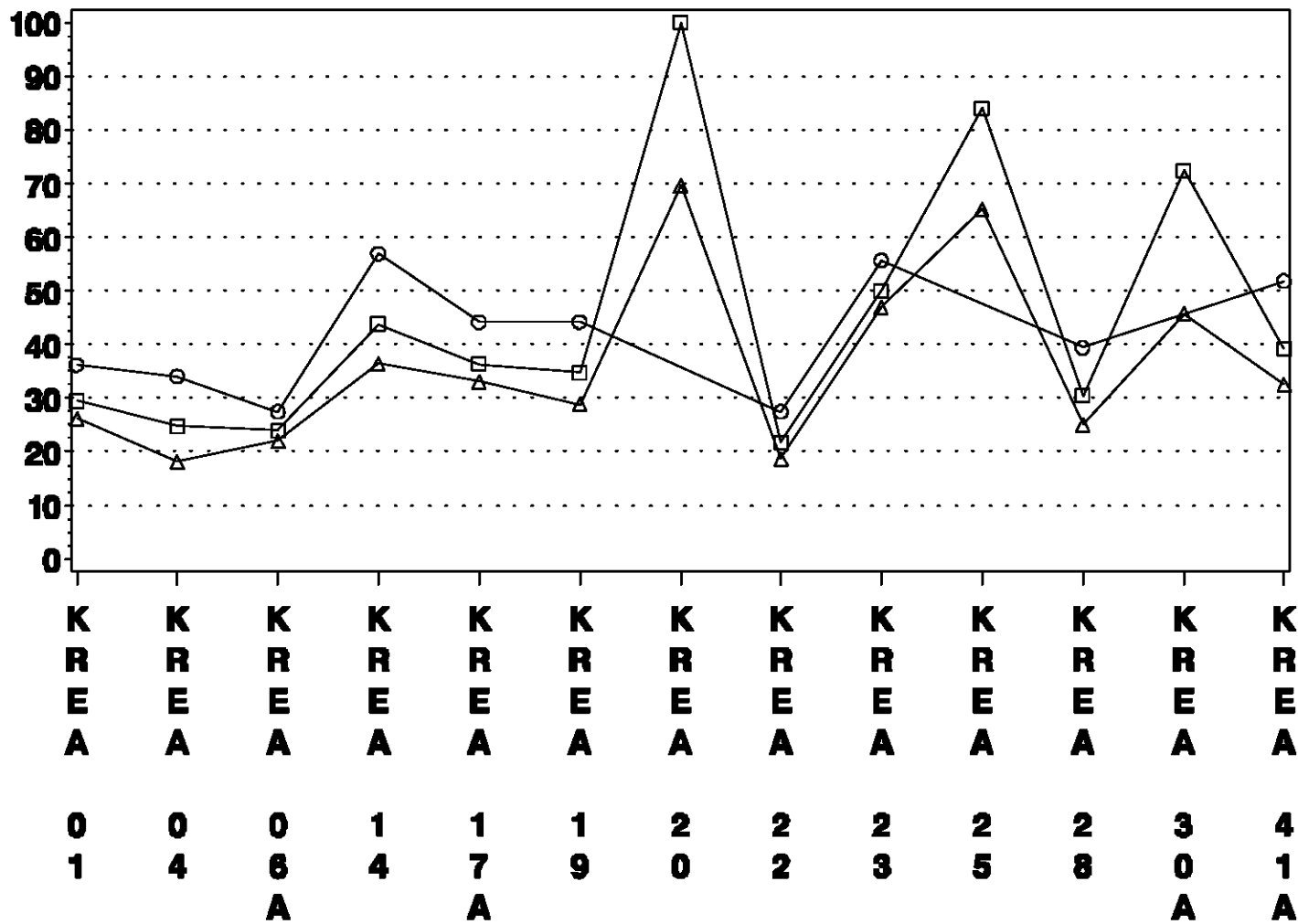


Figure 4

Parameter = TPO4

Detectable APC



Station ID

Samples Per Year ○○○ 12 □□□ 24 ▲▲▲ 52

Figure 5

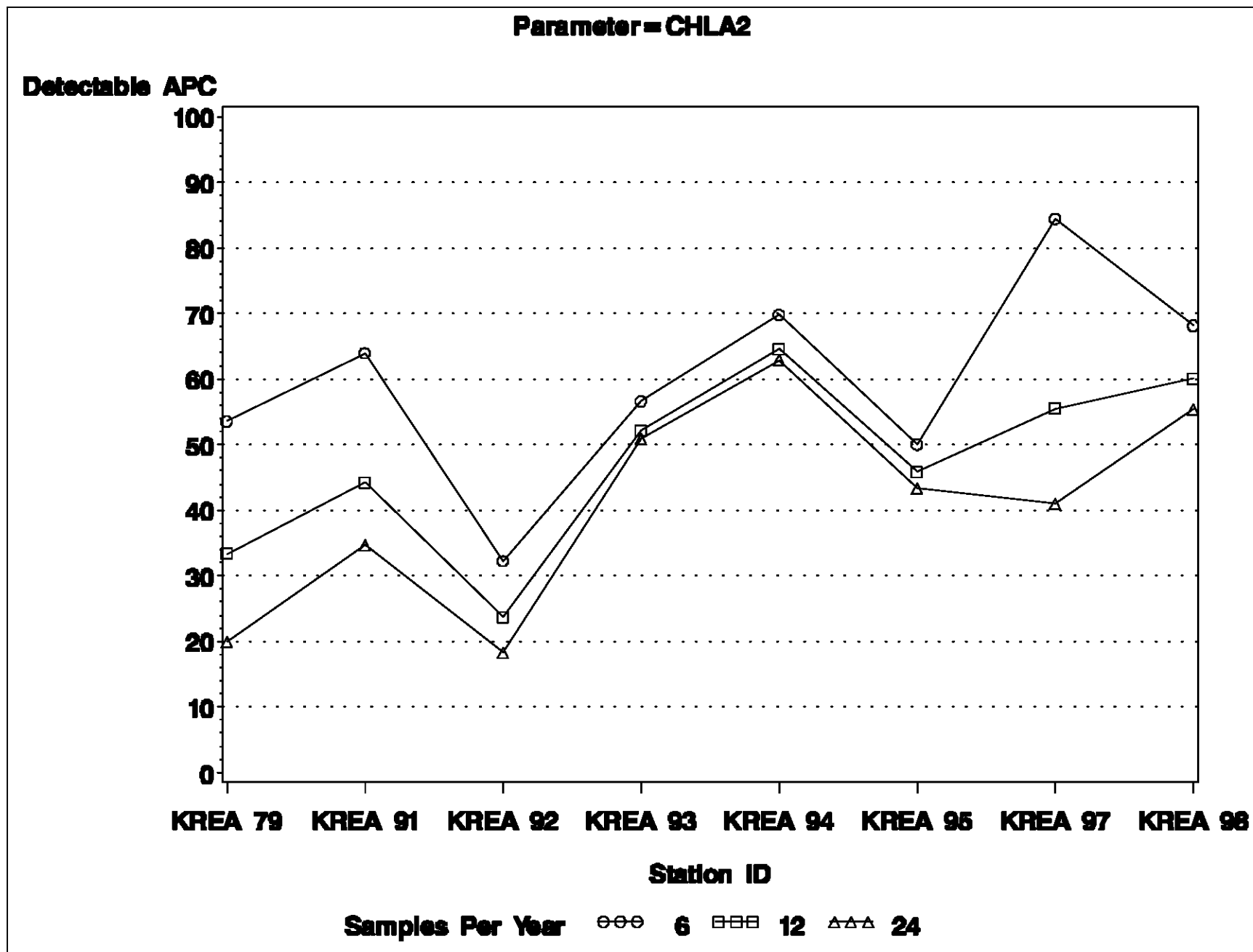


Figure 6

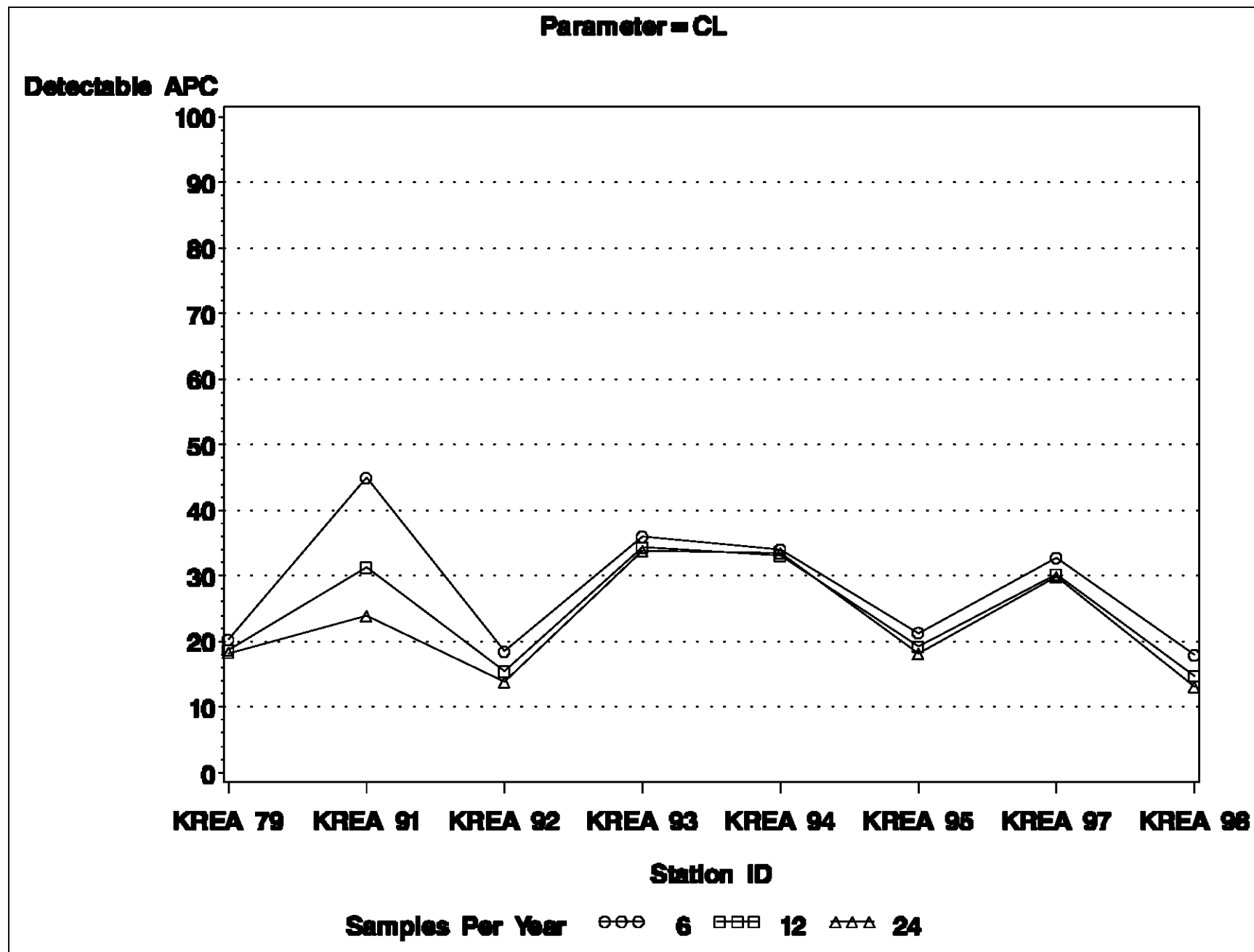


Figure 7

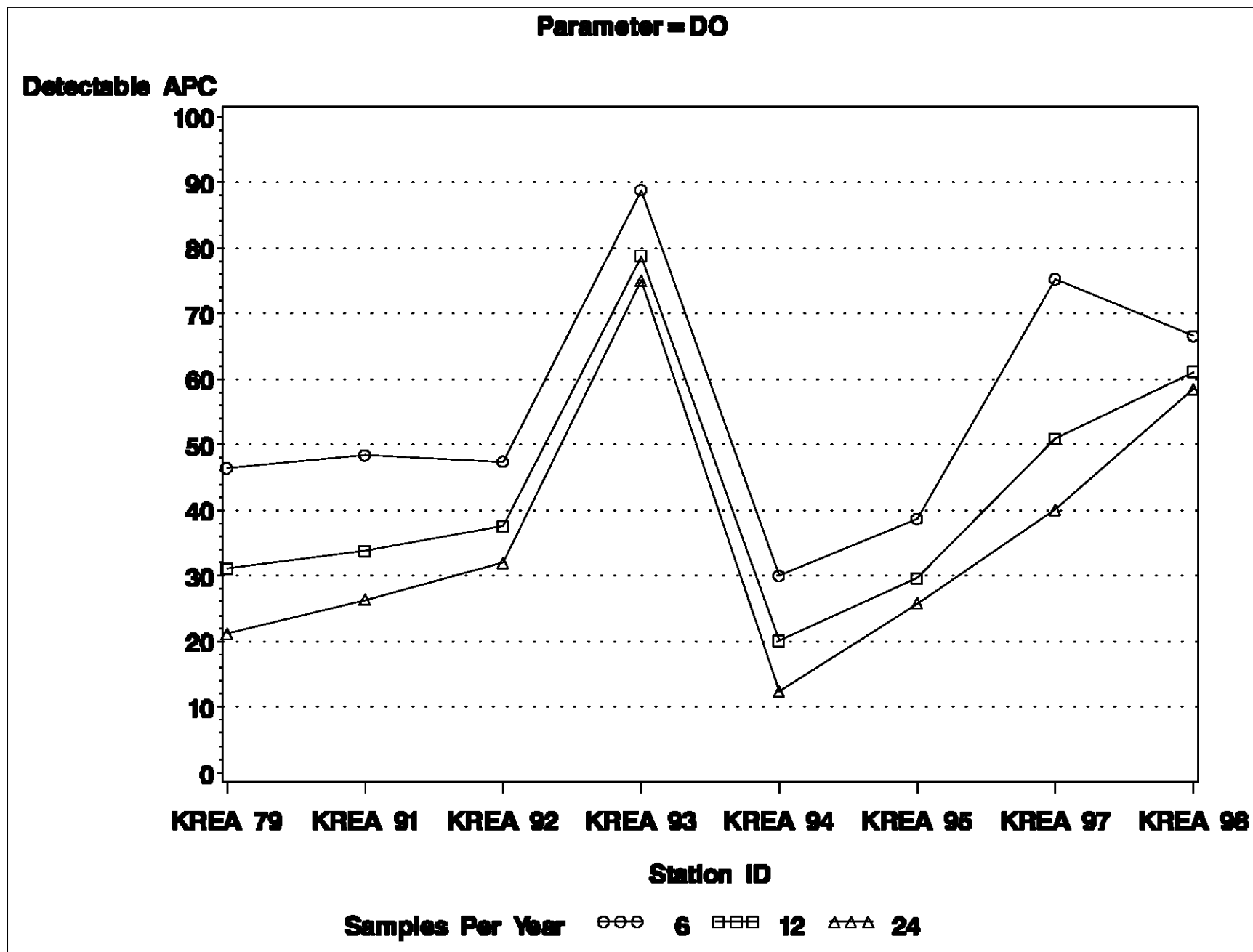


Figure 8

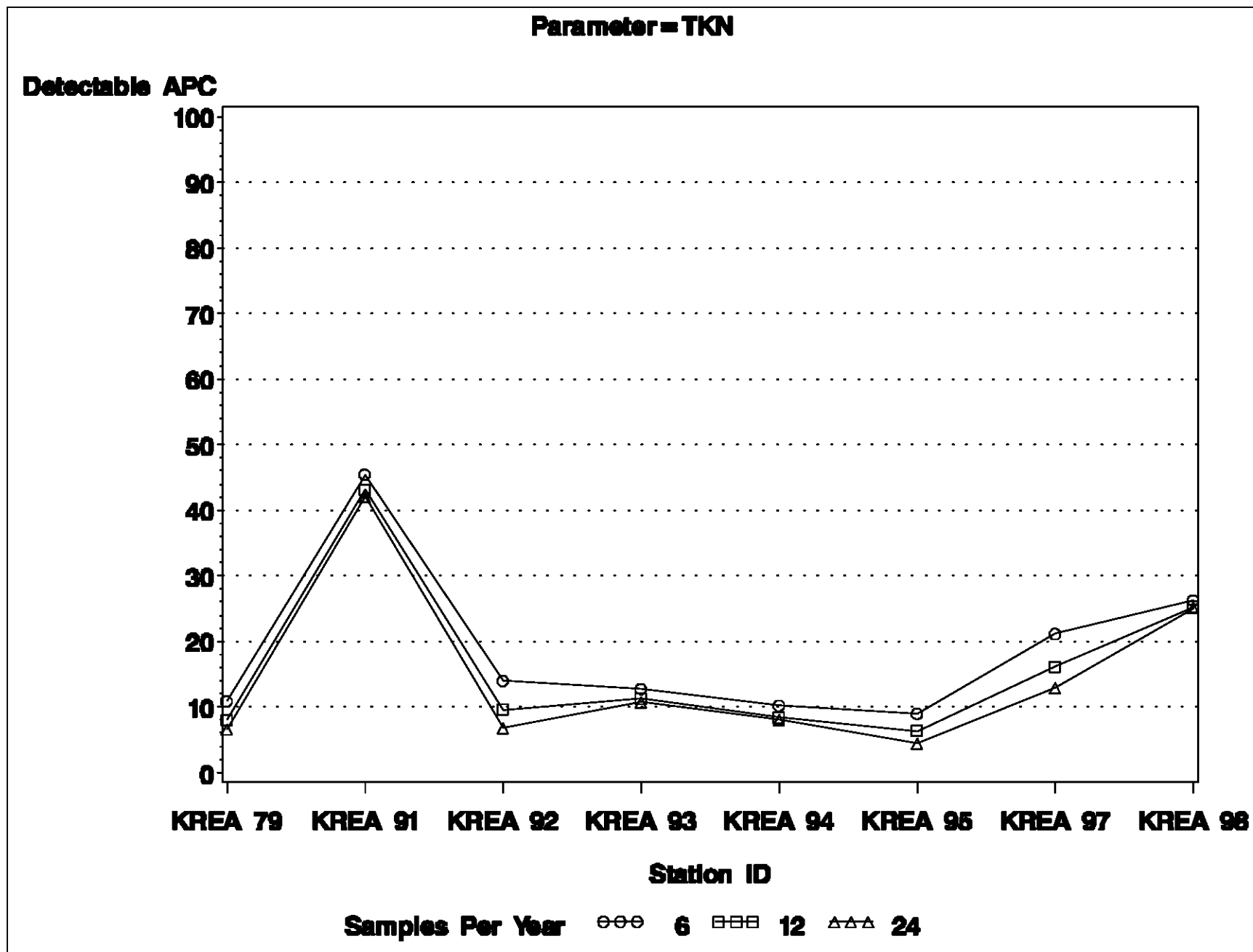


Figure 9

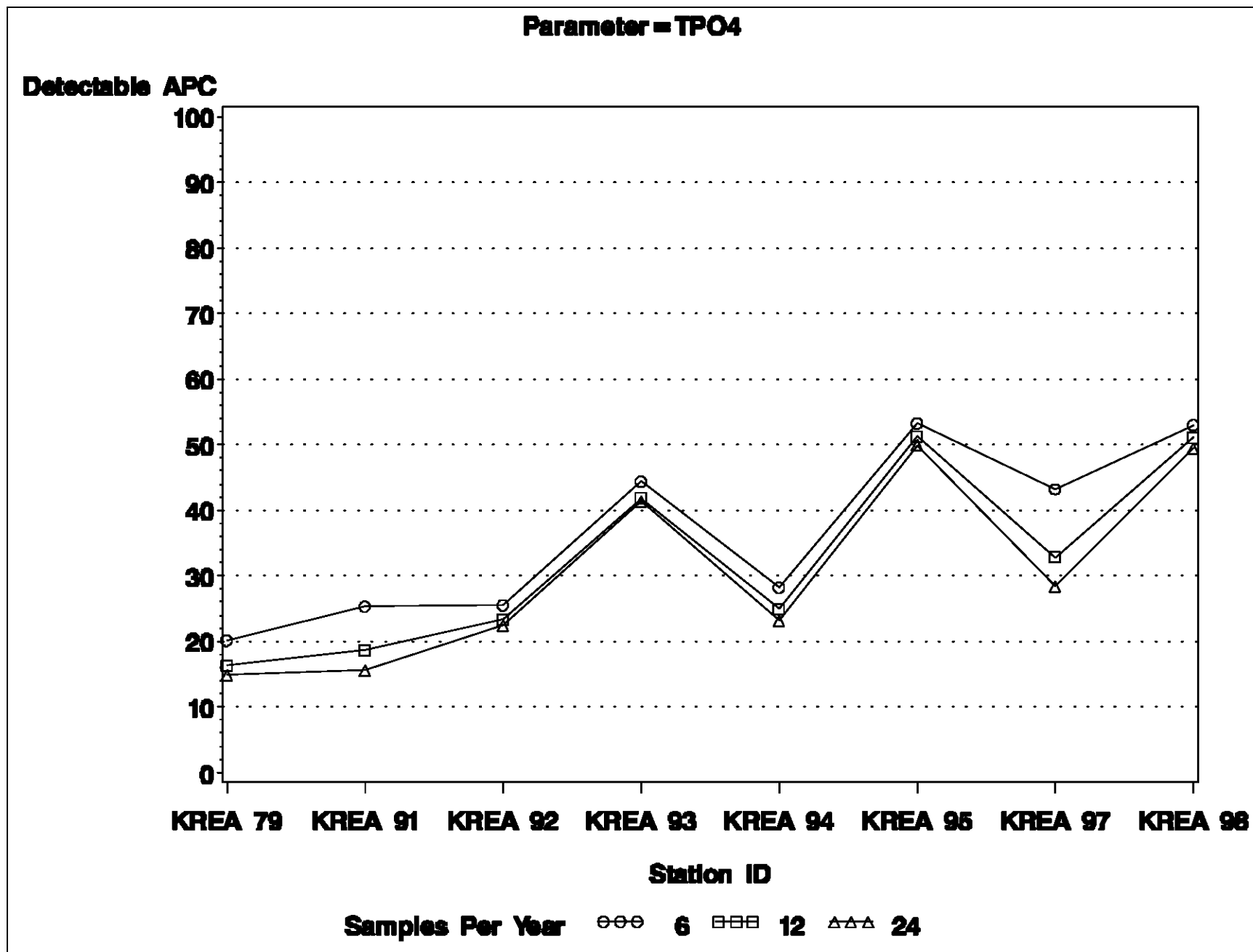


Figure 10

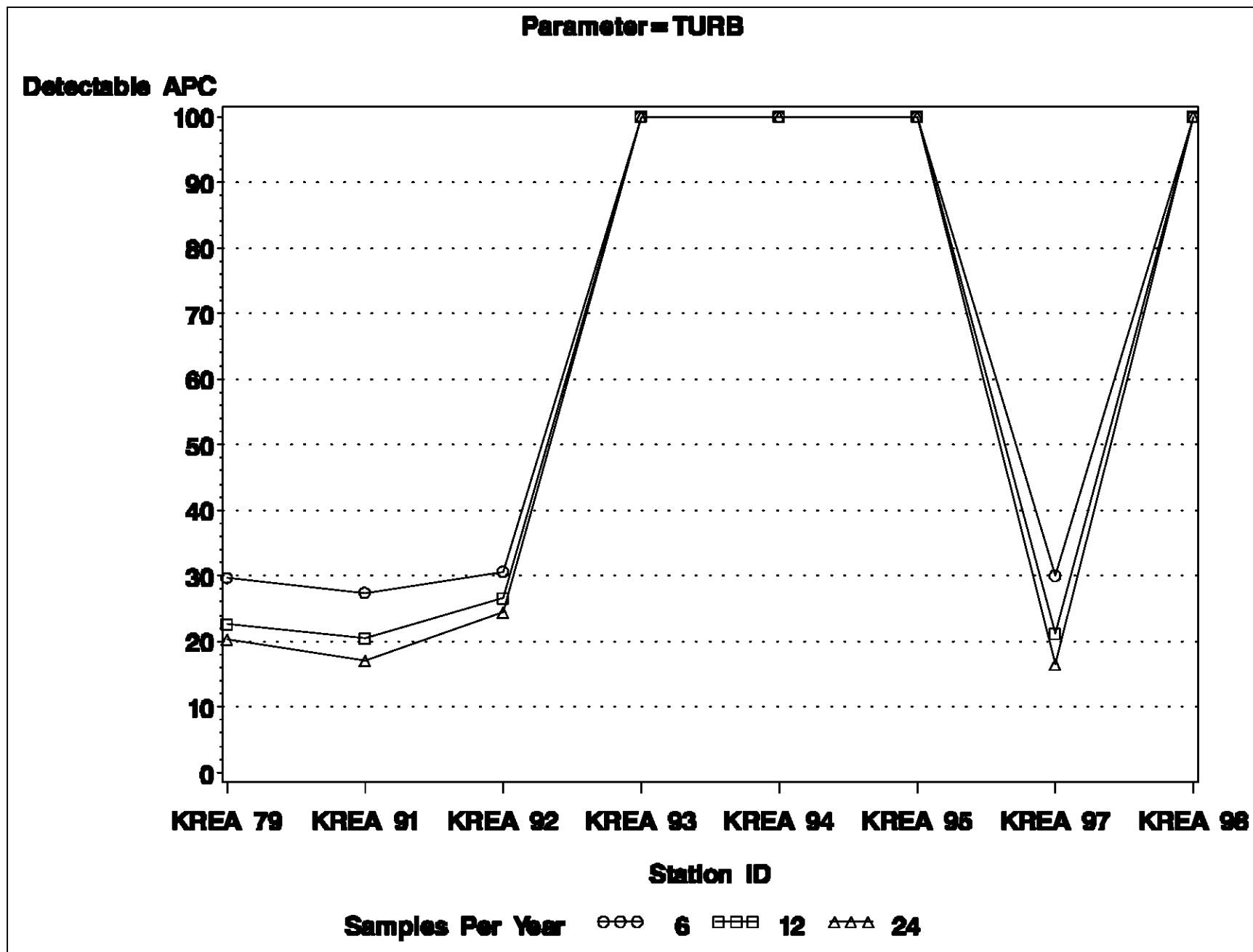


Figure 11

APPENDIX A

TIME SERIES PLOTS OF WATER QUALITY PARAMETERS OVERLAID WITH FITTED FIXED EFFECTS MODEL

Table A-1. Index of Figures Included in Appendix A

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 1 | KREA 01 | DO | 24 | 24 | 0.22 |
| 2 | KREA 04 | DO | 24 | 12 | 0.49 |
| 3* | KREA 06A | DO | 24 | 12 | 0.36 |
| 4 | KREA 14 | DO | 24 | 12 | 0.56 |
| 5 | KREA 17A | DO | 24 | 12 | 0.42 |
| 6 | KREA 19 | DO | 24 | 24 | 0.22 |
| 7 | KREA 20 | DO | 24 | 6 | 0.78 |
| 8 | KREA 22 | DO | 24 | 12 | 0.24 |
| 9 | KREA 23 | DO | 24 | 6 | 0.38 |
| 10 | KREA 25 | DO | 24 | 6 | 0.77 |
| 11 | KREA 28 | DO | 24 | 12 | 0.58 |
| 12* | KREA 30A | DO | 24 | 24 | 0.78 |
| 13 | KREA 41A | DO | 24 | 24 | 0.39 |
| 14 | KREA 01 | TKN | 24 | 24 | 0.22 |
| 15 | KREA 04 | TKN | 24 | 12 | 0.49 |
| 16 | KREA 06A | TKN | 24 | 12 | 0.36 |
| 17 | KREA 14 | TKN | 24 | 12 | 0.56 |
| 18 | KREA 17A | TKN | 24 | 12 | 0.42 |
| 19 | KREA 19 | TKN | 24 | 24 | 0.22 |
| 20 | KREA 20 | TKN | 24 | 6 | 0.78 |
| 21 | KREA 22 | TKN | 24 | 12 | 0.24 |
| 22 | KREA 23 | TKN | 24 | 6 | 0.38 |
| 23 | KREA 25 | TKN | 24 | 6 | 0.77 |
| 24 | KREA 28 | TKN | 24 | 12 | 0.58 |
| 25 | KREA 30A | TKN | 24 | 24 | 0.78 |
| 26 | KREA 41A | TKN | 24 | 24 | 0.39 |
| 27 | KREA 01 | TPO4 | 24 | 24 | 0.22 |
| 28 | KREA 04 | TPO4 | 24 | 12 | 0.49 |
| 29 | KREA 06A | TPO4 | 24 | 12 | 0.36 |
| 30 | KREA 14 | TPO4 | 24 | 12 | 0.56 |
| 31 | KREA 17A | TPO4 | 24 | 12 | 0.42 |
| 32 | KREA 19 | TPO4 | 24 | 24 | 0.22 |
| 33** | KREA 20 | TPO4 | 24 | 6 | 0.78 |

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 34 | KREA 22 | TPO4 | 24 | 12 | 0.24 |
| 35 | KREA 23 | TPO4 | 24 | 6 | 0.38 |
| 36 | KREA 25 | TPO4 | 24 | 6 | 0.77 |
| 37 | KREA 28 | TPO4 | 24 | 12 | 0.58 |
| 38 | KREA 30A | TPO4 | 24 | 24 | 0.78 |
| 39 | KREA 41A | TPO4 | 24 | 24 | 0.39 |
| 40 | KREA 01 | CL | 24 | 24 | 0.22 |
| 41 | KREA 04 | CL | 24 | 12 | 0.49 |
| 42 | KREA 17A | CL | 24 | 12 | 0.42 |
| 43 | KREA 20 | CL | 24 | 6 | 0.78 |
| 44 | KREA 22 | CL | 24 | 12 | 0.24 |
| 45 | KREA 23 | CL | 24 | 6 | 0.38 |
| 46 | KREA 25 | CL | 24 | 6 | 0.77 |
| 47 | KREA 28 | CL | 24 | 12 | 0.58 |
| 48 | KREA 30A | CL | 24 | 24 | 0.78 |
| 49 | KREA 79 | DO | 12 | 12 | 0.11 |
| 50 | KREA 91 | DO | 12 | 12 | 0.25 |
| 51 | KREA 92 | DO | 12 | 12 | 0.00 |
| 52 | KREA 93 | DO | 12 | 12 | 0.06 |
| 53* | KREA 94 | DO | 12 | 12 | 0.02 |
| 54 | KREA 95 | DO | 12 | 12 | 0.00 |
| 55 | KREA 97 | DO | 12 | 12 | 0.45 |
| 56 | KREA 98 | DO | 12 | 12 | 0.15 |
| 57 | KREA 79 | TURB | 12 | 12 | 0.11 |
| 58 | KREA 91 | TURB | 12 | 12 | 0.25 |
| 59 | KREA 92 | TURB | 12 | 12 | 0.00 |
| 60 | KREA 93 | TURB | 12 | 12 | 0.06 |
| 61 | KREA 94 | TURB | 12 | 12 | 0.02 |
| 62 | KREA 95 | TURB | 12 | 12 | 0.00 |
| 63 | KREA 97 | TURB | 12 | 12 | 0.45 |
| 64 | KREA 98 | TURB | 12 | 12 | 0.15 |
| 65 | KREA 79 | TKN | 12 | 12 | 0.11 |
| 66 | KREA 91 | TKN | 12 | 12 | 0.25 |
| 67** | KREA 92 | TKN | 12 | 12 | 0.00 |
| 68 | KREA 93 | TKN | 12 | 12 | 0.06 |
| 69 | KREA 94 | TKN | 12 | 12 | 0.02 |
| 70 | KREA 95 | TKN | 12 | 12 | 0.00 |
| 71 | KREA 97 | TKN | 12 | 12 | 0.45 |
| 72 | KREA 98 | TKN | 12 | 12 | 0.15 |
| 73 | KREA 79 | TPO4 | 12 | 12 | 0.11 |
| 74 | KREA 91 | TPO4 | 12 | 12 | 0.25 |
| 75 | KREA 92 | TPO4 | 12 | 12 | 0.00 |
| 76 | KREA 93 | TPO4 | 12 | 12 | 0.06 |
| 77 | KREA 94 | TPO4 | 12 | 12 | 0.02 |

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 78 | KREA 95 | TPO4 | 12 | 12 | 0.00 |
| 79 | KREA 97 | TPO4 | 12 | 12 | 0.45 |
| 80 | KREA 98 | TPO4 | 12 | 12 | 0.15 |
| 81 | KREA 79 | CL | 12 | 12 | 0.11 |
| 82** | KREA 91 | CL | 12 | 12 | 0.25 |
| 83** | KREA 92 | CL | 12 | 12 | 0.00 |
| 84 | KREA 93 | CL | 12 | 12 | 0.06 |
| 85 | KREA 94 | CL | 12 | 12 | 0.02 |
| 86 | KREA 95 | CL | 12 | 12 | 0.00 |
| 87 | KREA 97 | CL | 12 | 12 | 0.45 |
| 88 | KREA 98 | CL | 12 | 12 | 0.15 |
| 89 | KREA 79 | CHLA2 | 12 | 12 | 0.11 |
| 90 | KREA 91 | CHLA2 | 12 | 12 | 0.25 |
| 91 | KREA 92 | CHLA2 | 12 | 12 | 0.00 |
| 92 | KREA 93 | CHLA2 | 12 | 12 | 0.06 |
| 93 | KREA 94 | CHLA2 | 12 | 12 | 0.02 |
| 94 | KREA 95 | CHLA2 | 12 | 12 | 0.00 |
| 95 | KREA 97 | CHLA2 | 12 | 12 | 0.45 |
| 96 | KREA 98 | CHLA2 | 12 | 12 | 0.15 |

* Model assumptions may be violated

** Time series data may contain overly influential outliers

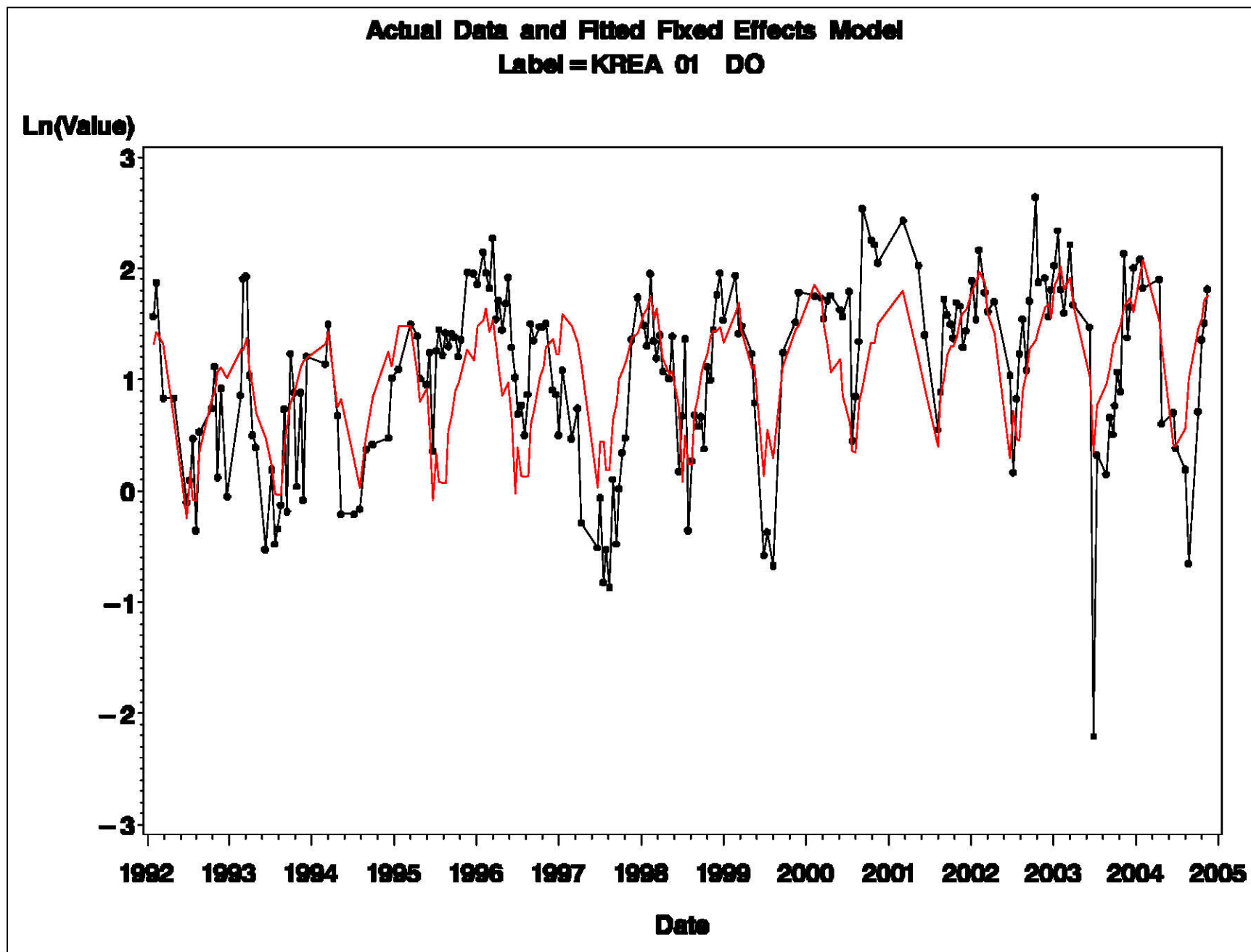


Figure A-1

Actual Data and Fitted Fixed Effects Model
Label = KREA 04 DO

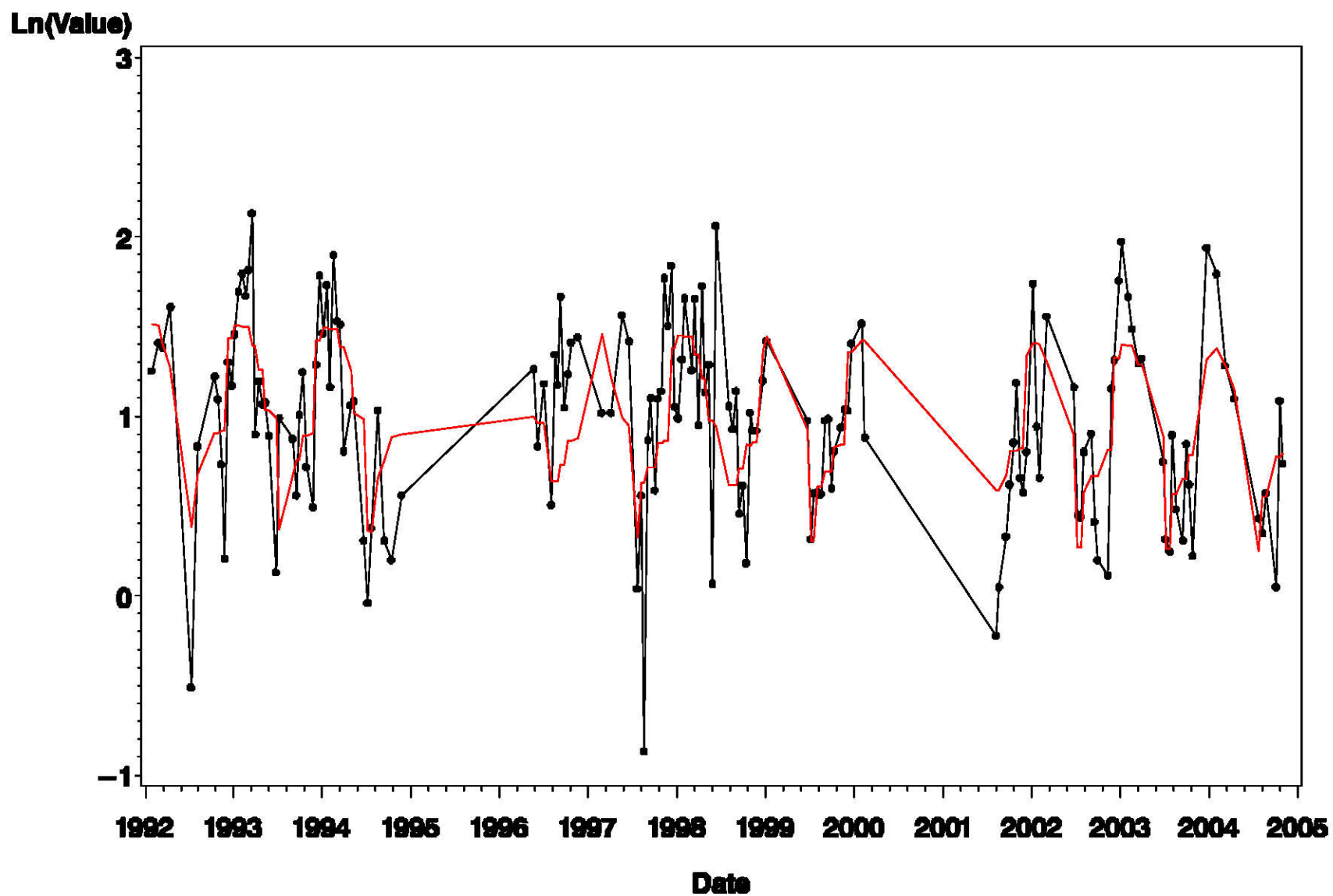


Figure A-2

Actual Data and Fitted Fixed Effects Model
Label = KREA 06A DO

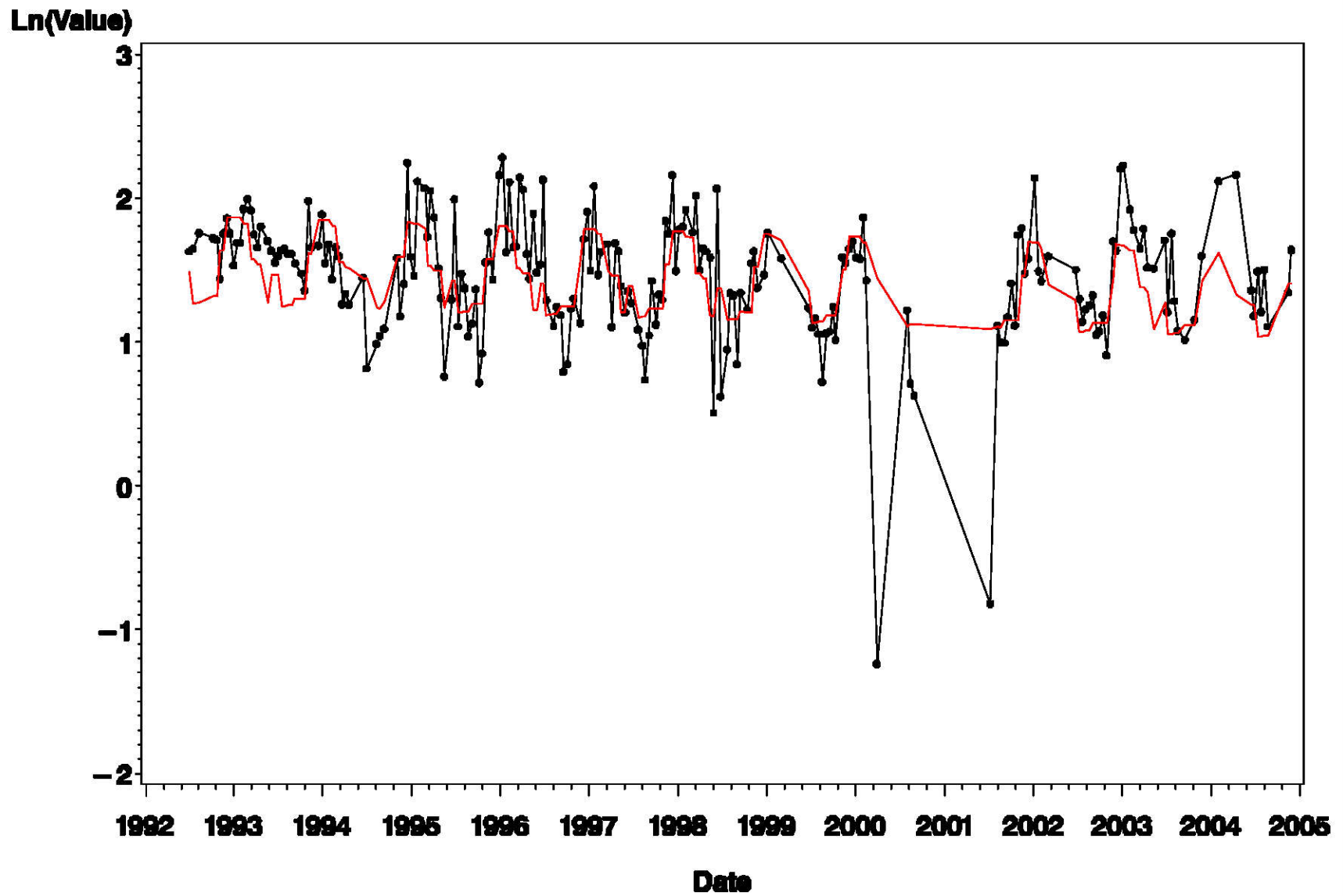


Figure A-3

Actual Data and Fitted Fixed Effects Model
Label = KREA 14 DO

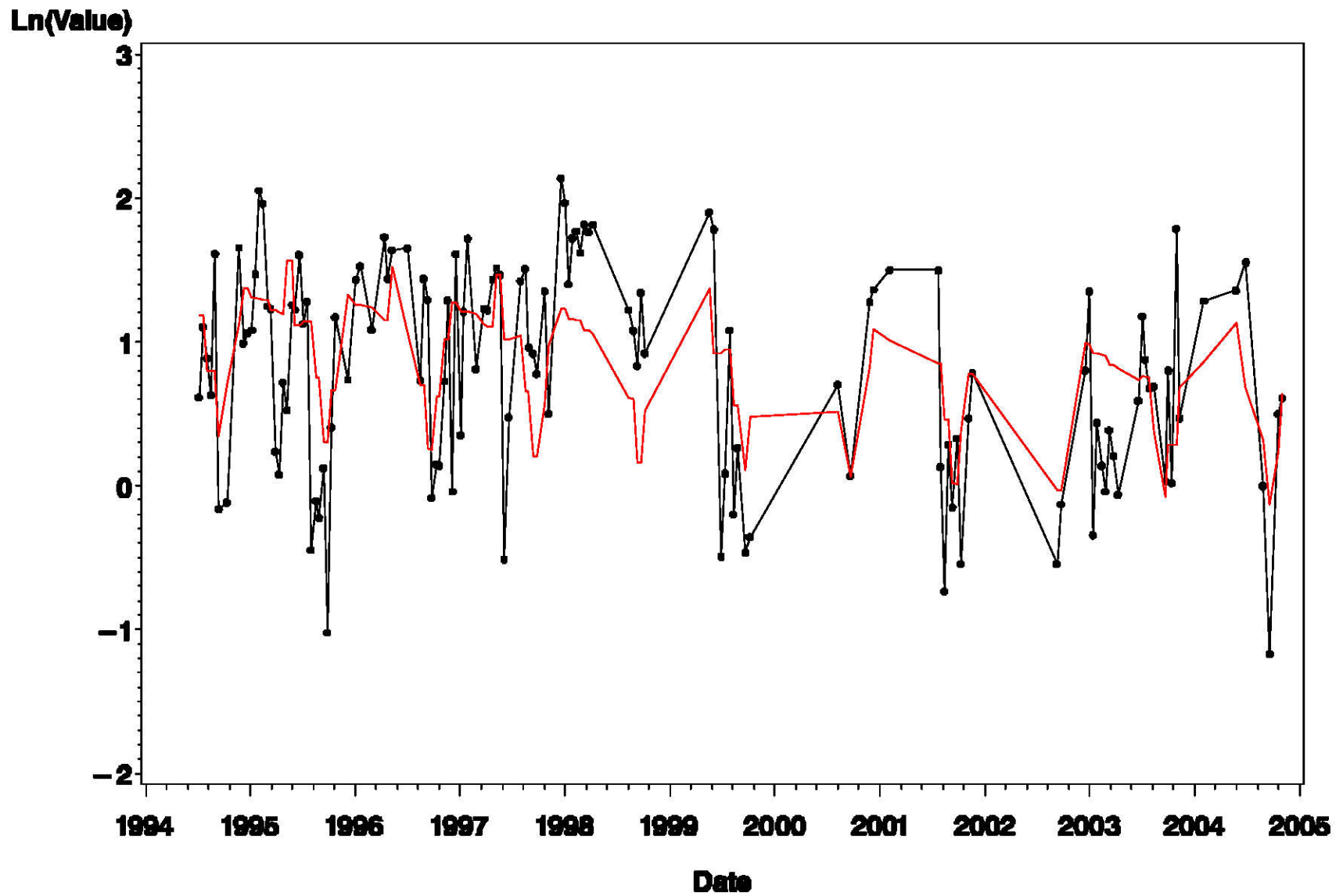


Figure A-4

Actual Data and Fitted Fixed Effects Model
Label=KREA 17A DO

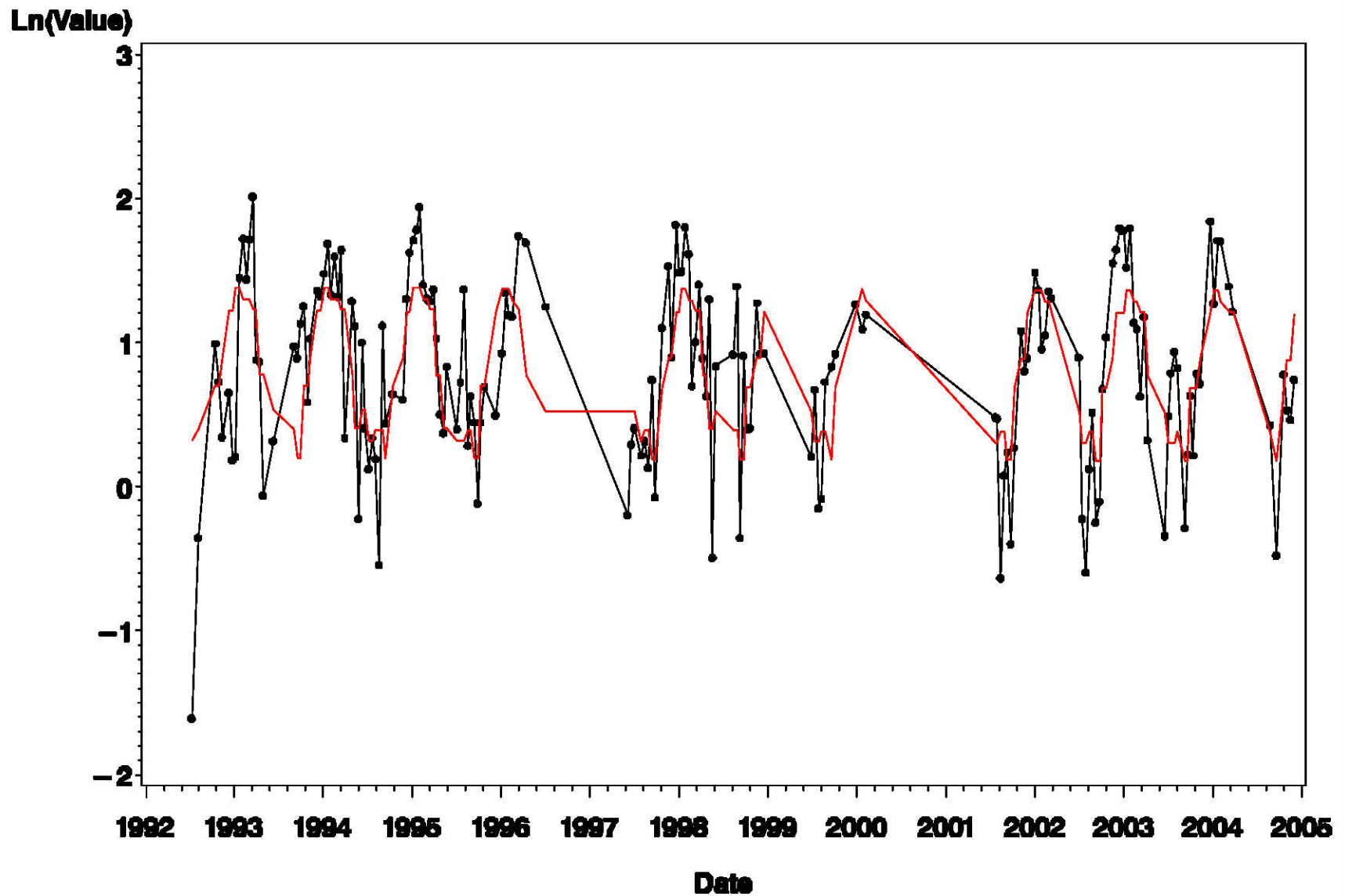


Figure A-5

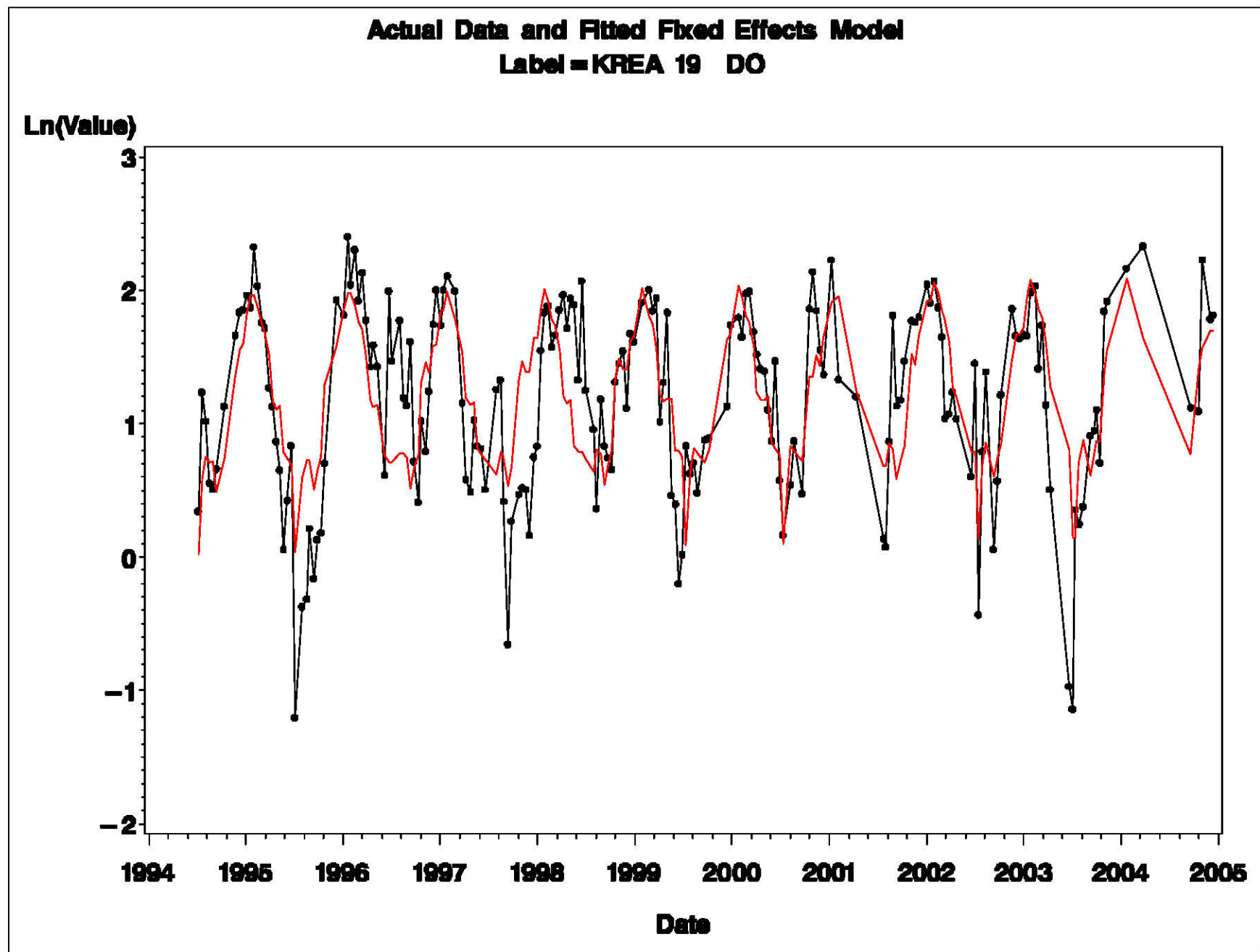


Figure A-6

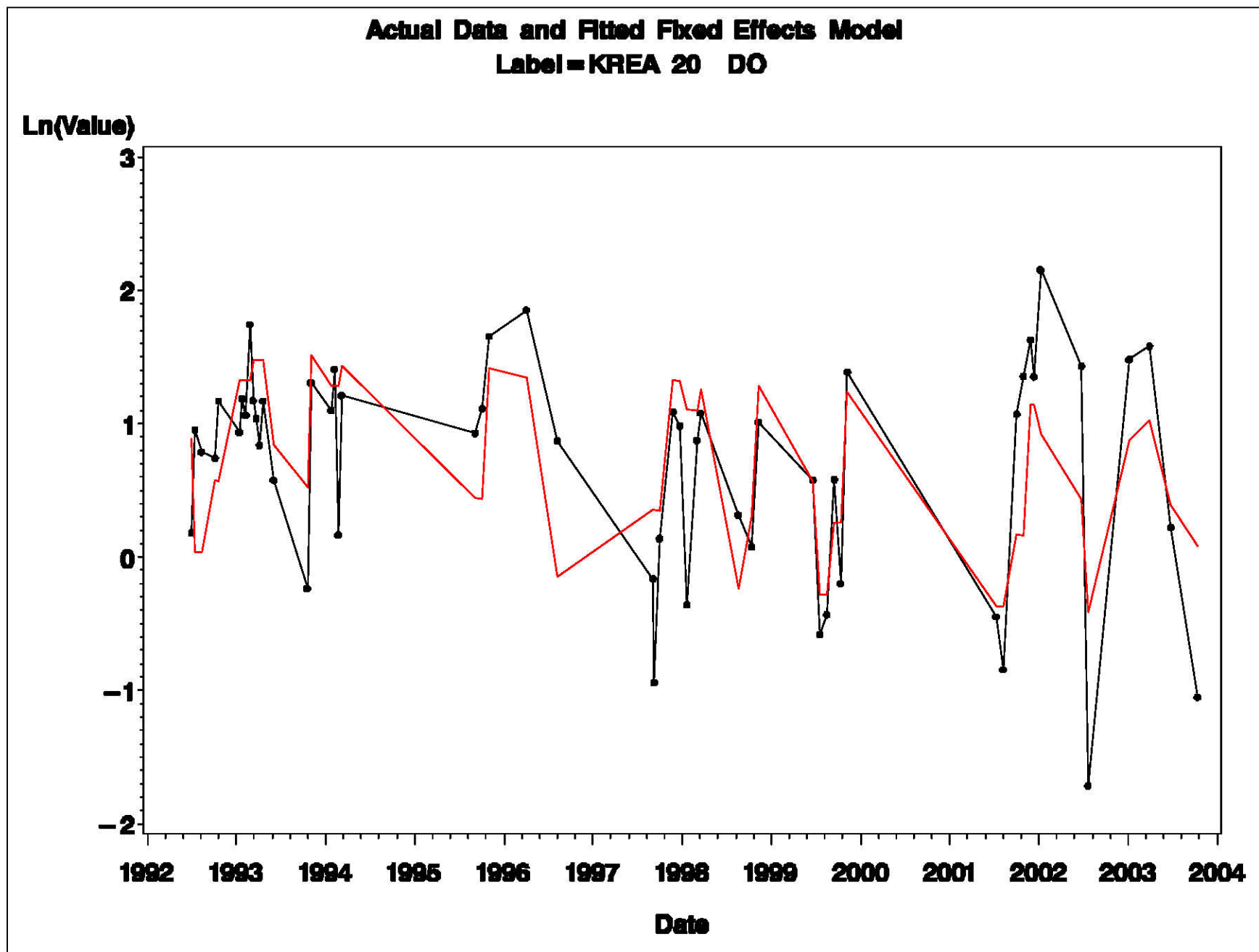


Figure A-7

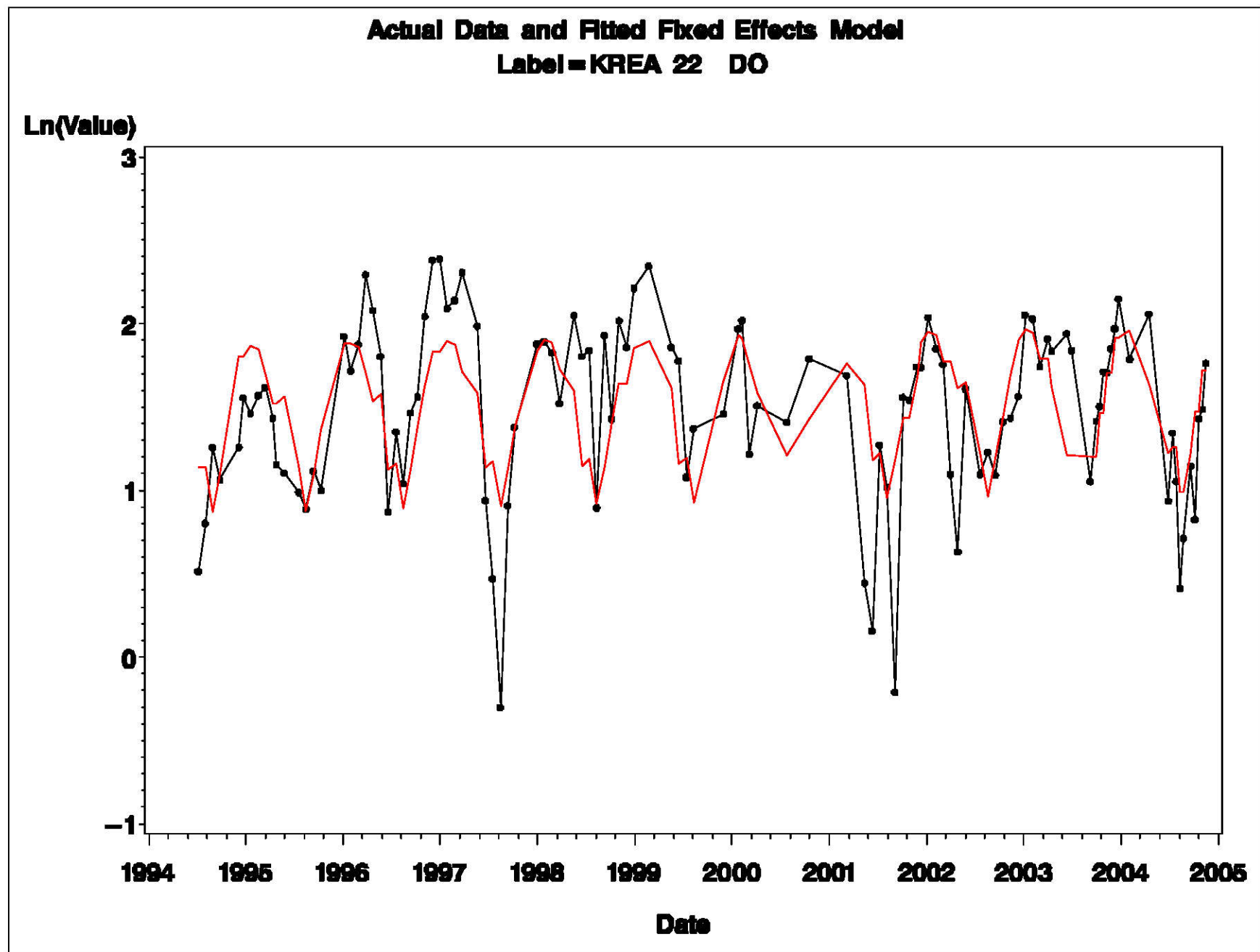


Figure A-8

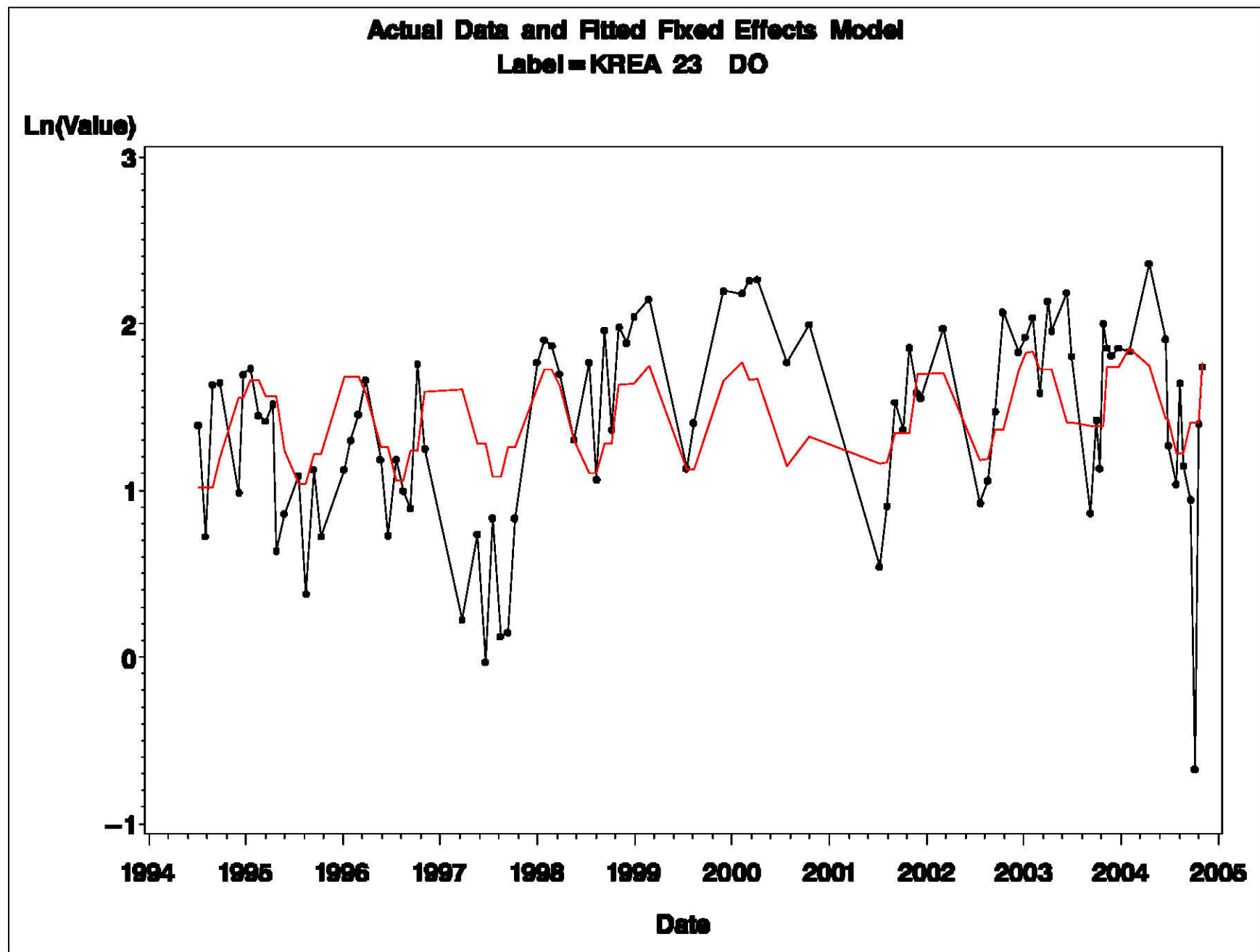


Figure A-9

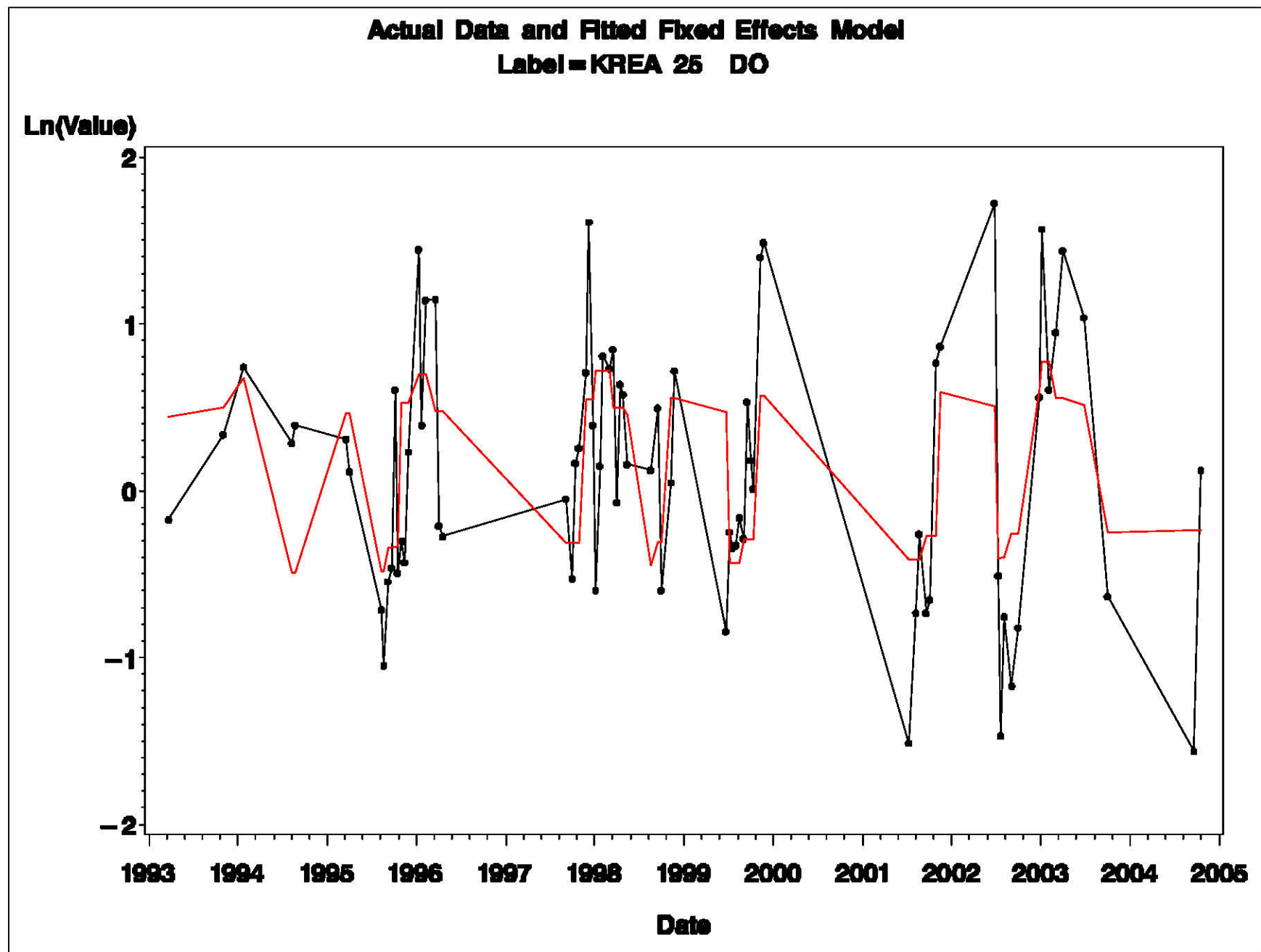


Figure A-10

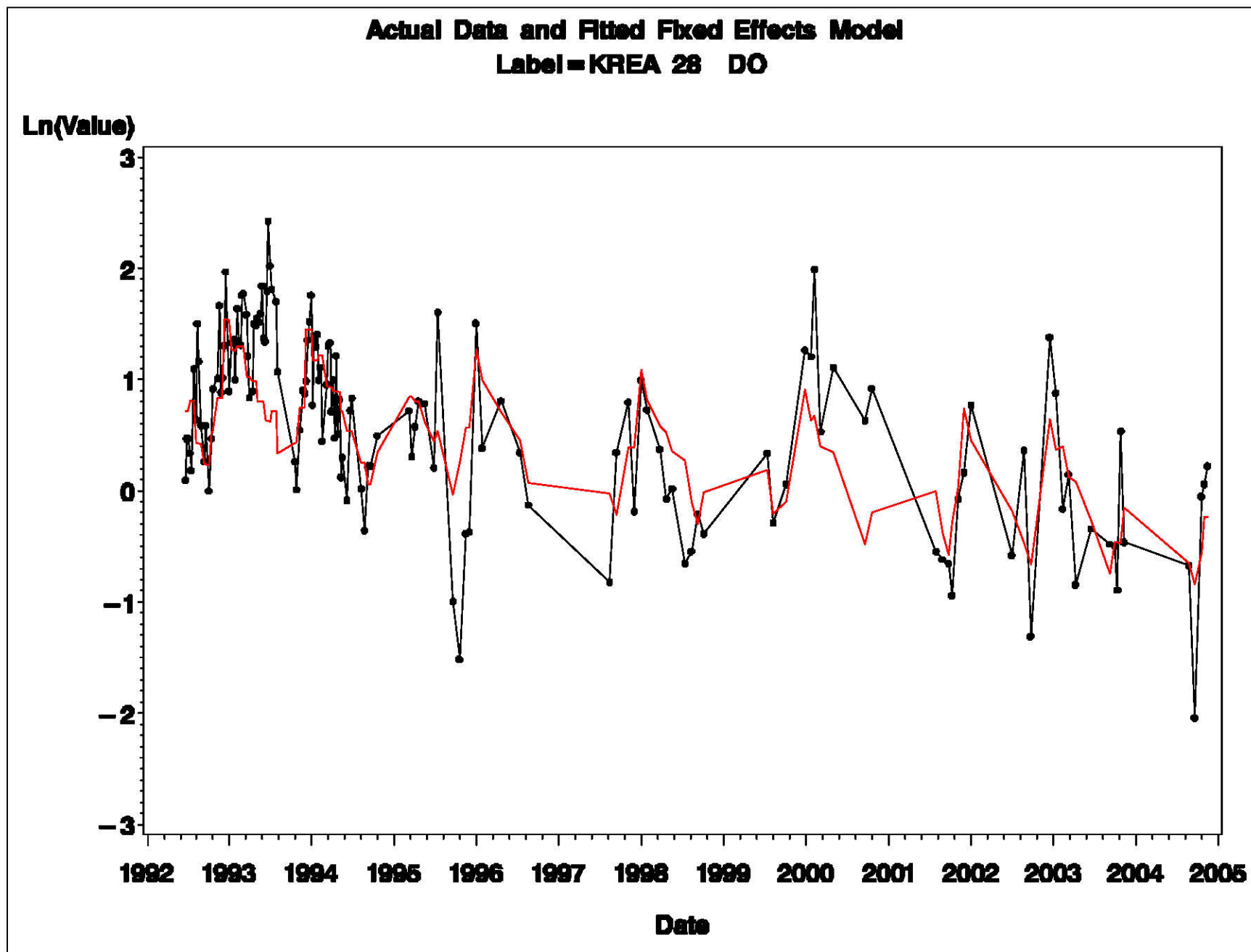


Figure A-11

Actual Data and Fitted Fixed Effects Model
Label = KREA 30A DO

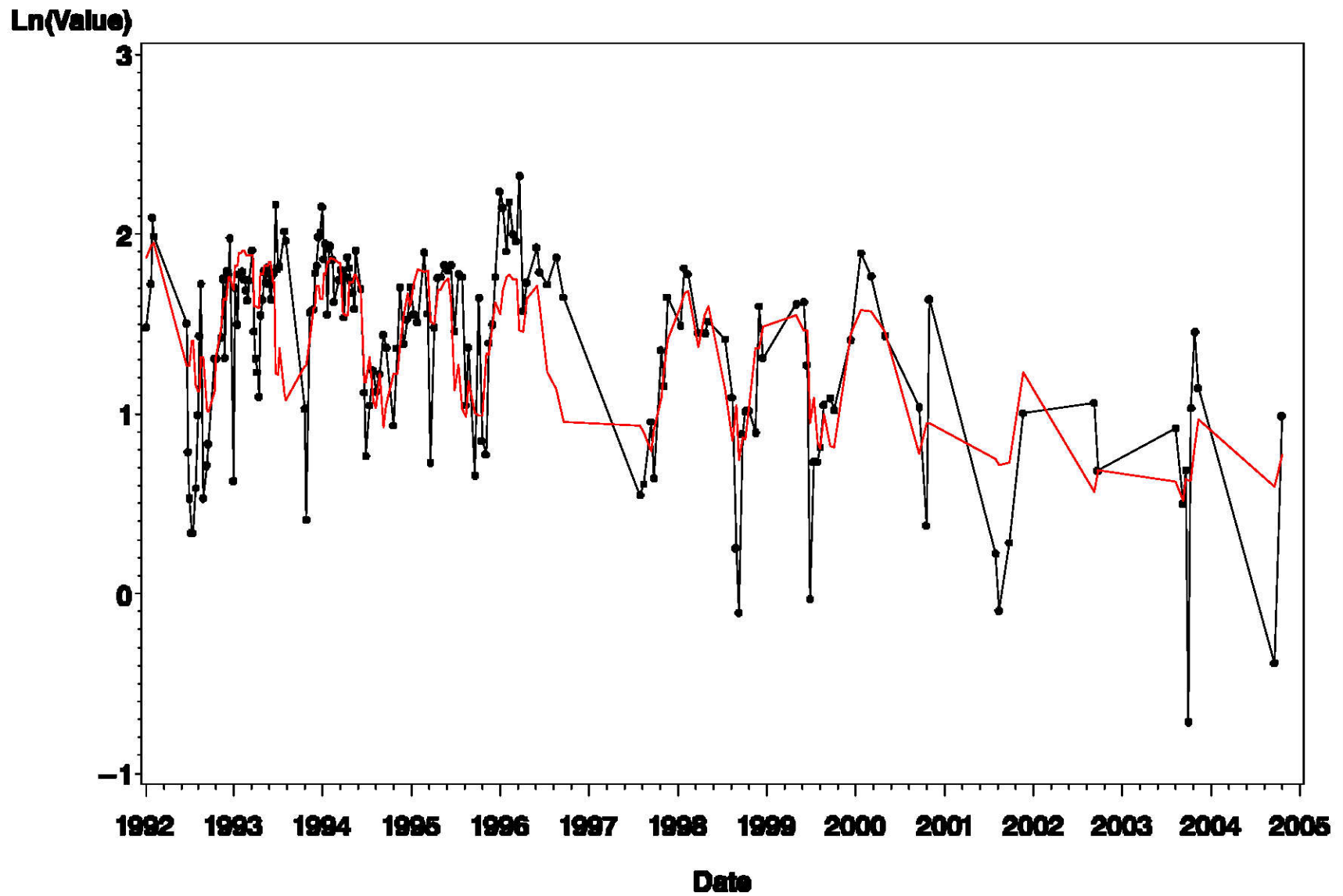


Figure A-12

Actual Data and Fitted Fixed Effects Model
Label=KREA 41A DO

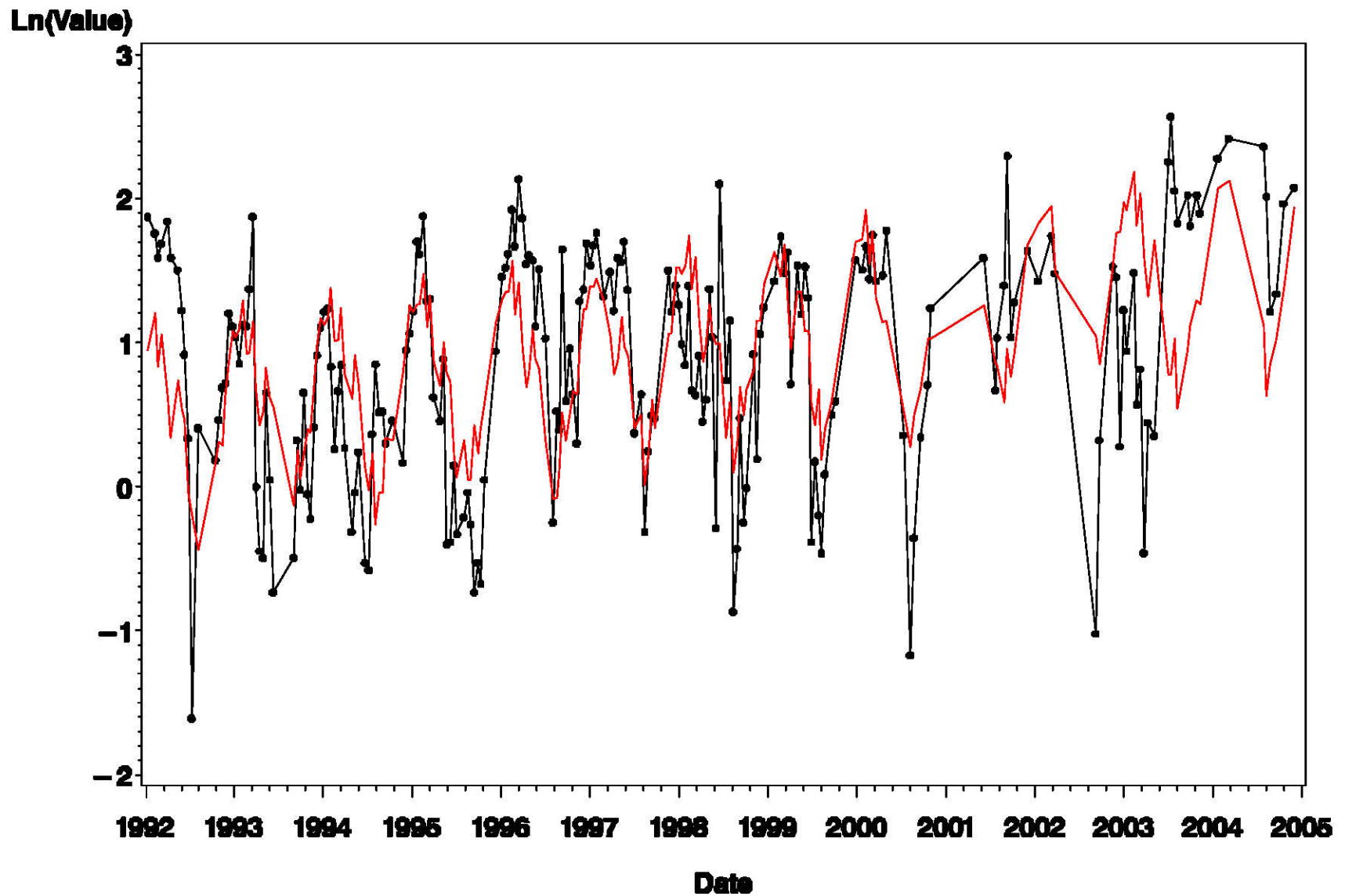


Figure A-13

Actual Data and Fitted Fixed Effects Model
Label=KREA 01 TKN

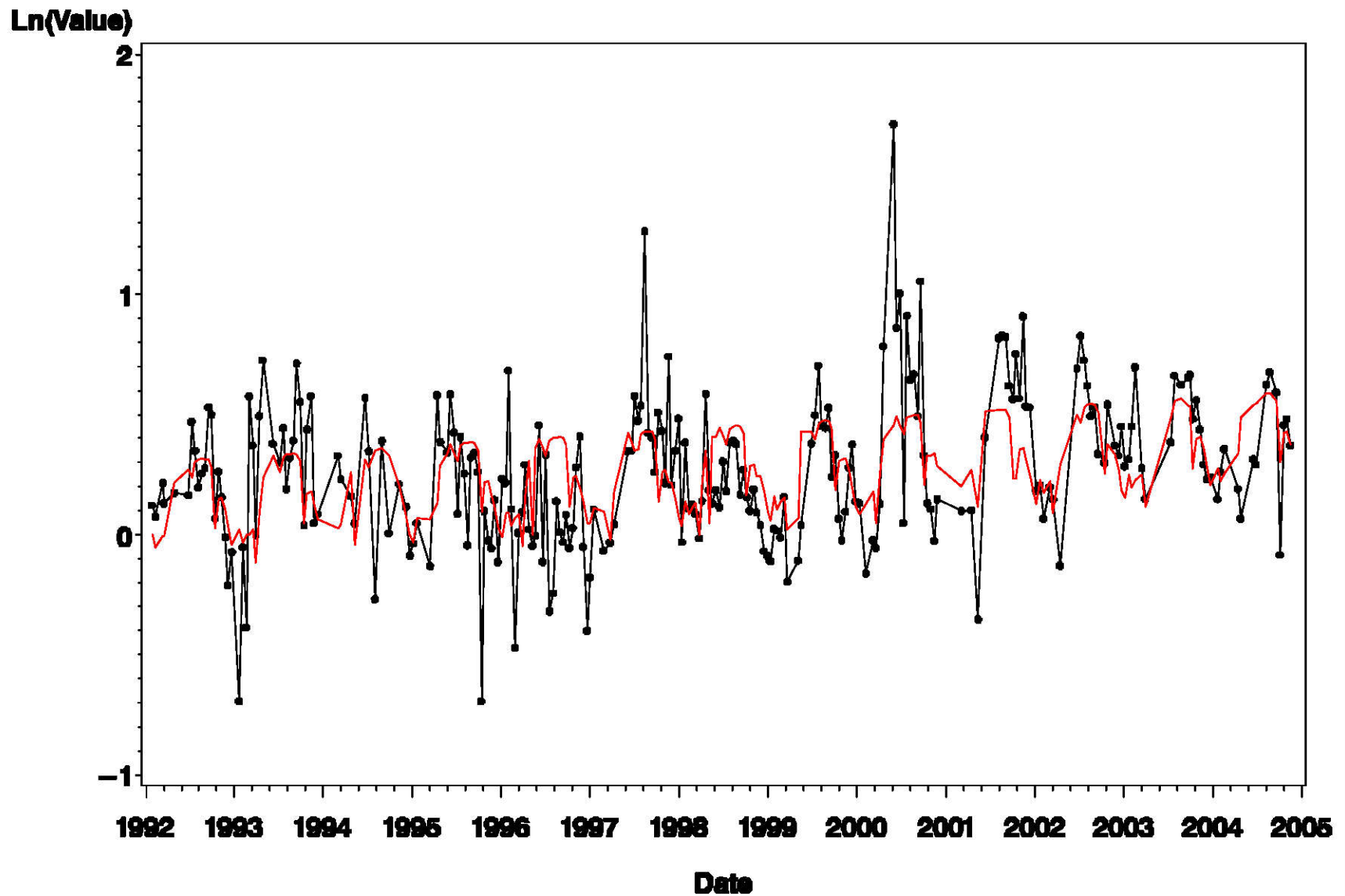


Figure A-14

Actual Data and Fitted Fixed Effects Model
Label=KREA 04 TKN

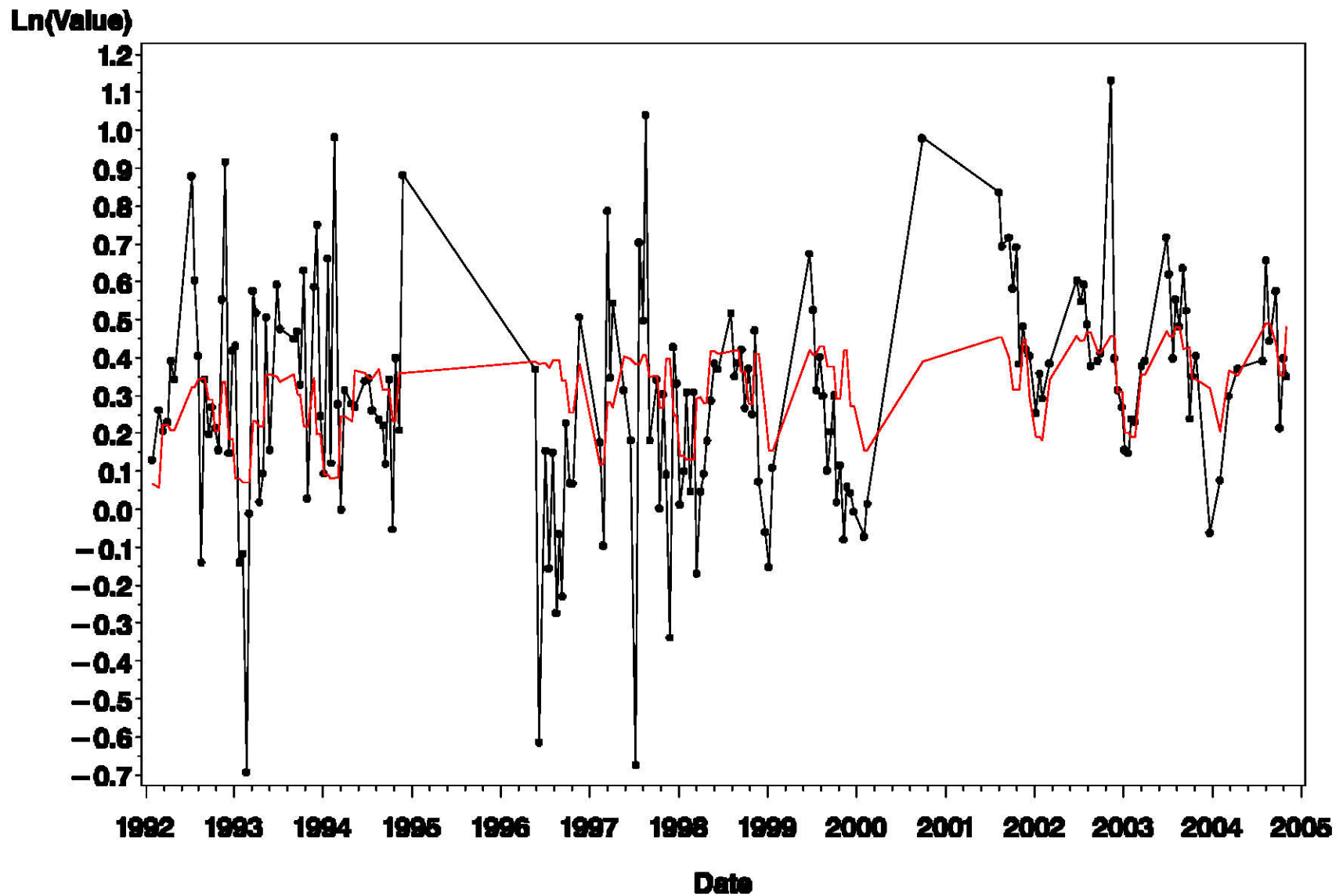


Figure A-15

Actual Data and Fitted Fixed Effects Model
Label = KREA 06A TKN

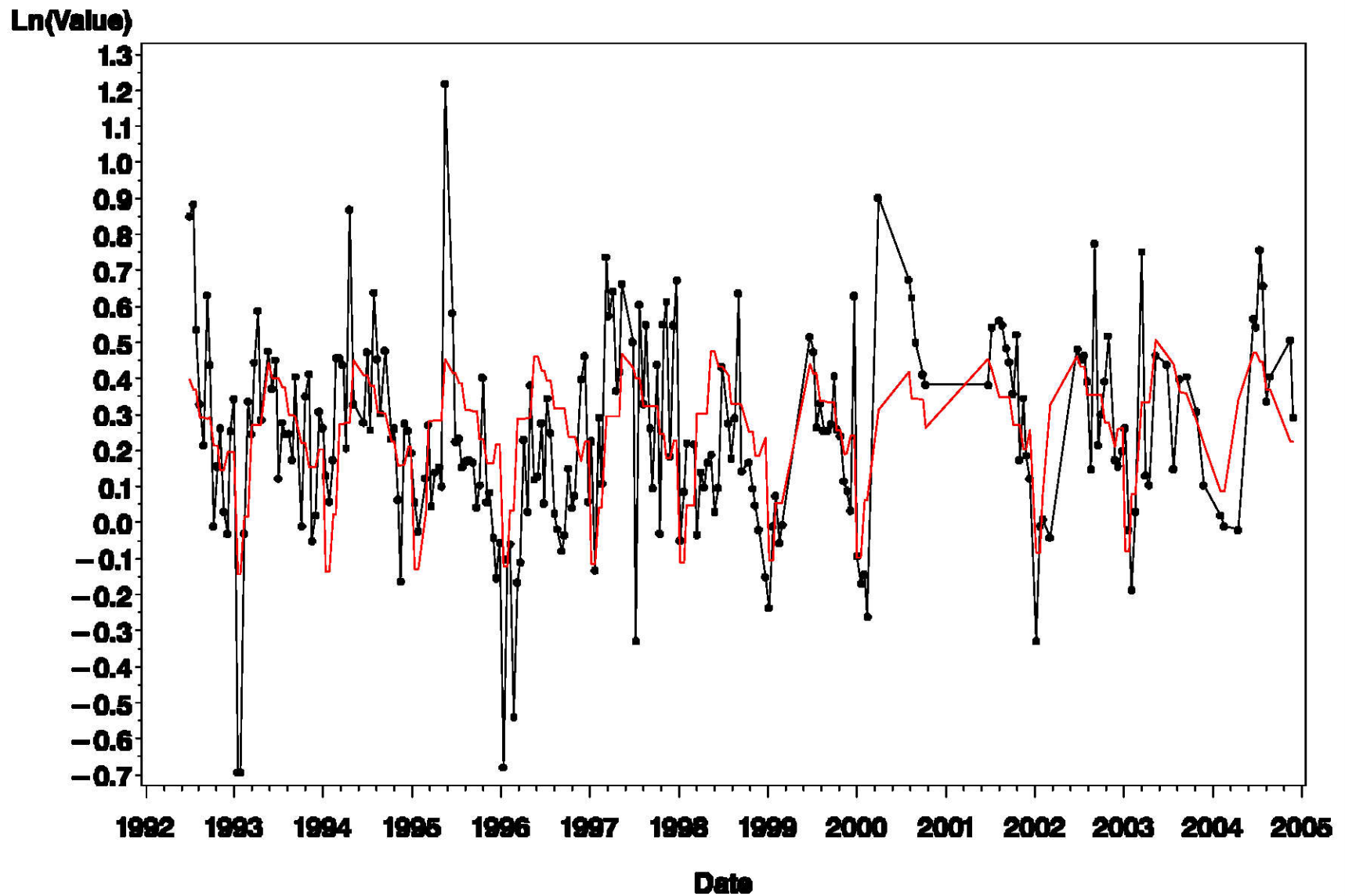


Figure A-16

Actual Data and Fitted Fixed Effects Model
Label=KREA 14 TKN

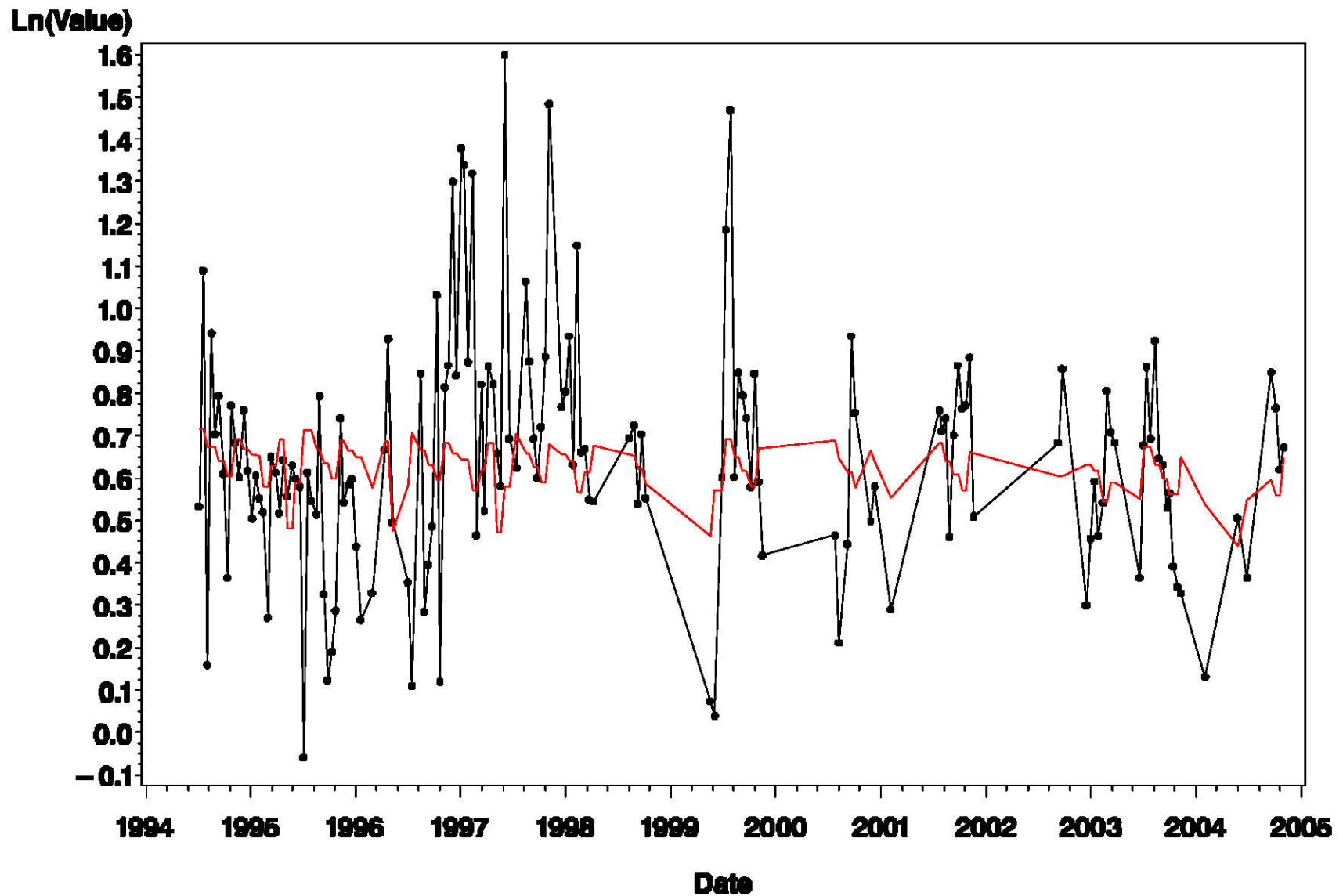


Figure A-17

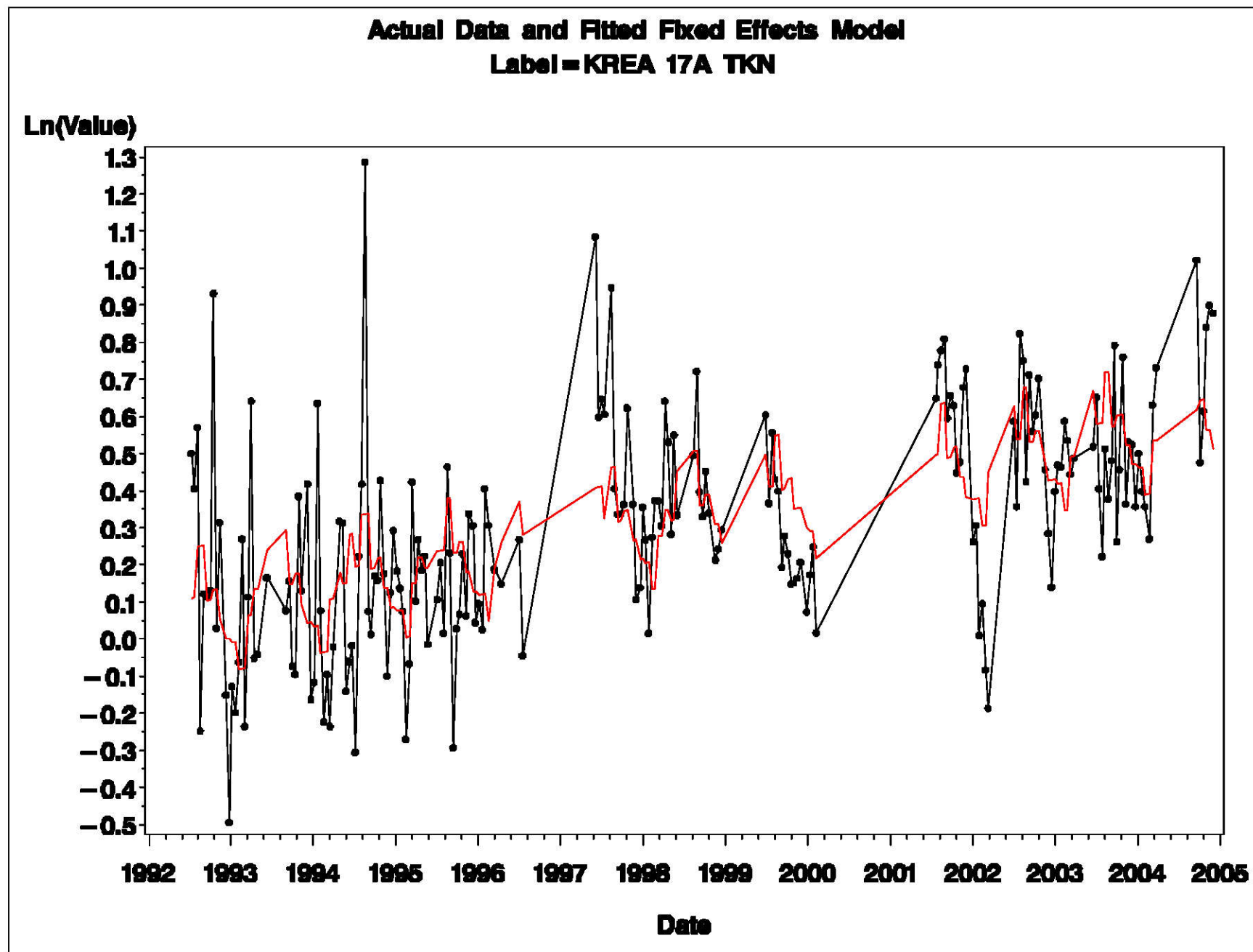


Figure A-18

Actual Data and Fitted Fixed Effects Model
Label=KREA 19 TKN

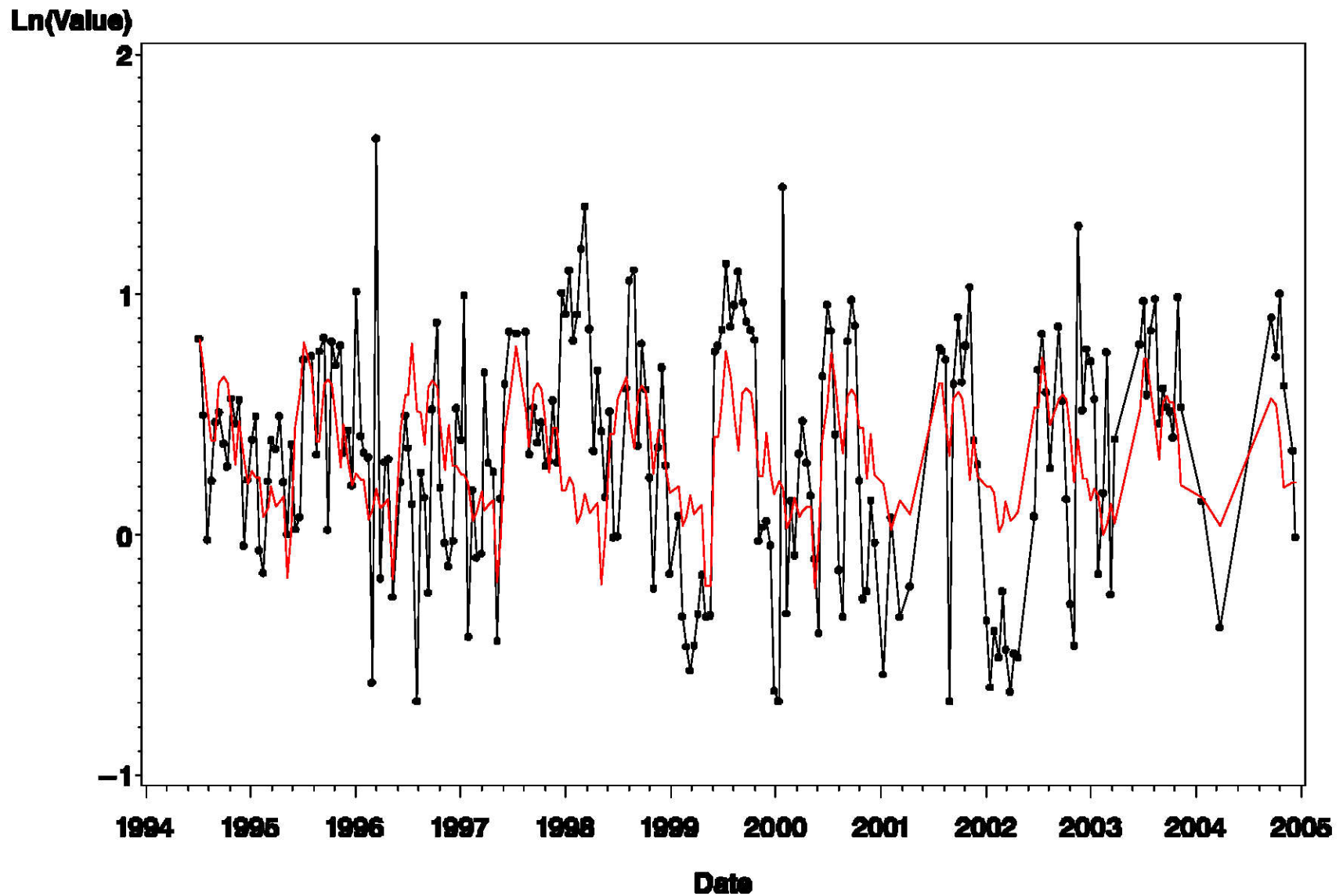


Figure A-19

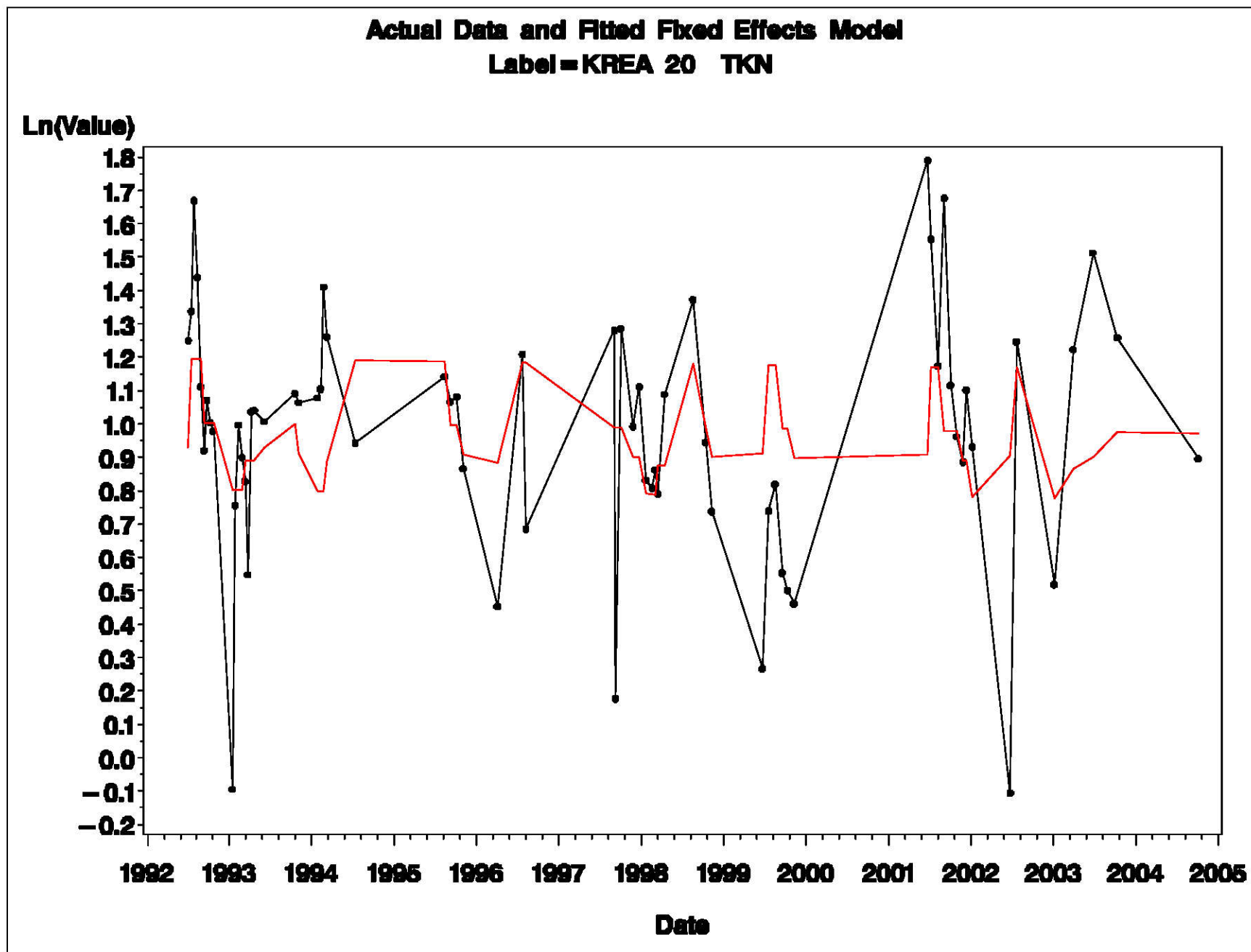


Figure A-20

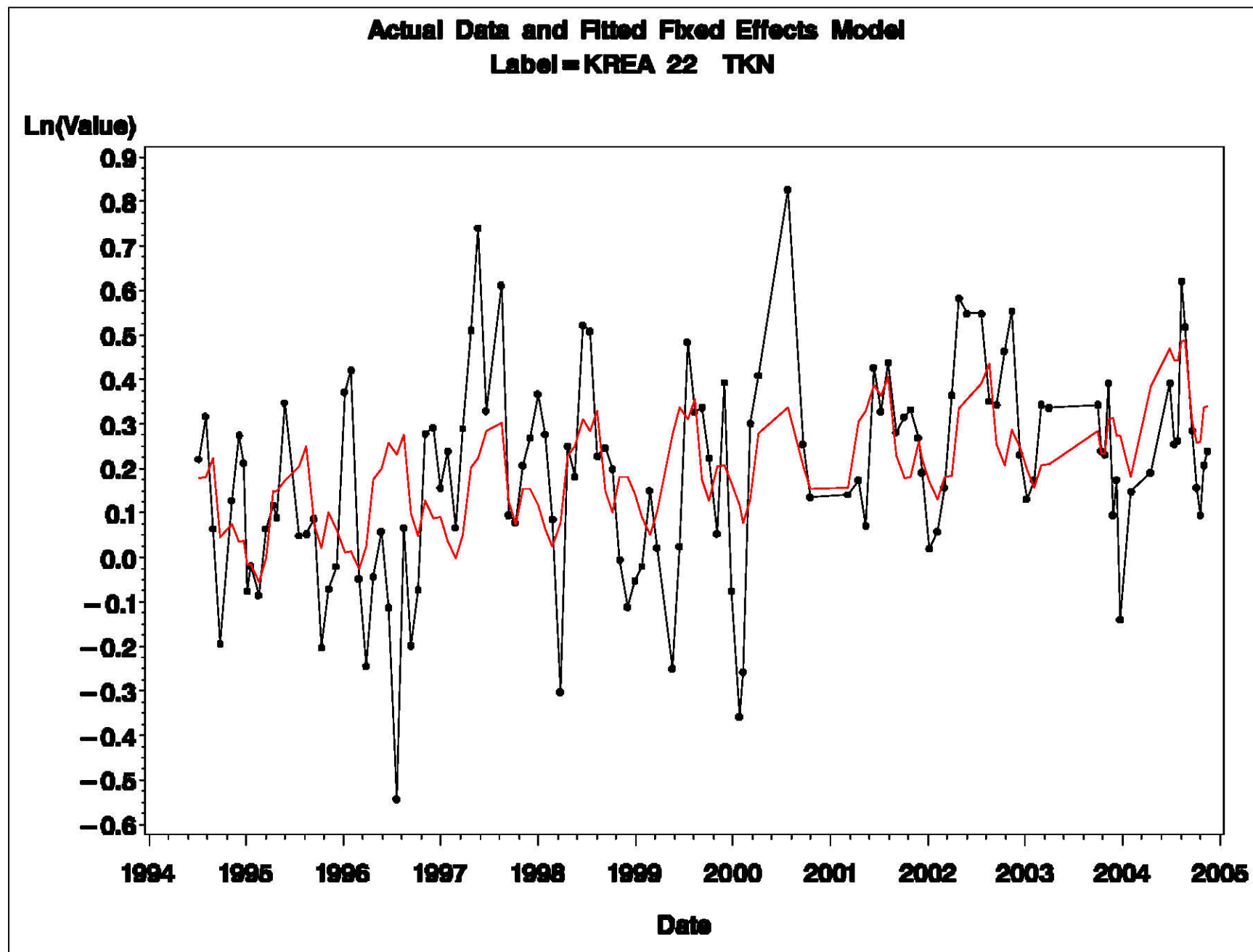


Figure A-21

Actual Data and Fitted Fixed Effects Model
Label=KREA 23 TKN

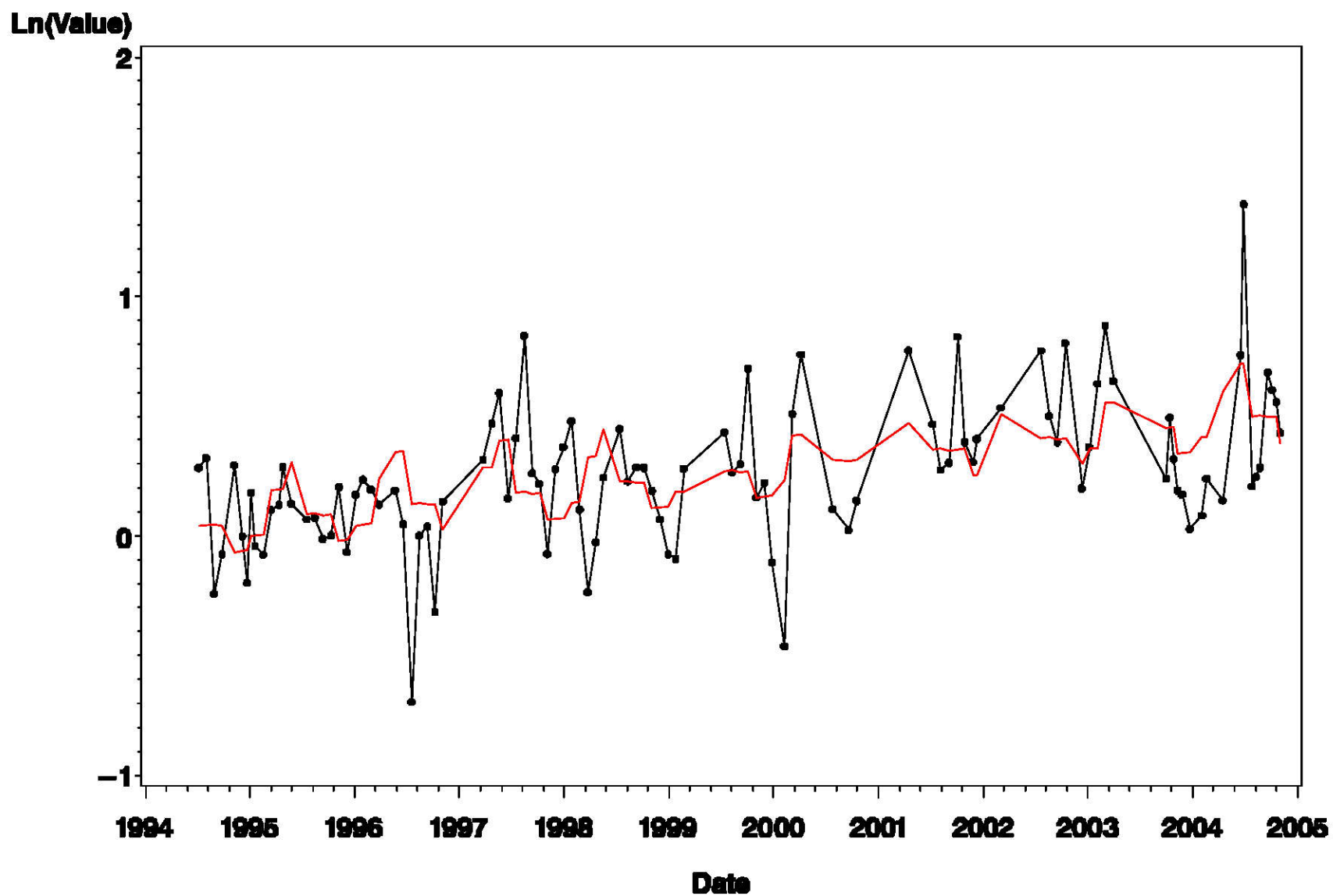


Figure A-22

Actual Data and Fitted Fixed Effects Model
Label=KREA 25 TKN

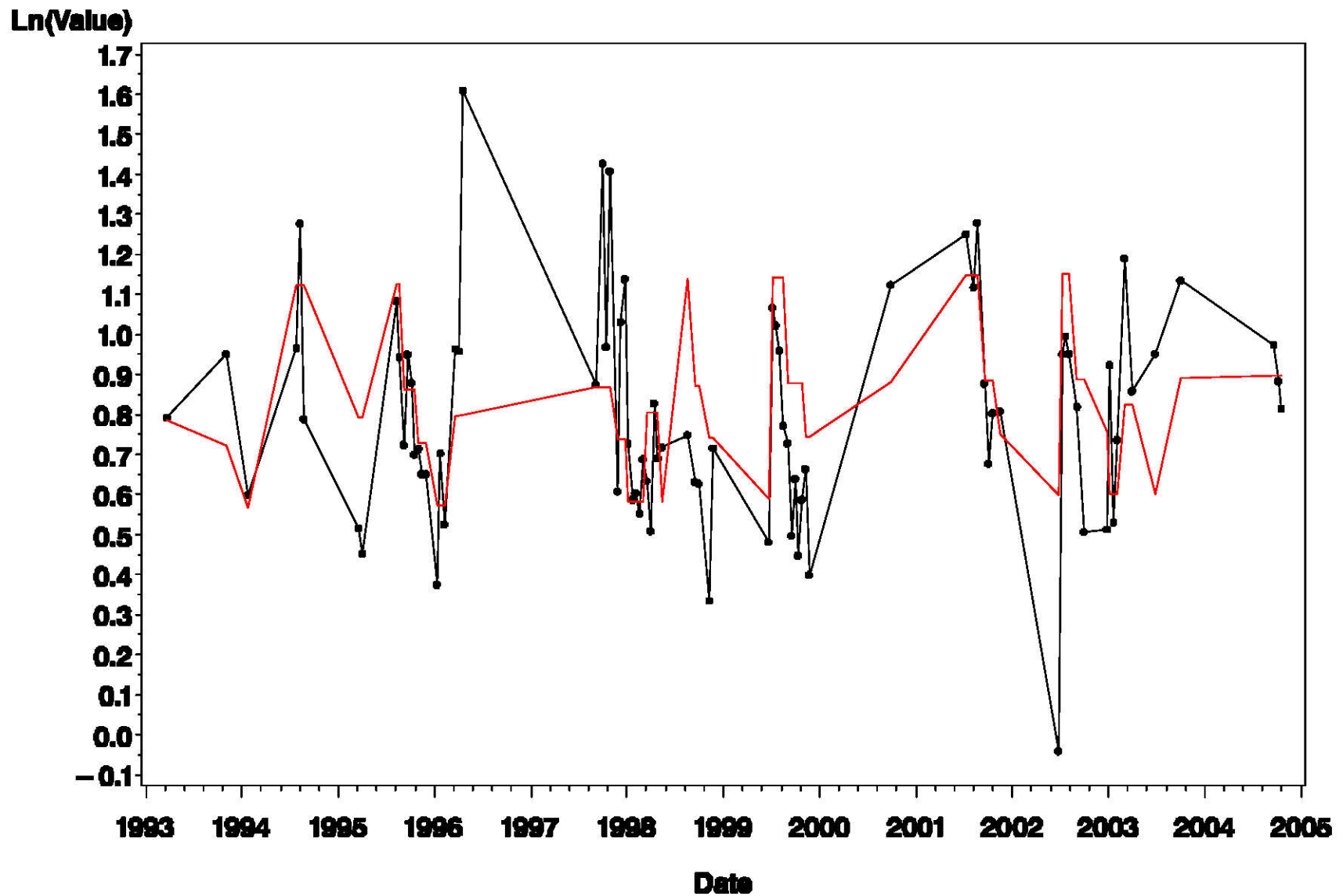


Figure A-23

Actual Data and Fitted Fixed Effects Model
Label=KREA 28 TKN

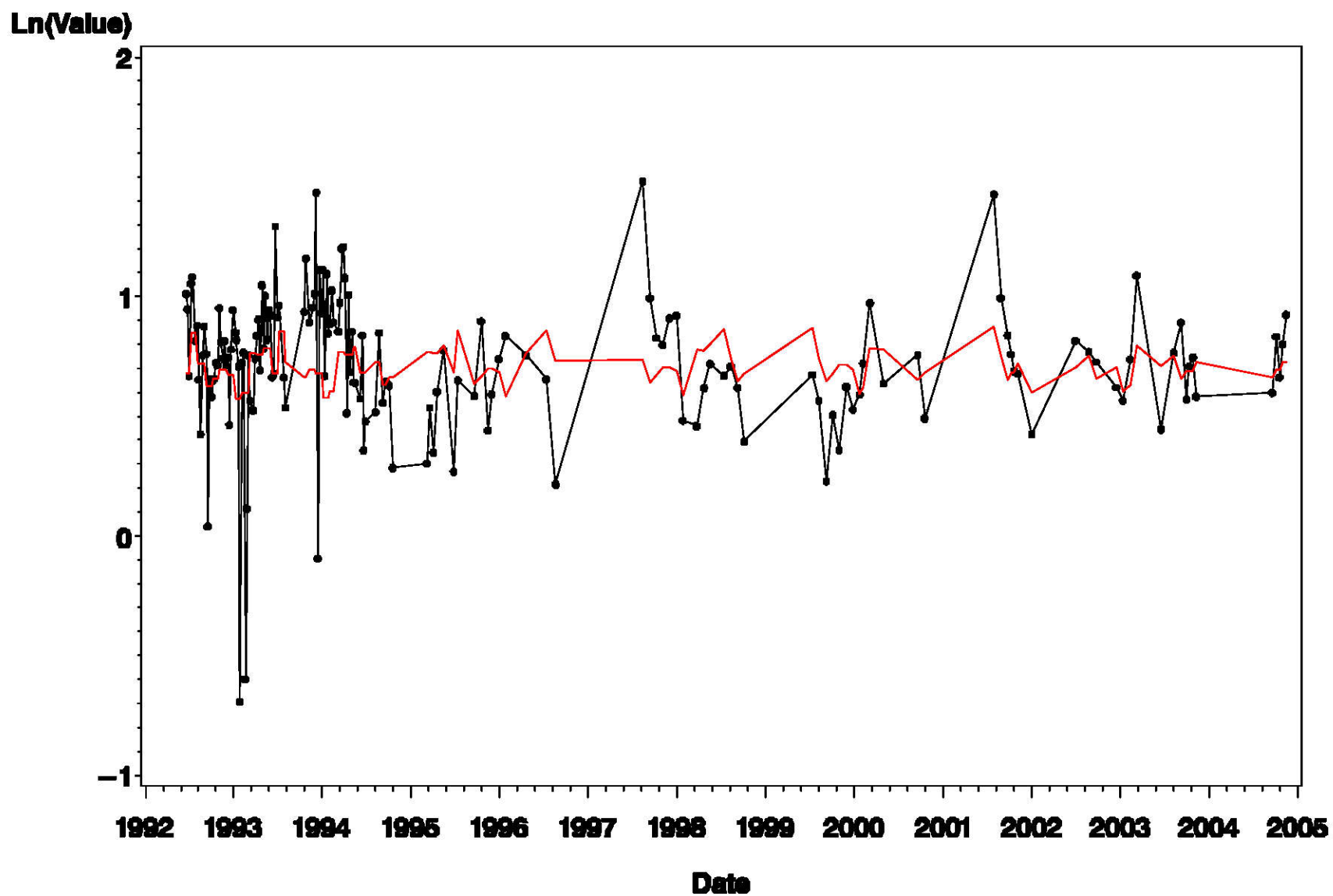


Figure A-24

Actual Data and Fitted Fixed Effects Model
Label = KREA 30A TKN

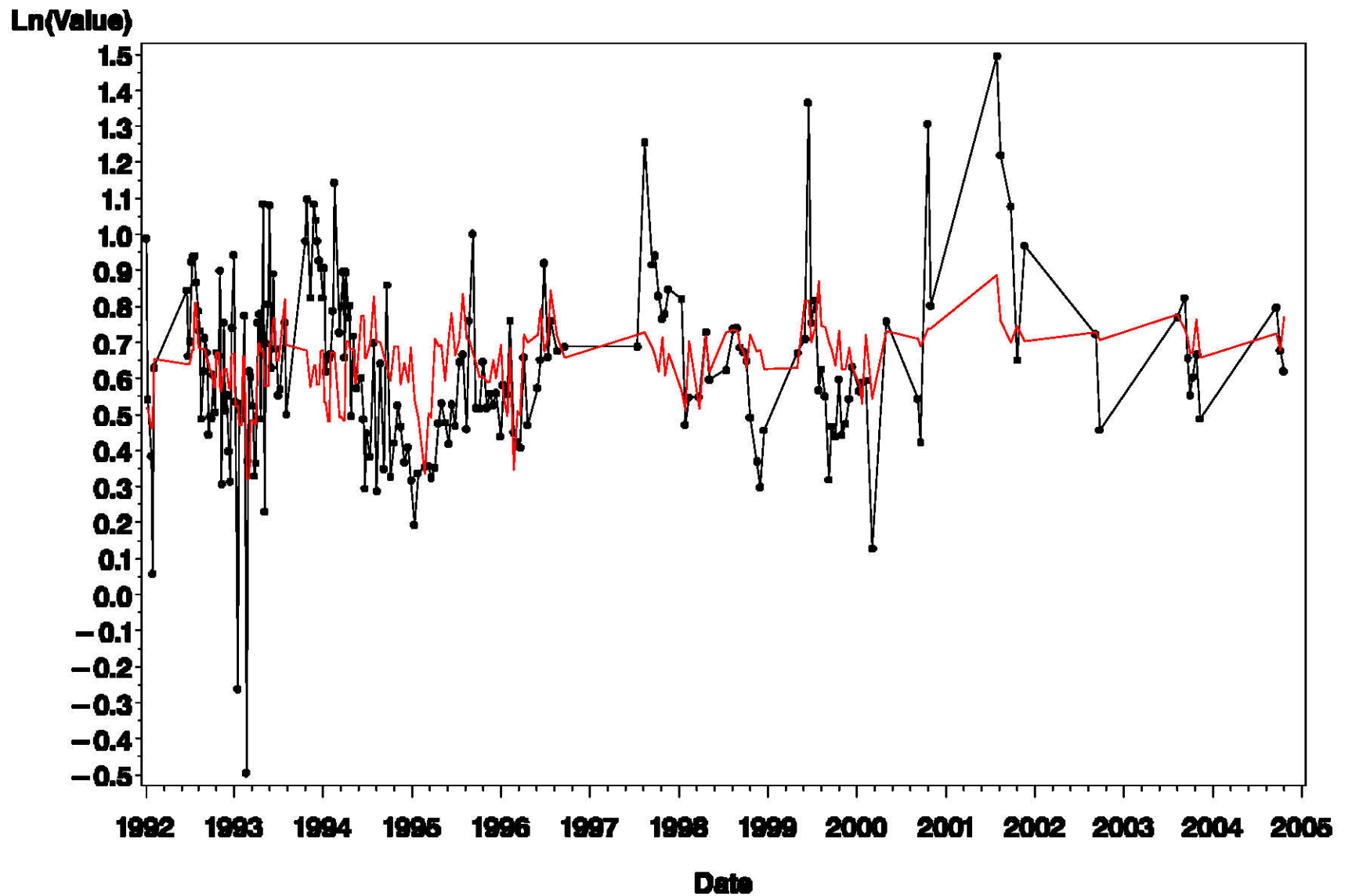


Figure A-25

Actual Data and Fitted Fixed Effects Model
Label=KREA 41A TKN

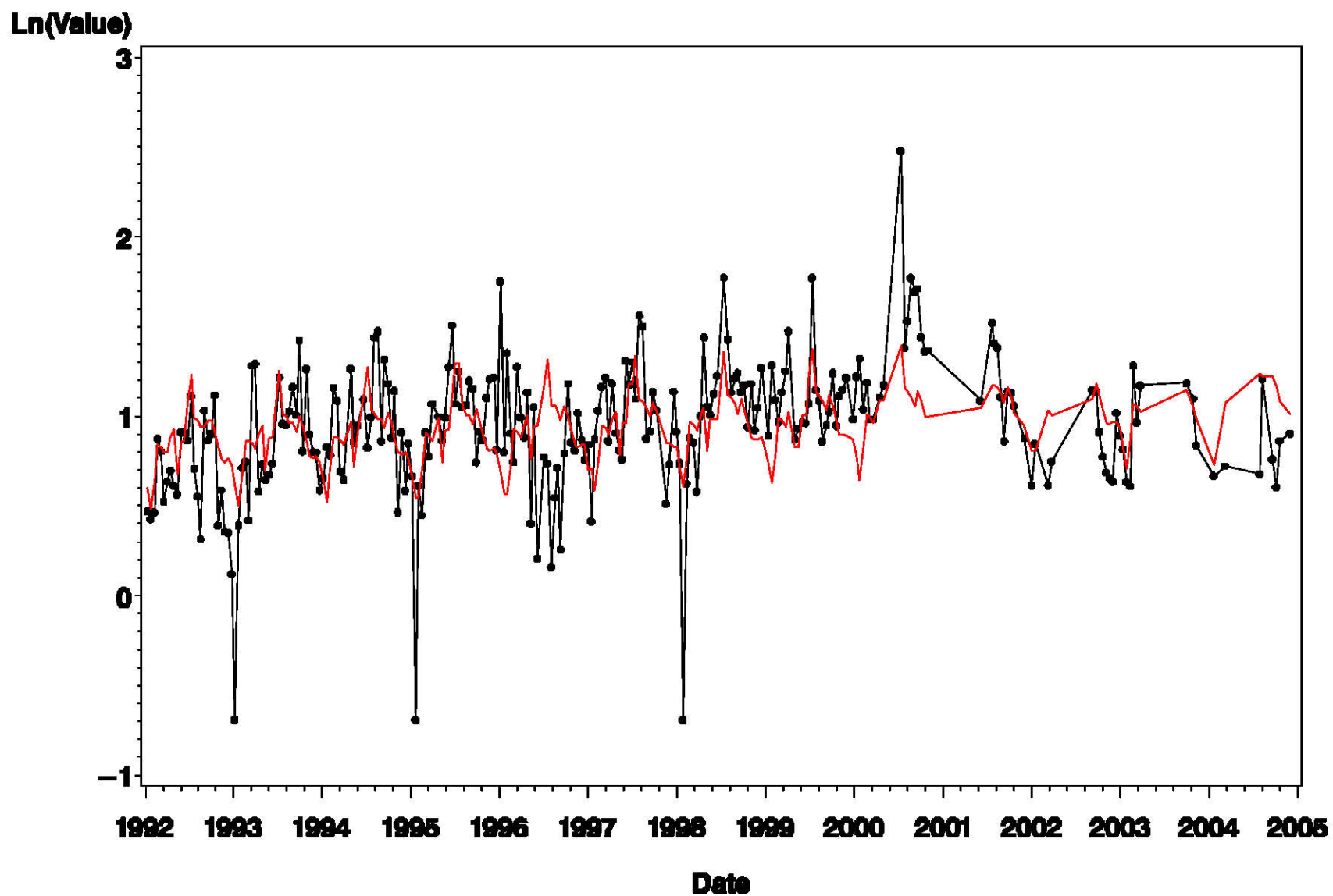


Figure A-26

Actual Data and Fitted Fixed Effects Model
Label=KREA 01 TPO4

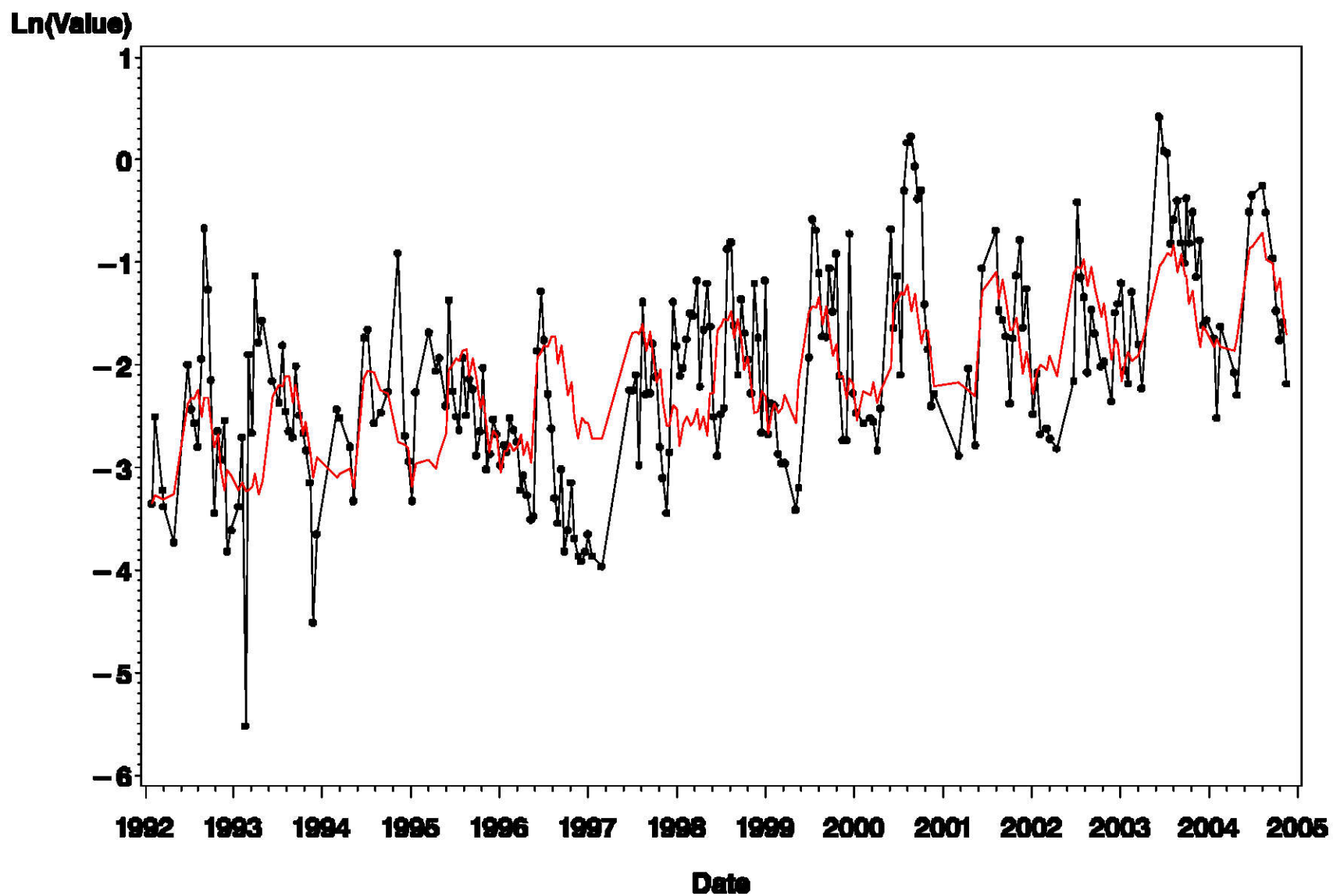


Figure A-27

Actual Data and Fitted Fixed Effects Model
Label = KREA 04 TPO4

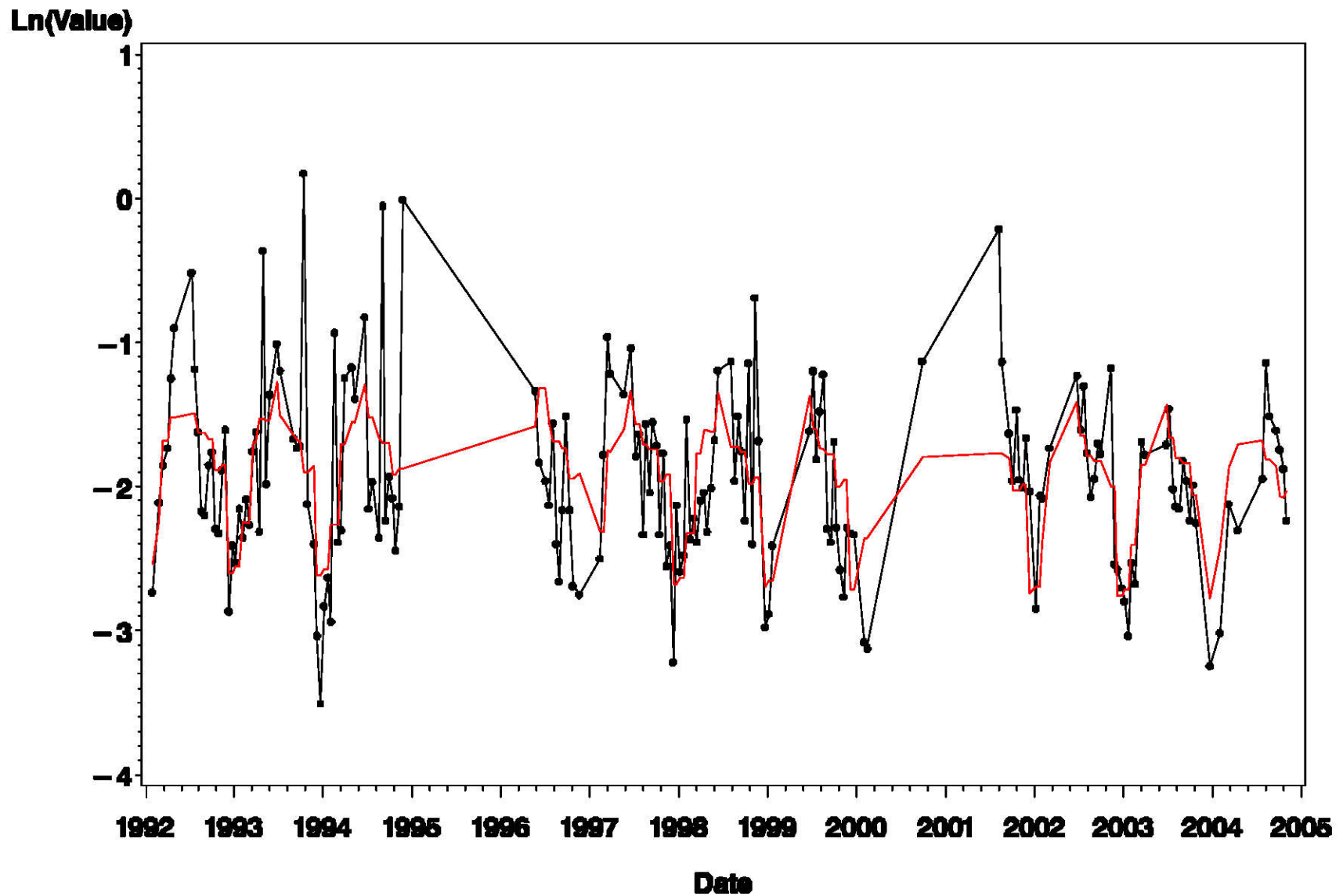


Figure A-28

Actual Data and Fitted Fixed Effects Model
Label=KREA 06A TPO4

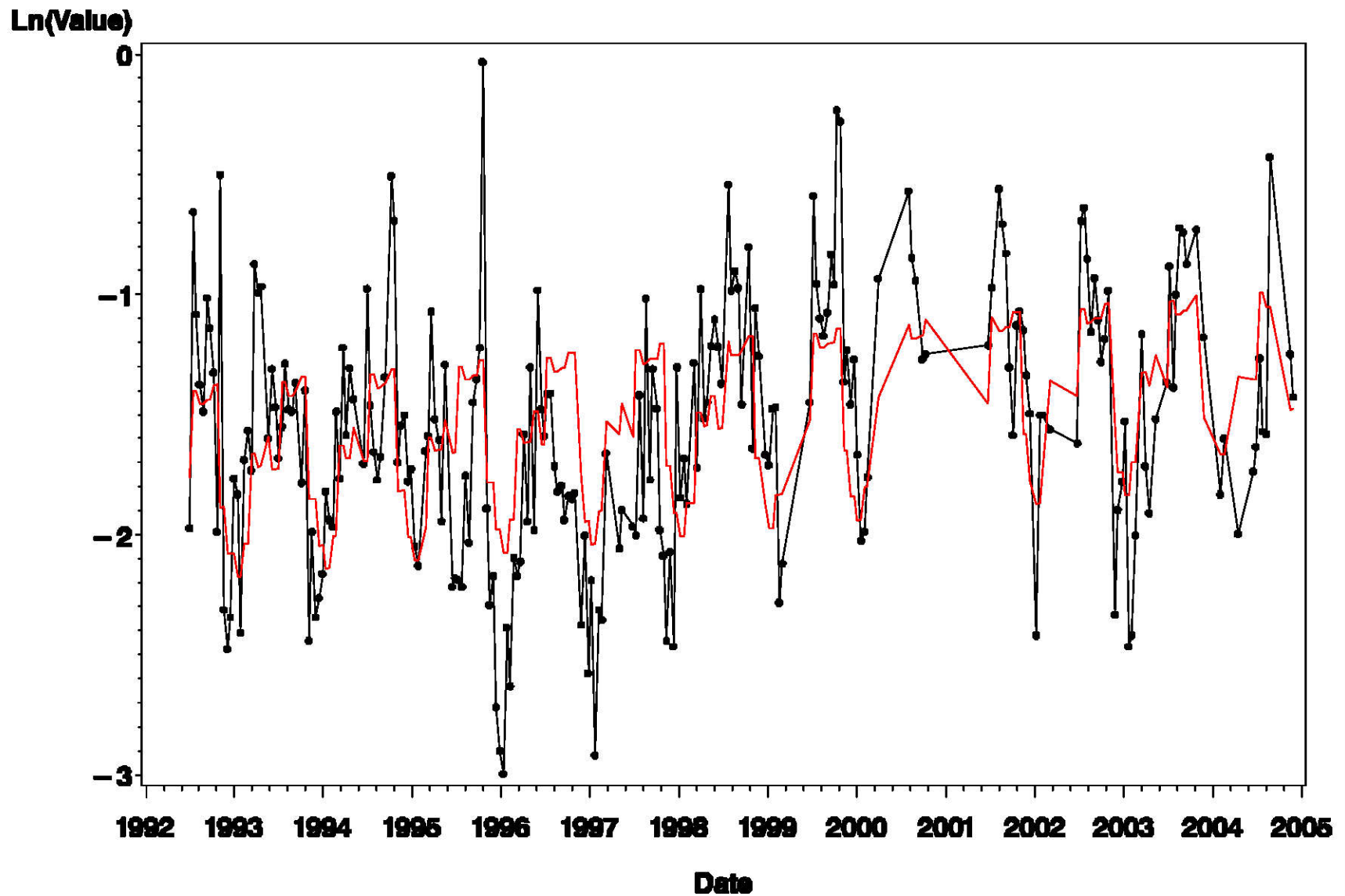


Figure A-29

Actual Data and Fitted Fixed Effects Model
Label=KREA 14 TPO4

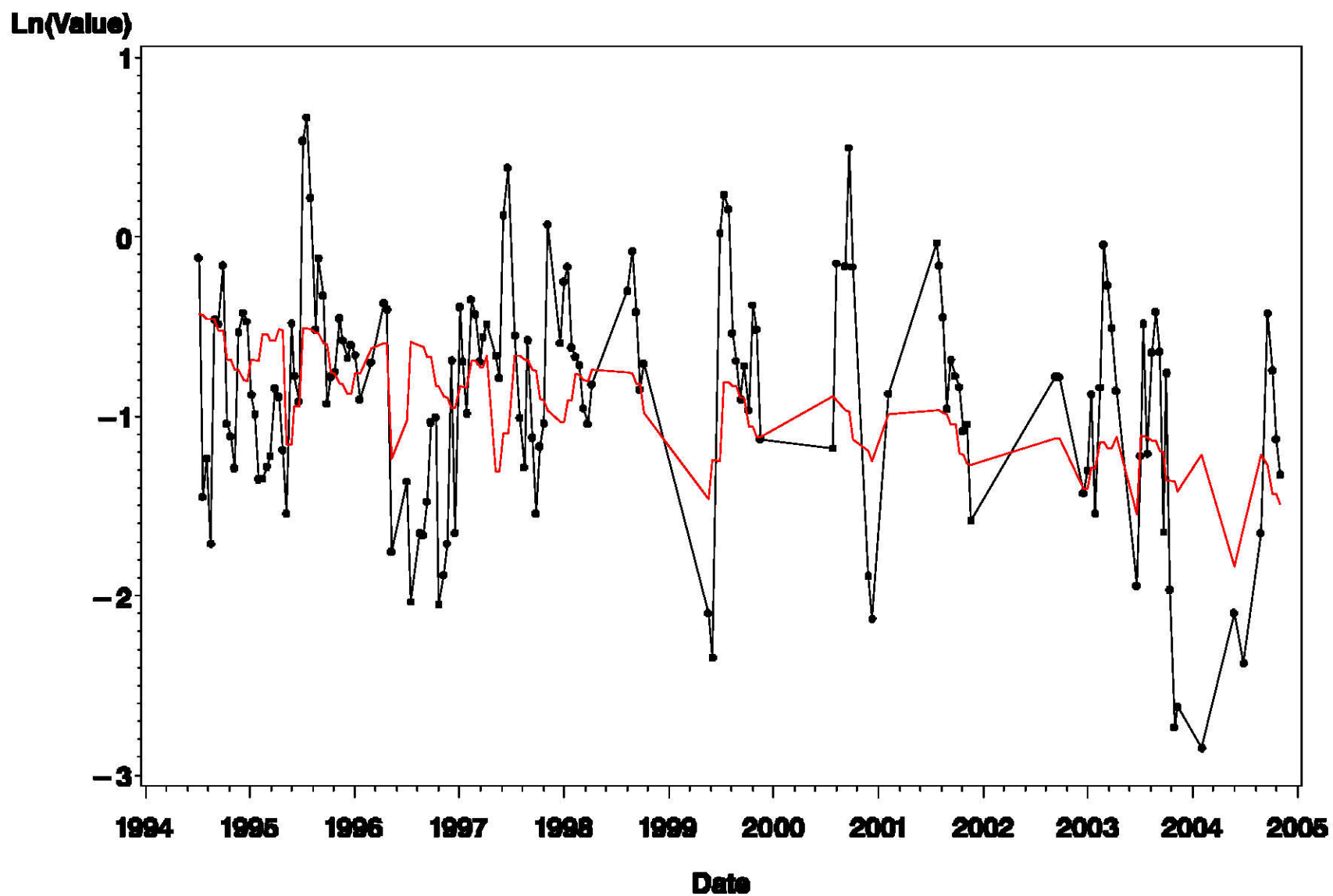


Figure A-30

Actual Data and Fitted Fixed Effects Model
Label=KREA 17A TPO4

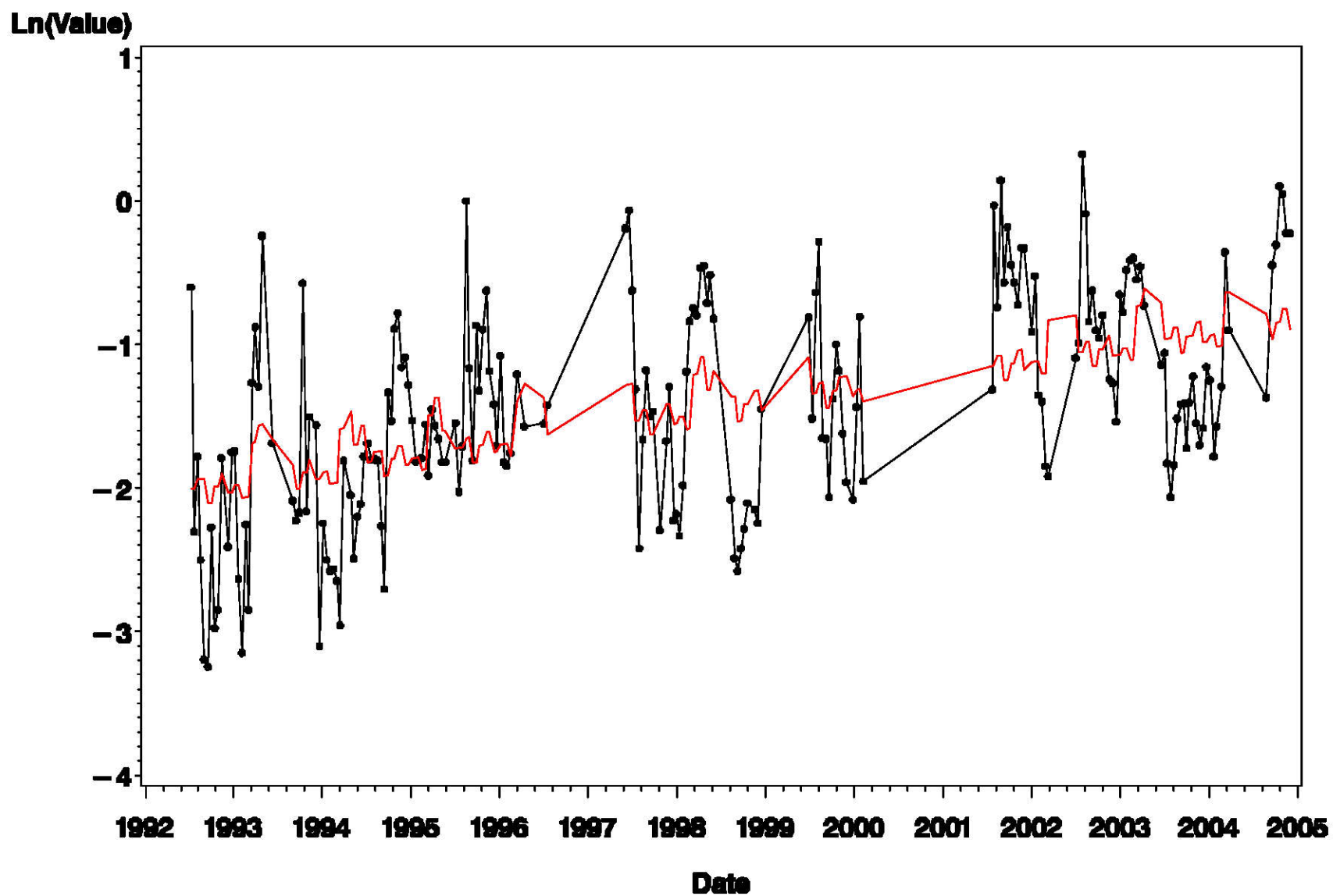


Figure A-31

Actual Data and Fitted Fixed Effects Model
Label=KREA 19 TPO4

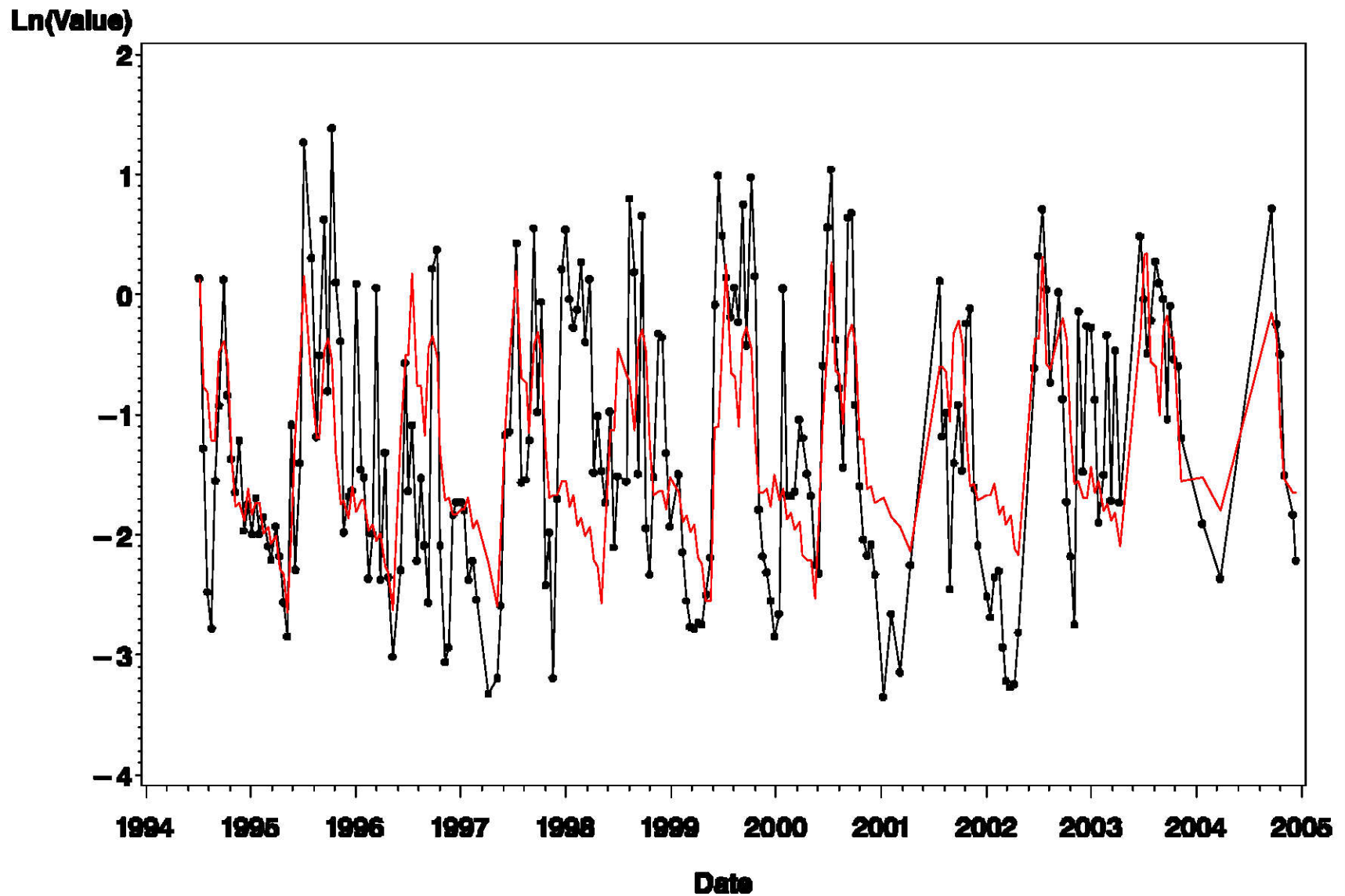


Figure A-32

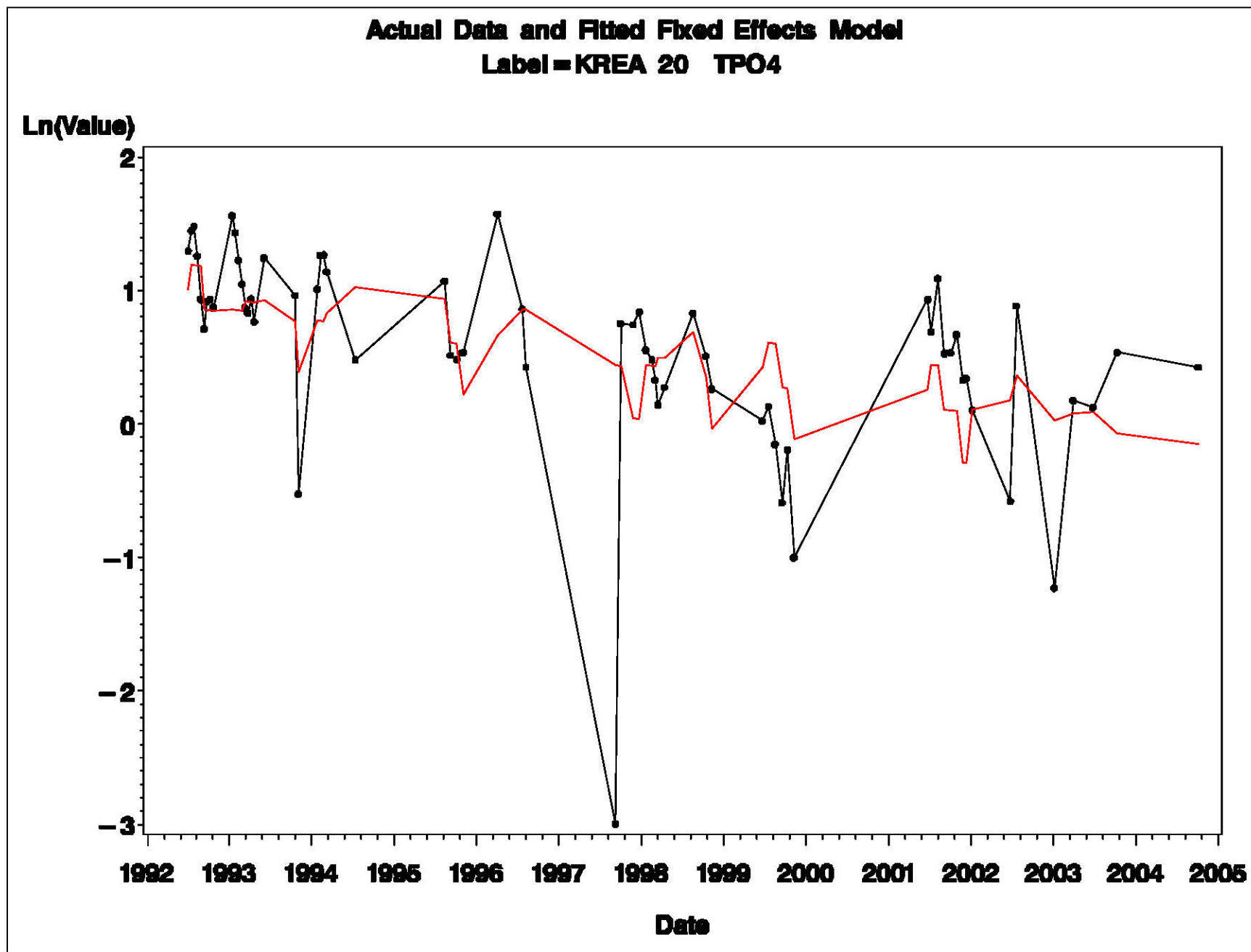


Figure A-33

Actual Data and Fitted Fixed Effects Model
Label = KREA 22 TPO4

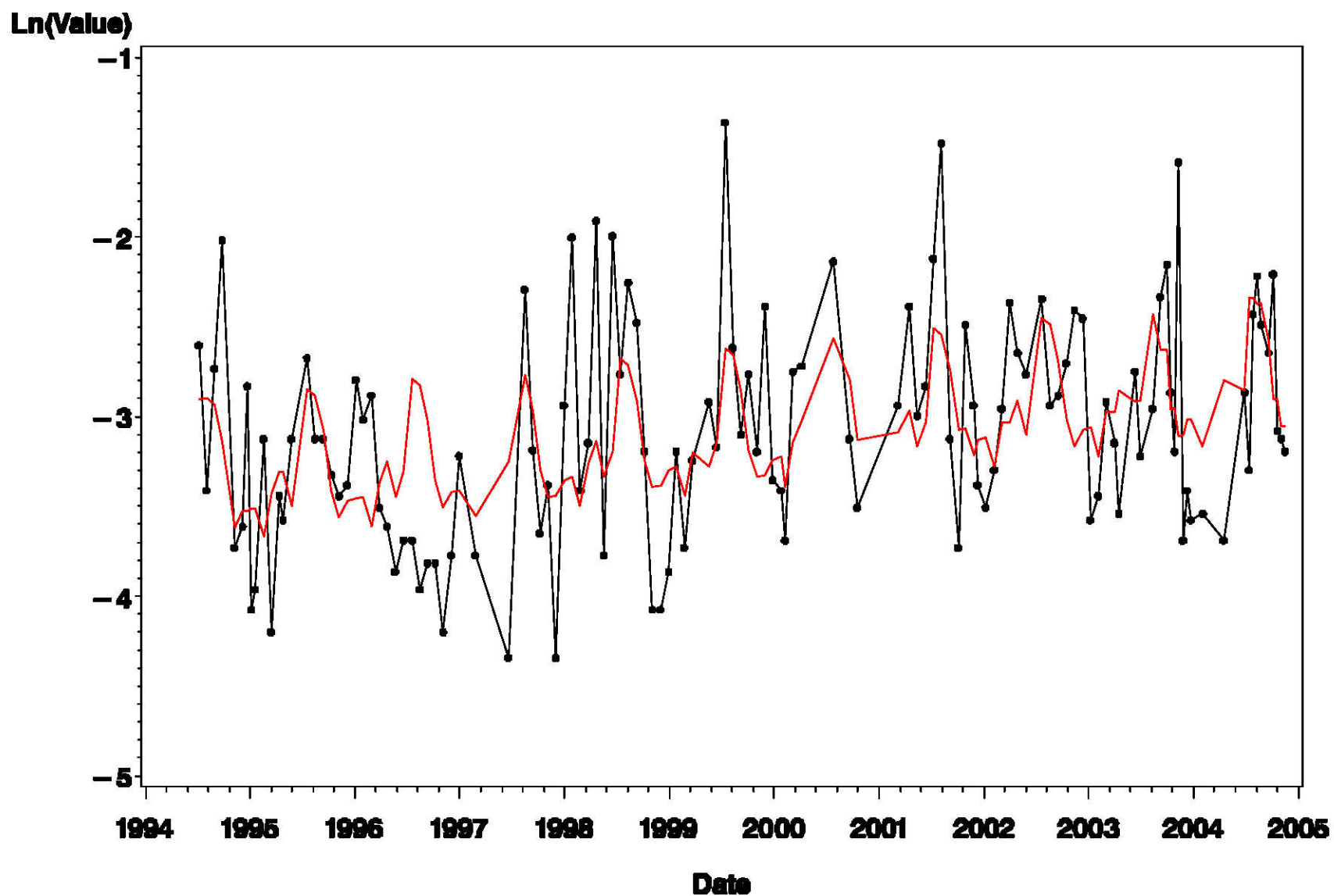


Figure A-34

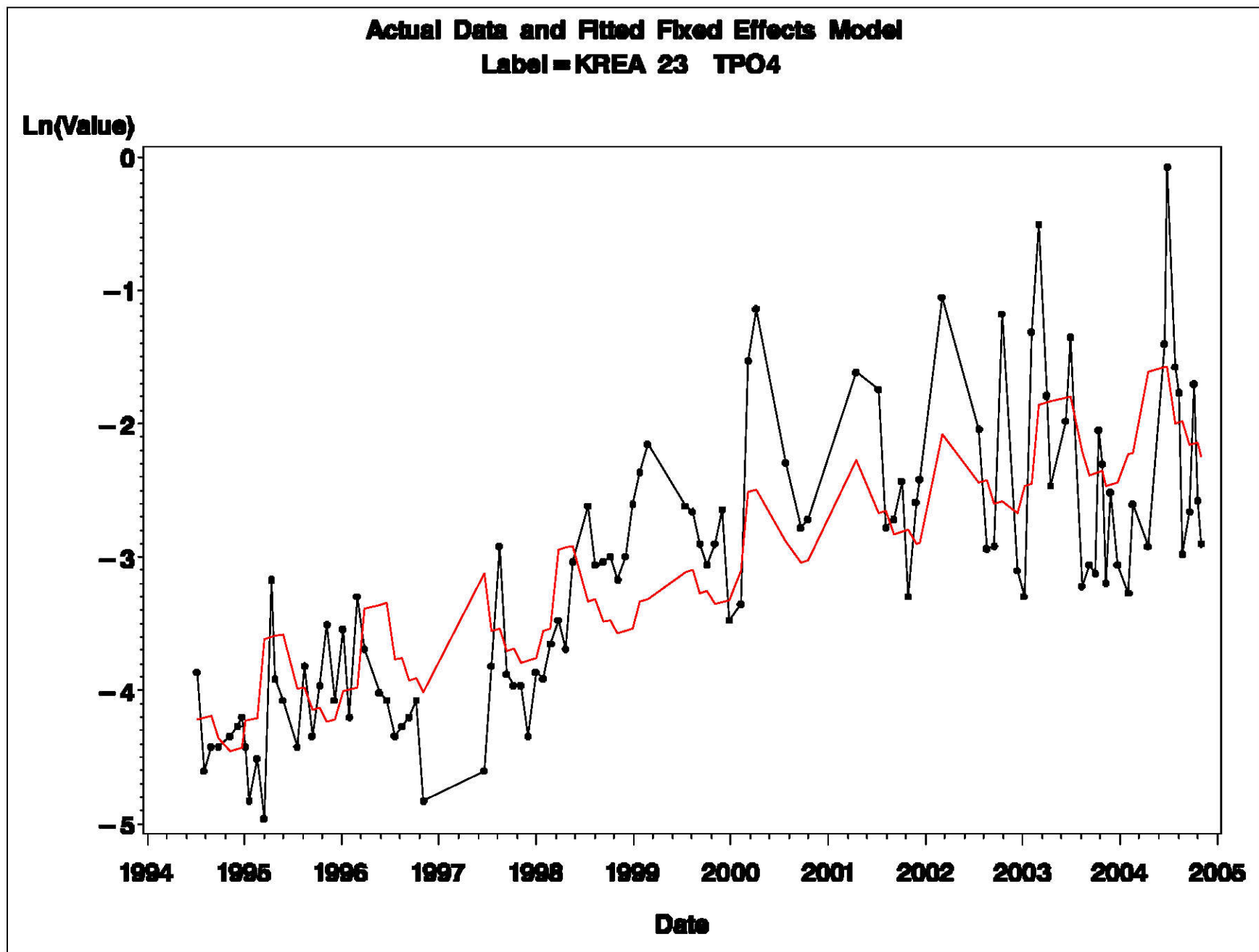


Figure A-35

Actual Data and Fitted Fixed Effects Model
Label = KREA 25 TPO4

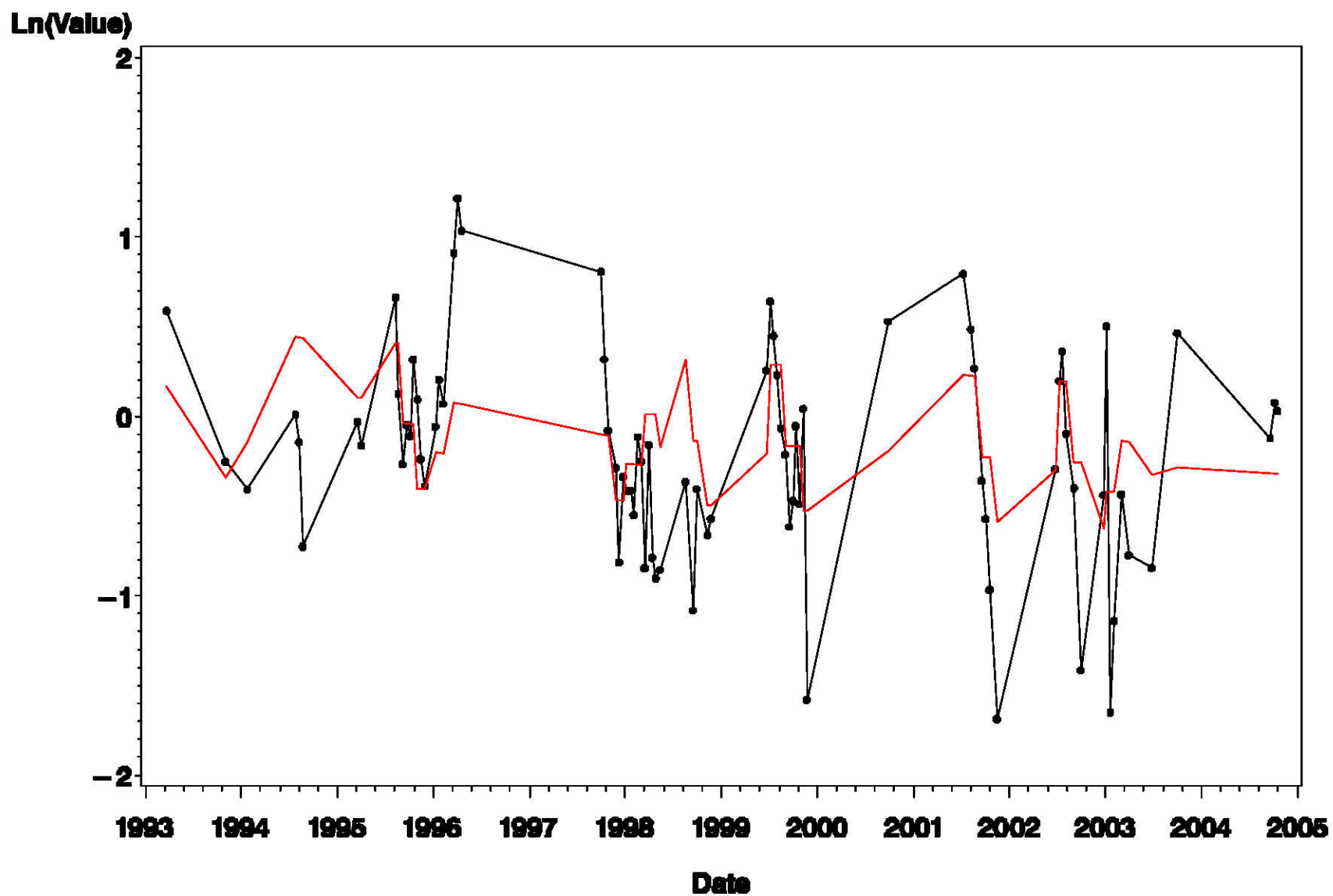


Figure A-36

Actual Data and Fitted Fixed Effects Model
Label = KREA 28 TPO4

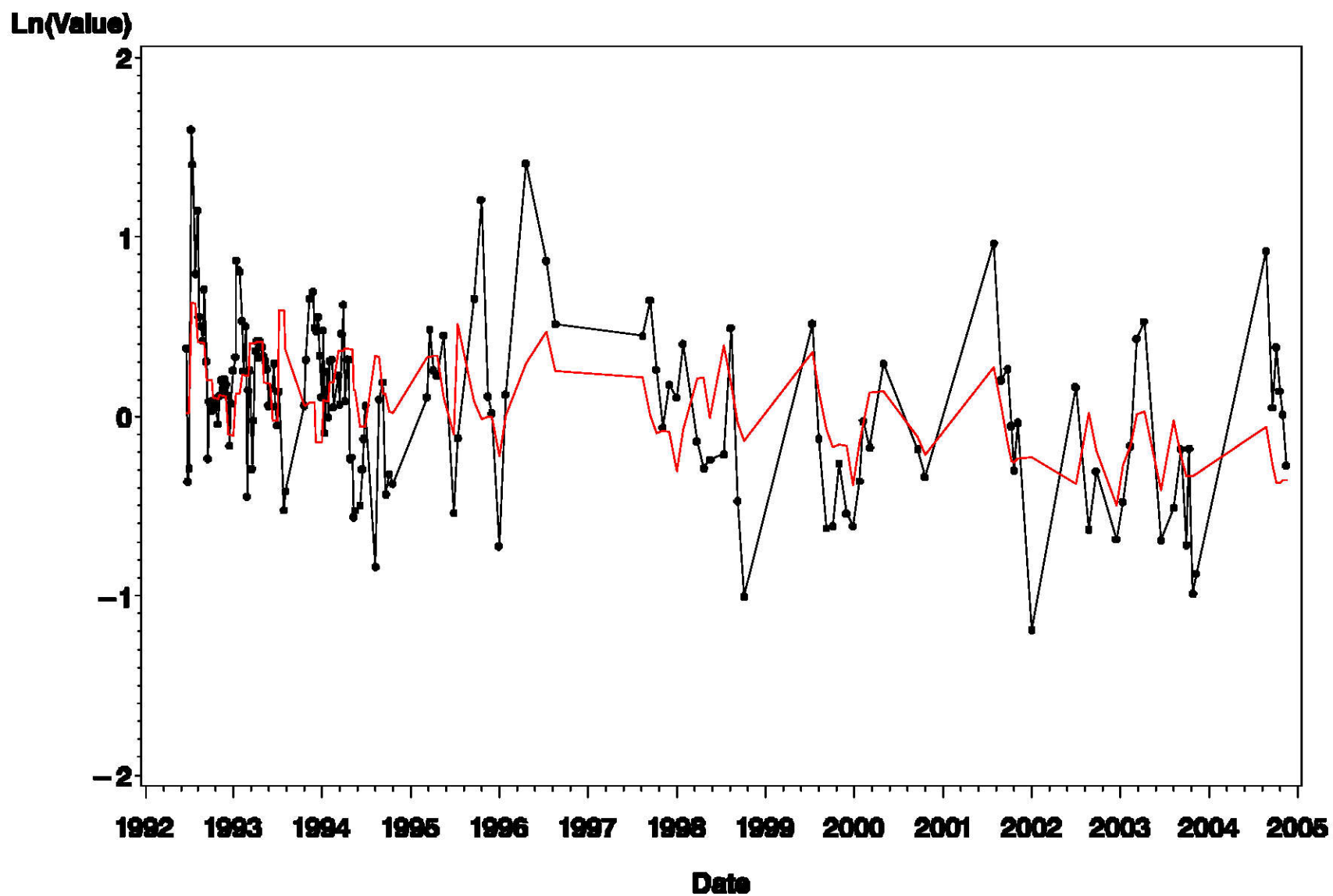


Figure A-37

Actual Data and Fitted Fixed Effects Model
Label=KREA 30A TPO4

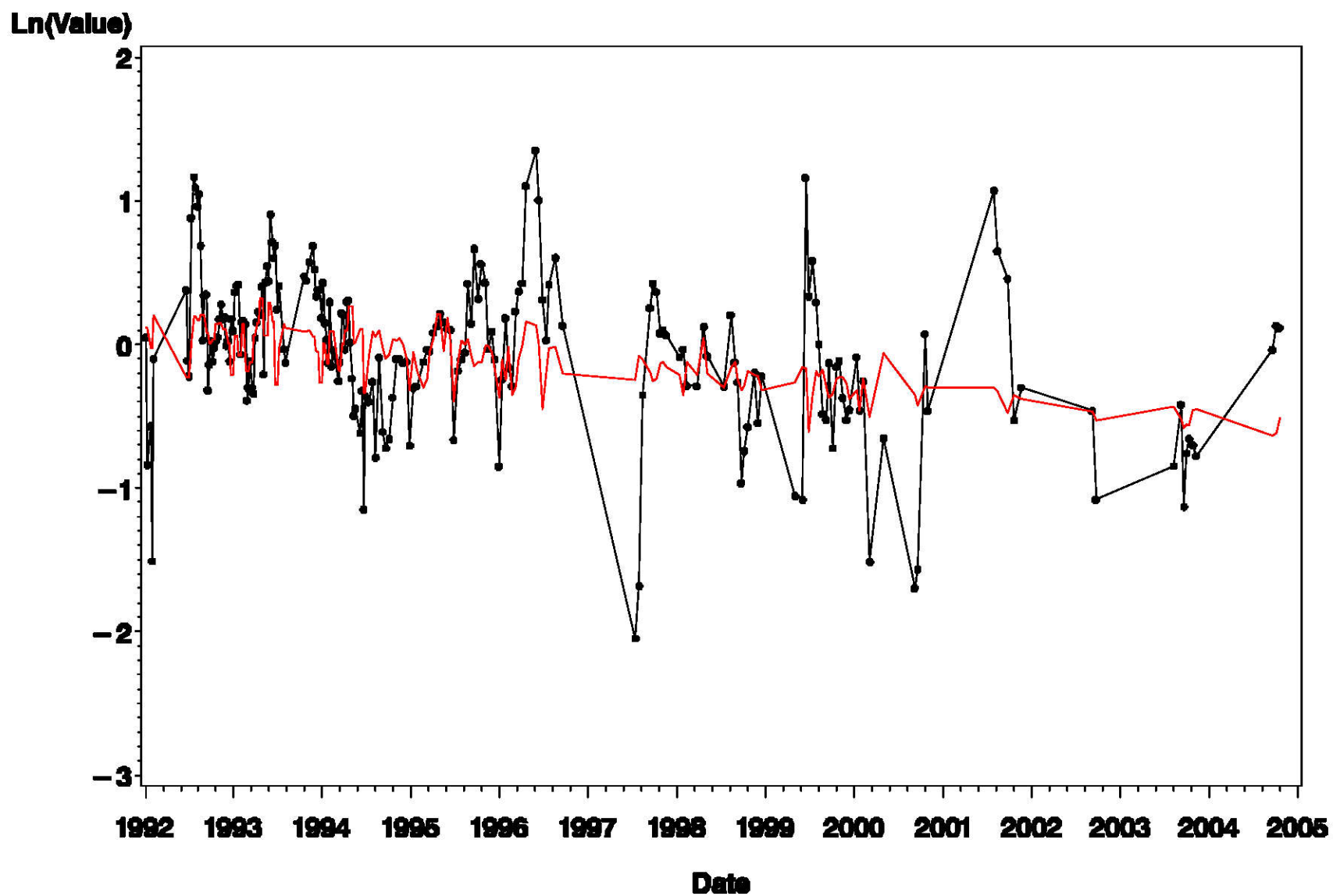


Figure A-38

Actual Data and Fitted Fixed Effects Model
Label=KREA 41A TPO4

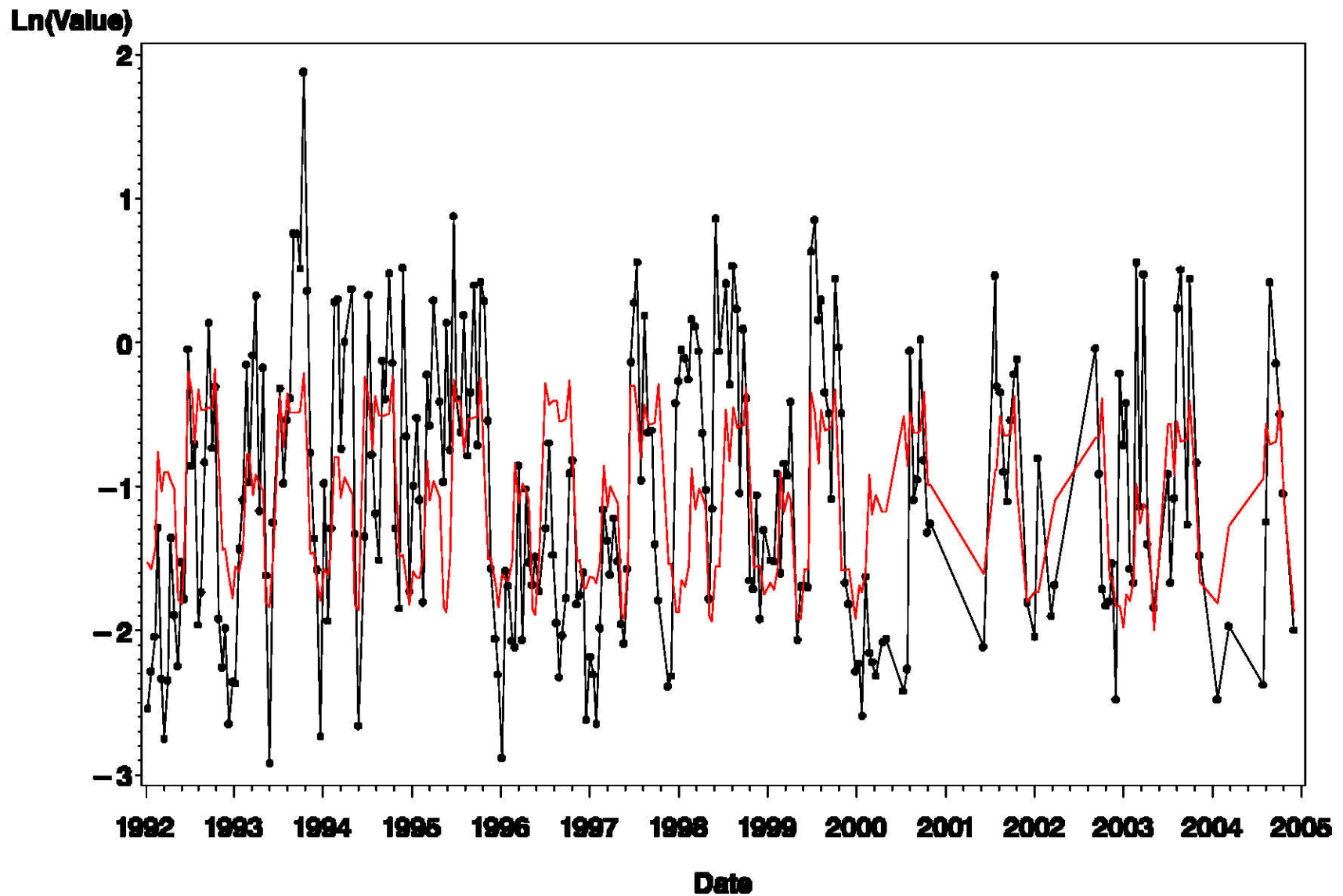


Figure A-39

Actual Data and Fitted Fixed Effects Model
Label=KREA 01 CL

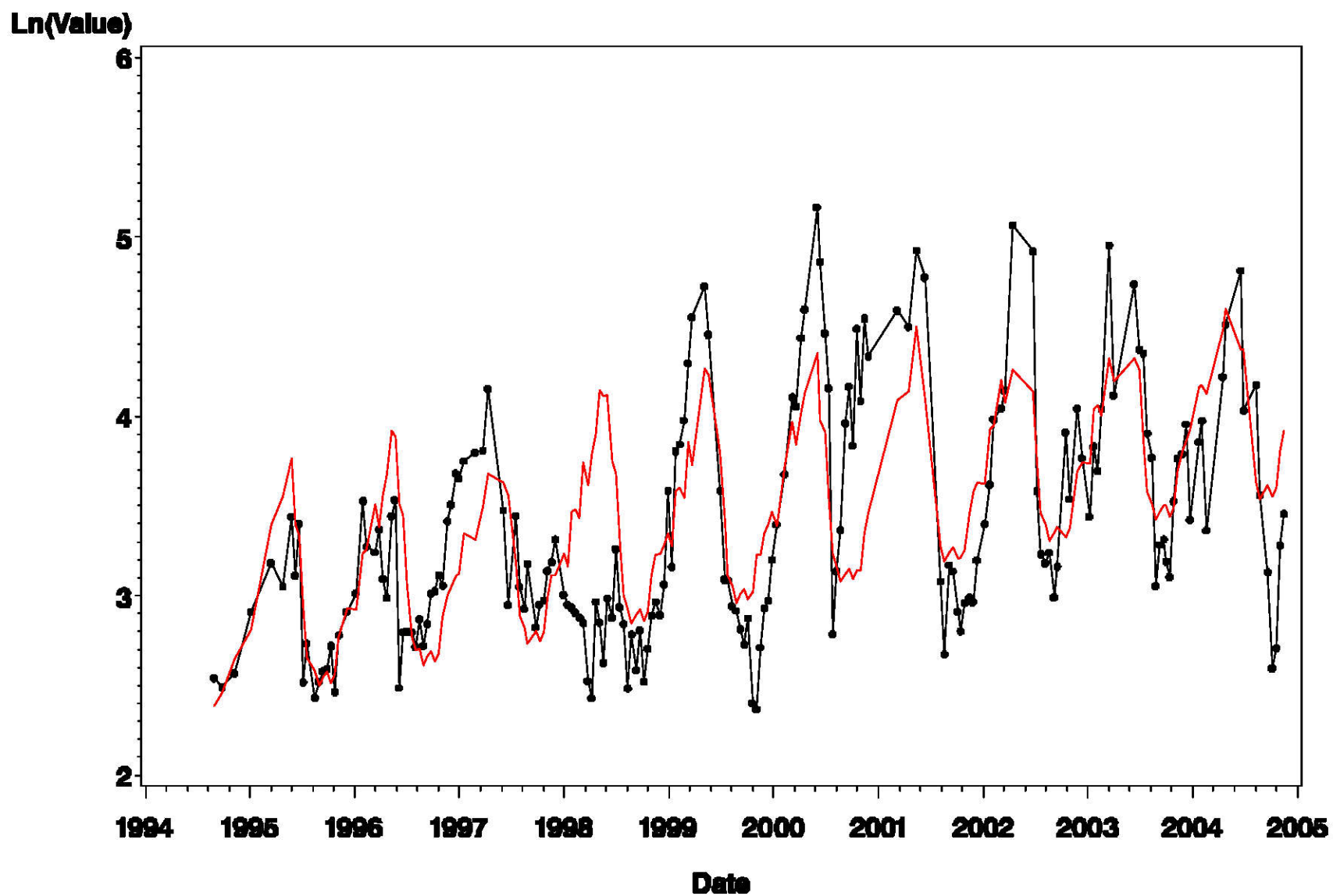


Figure A-40

Actual Data and Fitted Fixed Effects Model
Label = KREA 04 CL

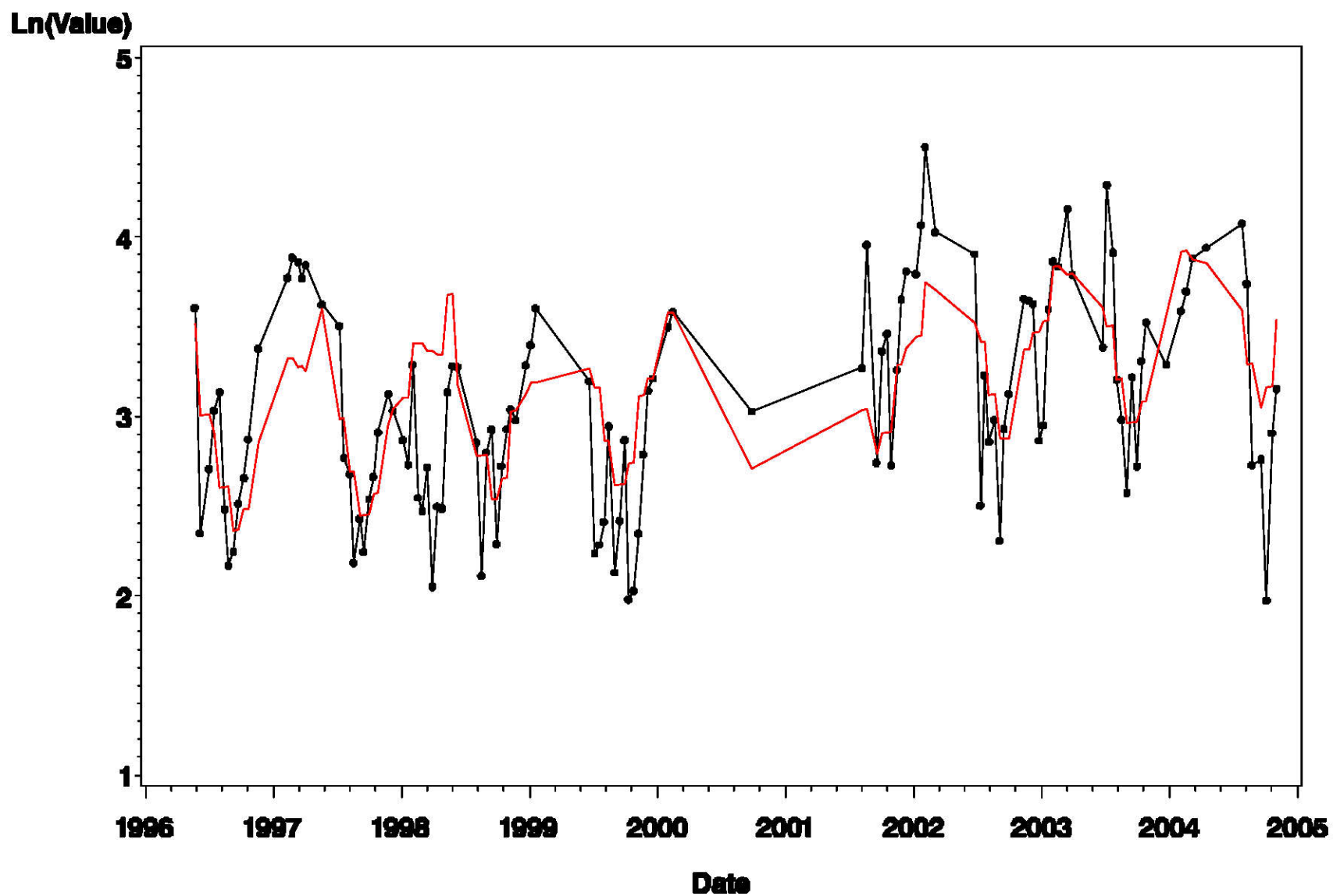


Figure A-41

Actual Data and Fitted Fixed Effects Model
Label = KREA 17A CL

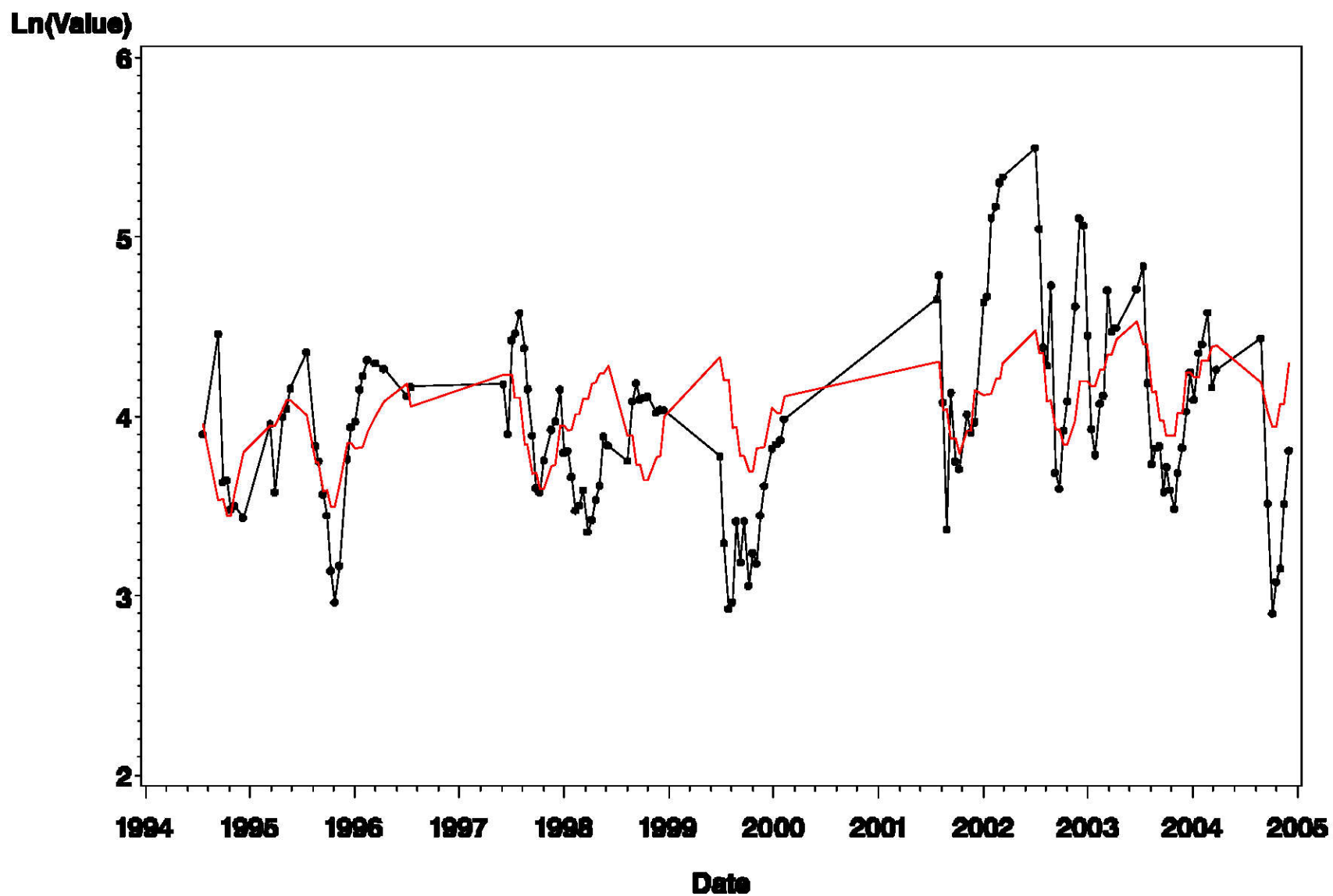


Figure A-42

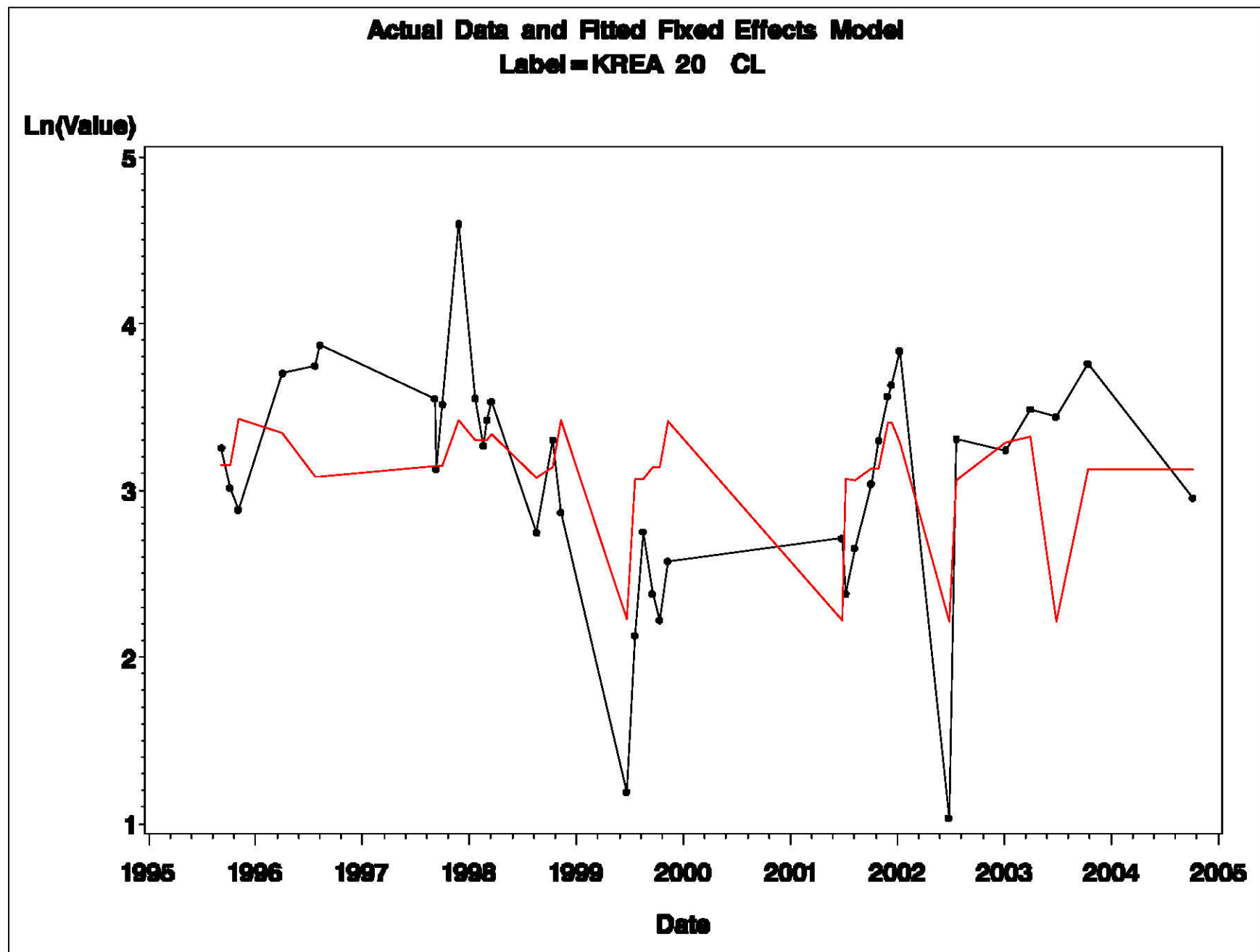


Figure A-43

Actual Data and Fitted Fixed Effects Model
Label = KREA 22 CL

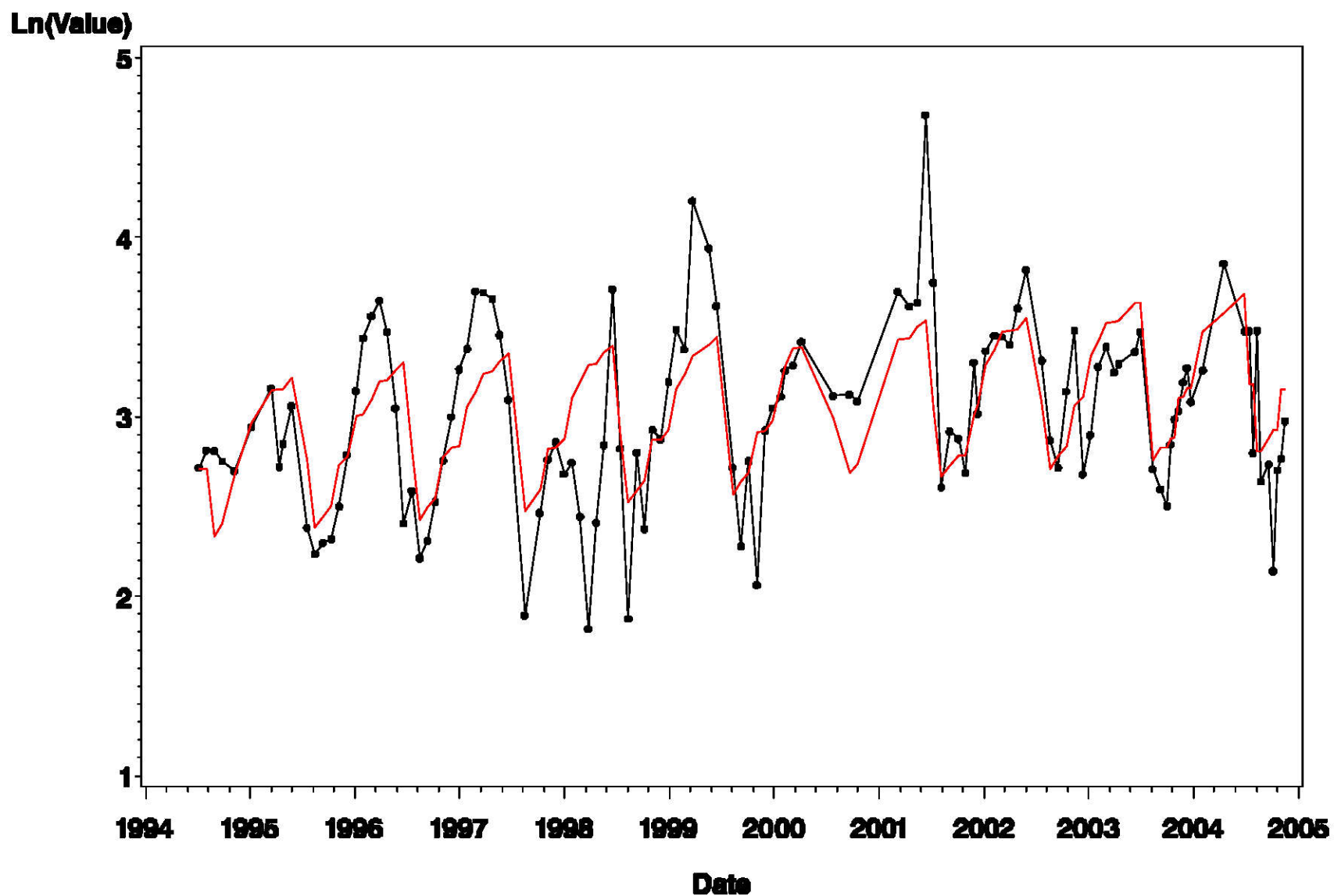


Figure A-44

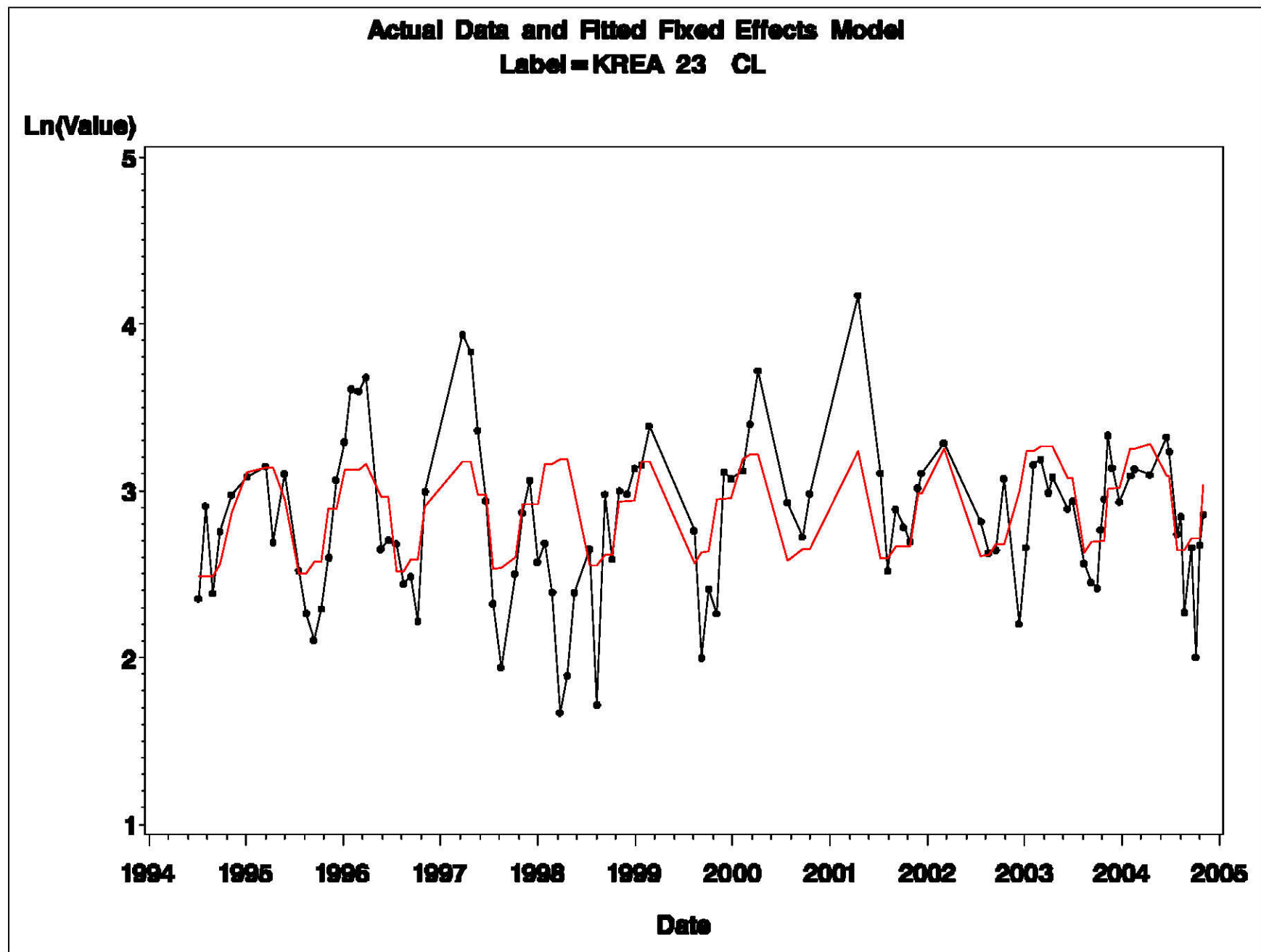


Figure A-45

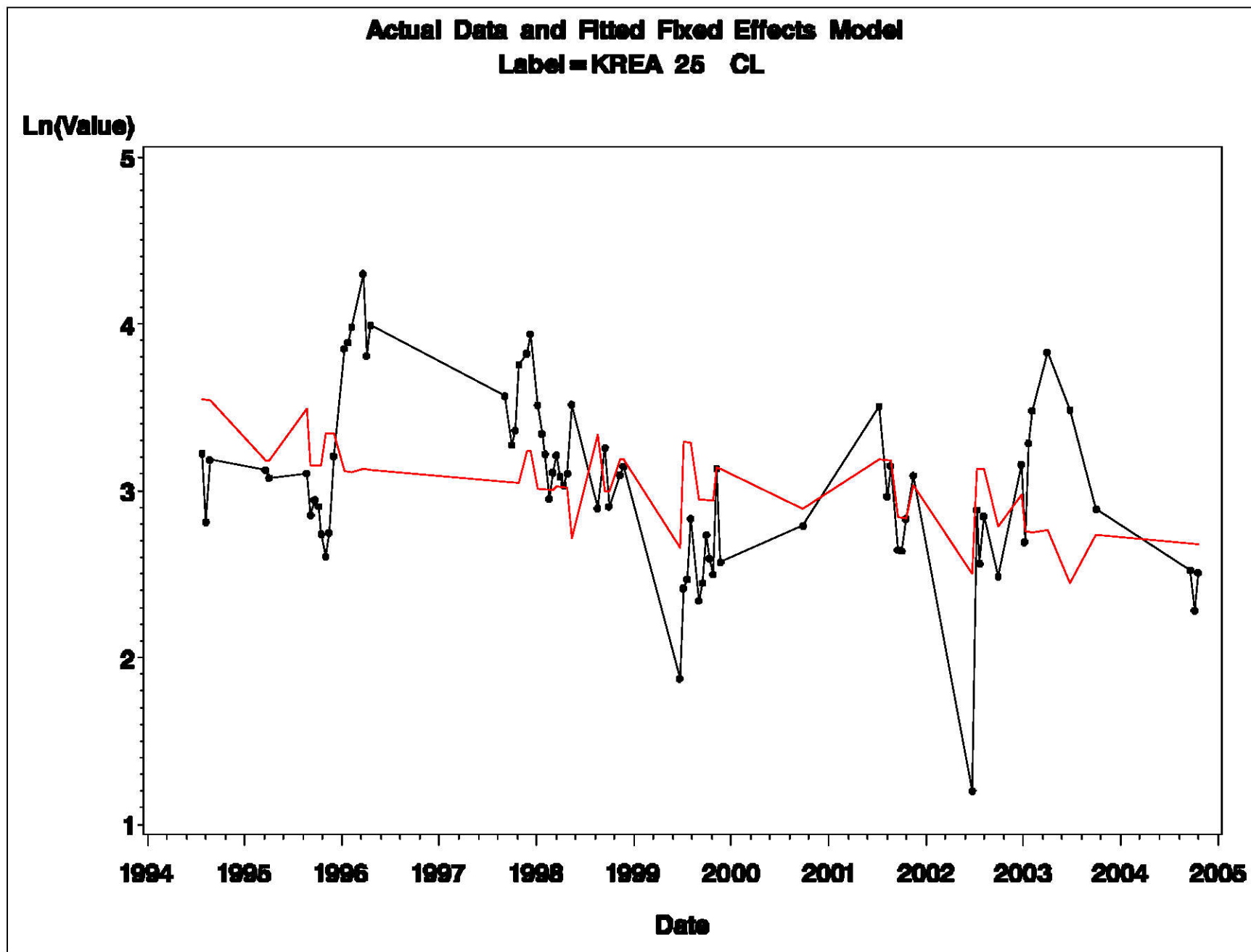


Figure A-46

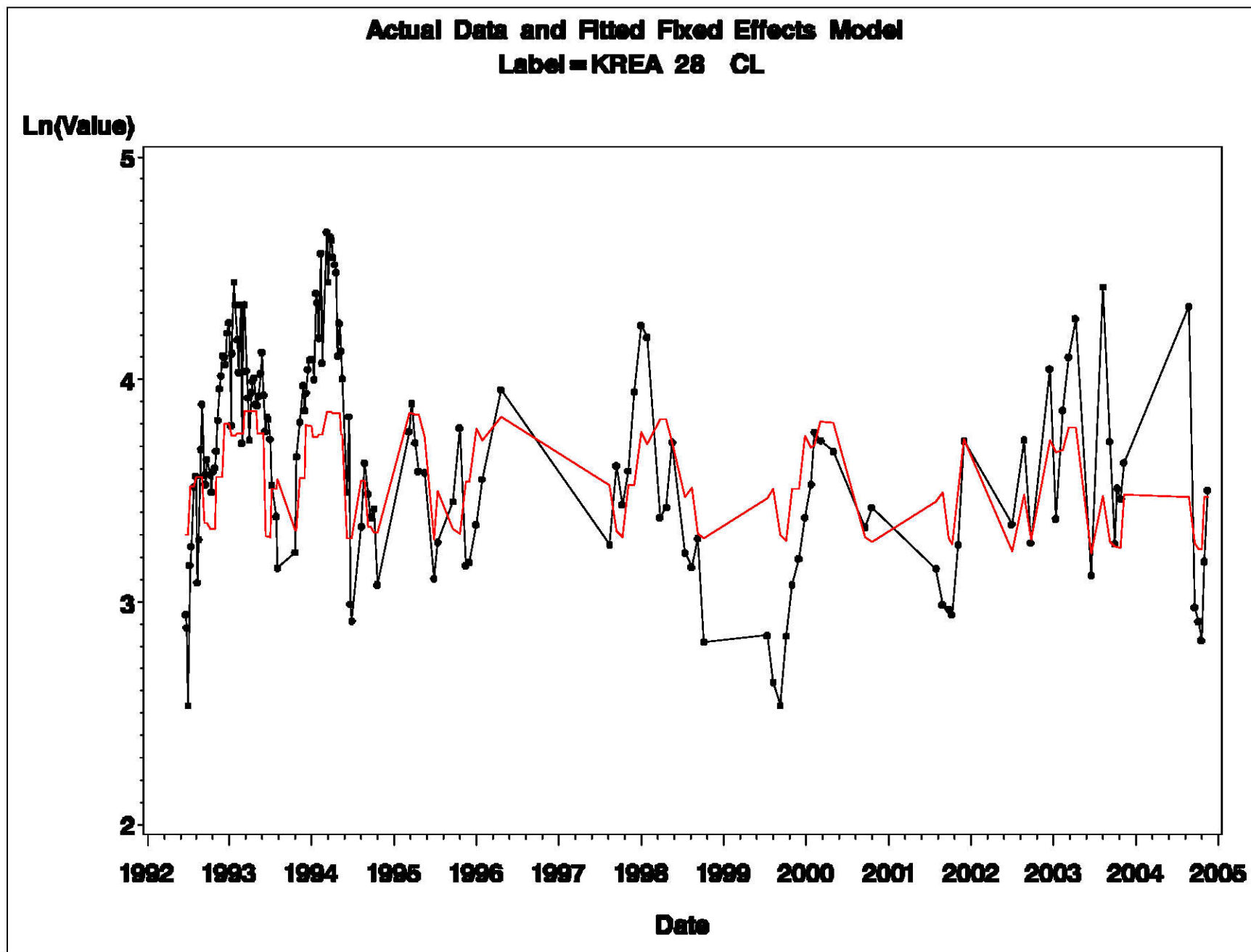


Figure A-47

Actual Data and Fitted Fixed Effects Model
Label = KREA 30A CL

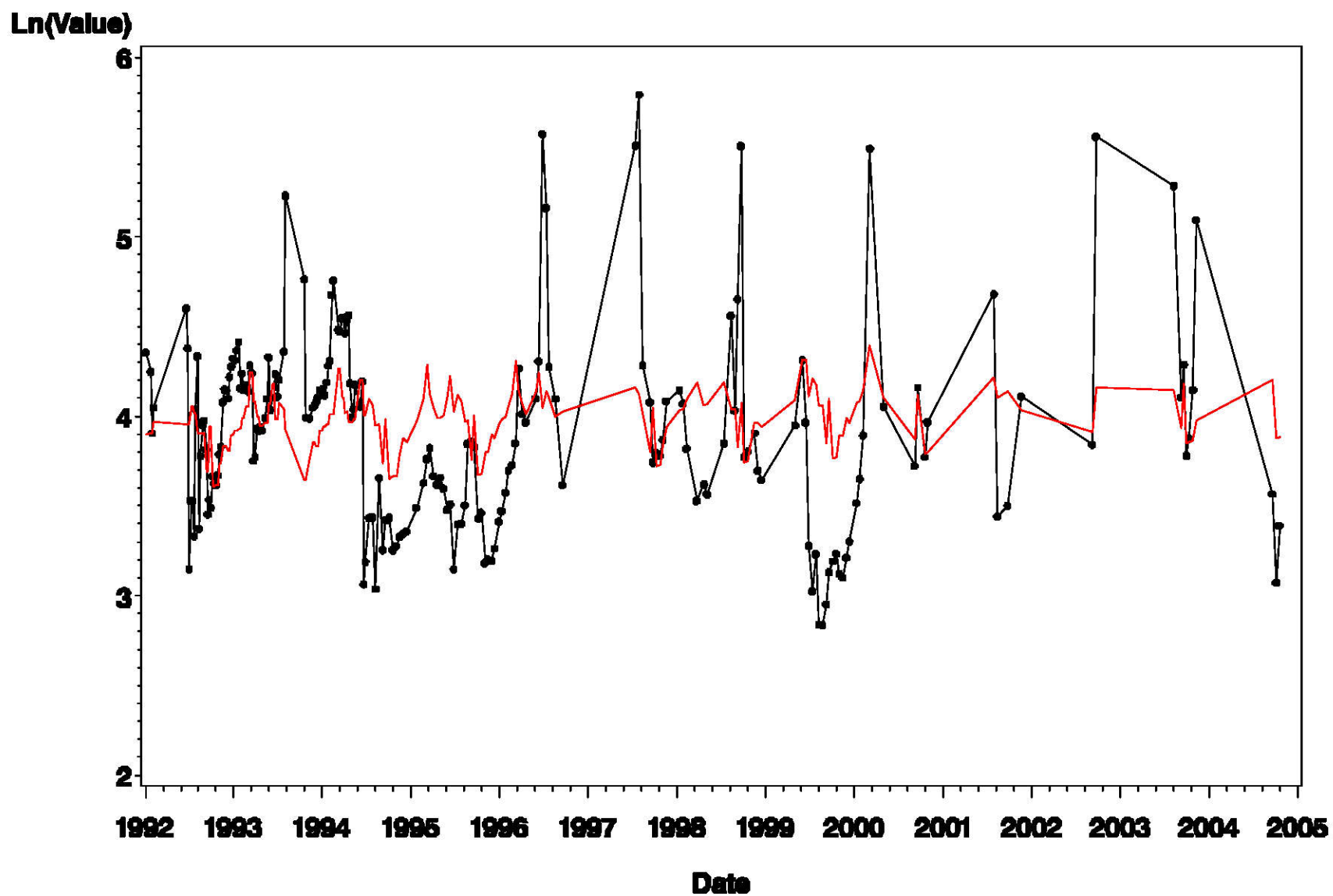


Figure A-48

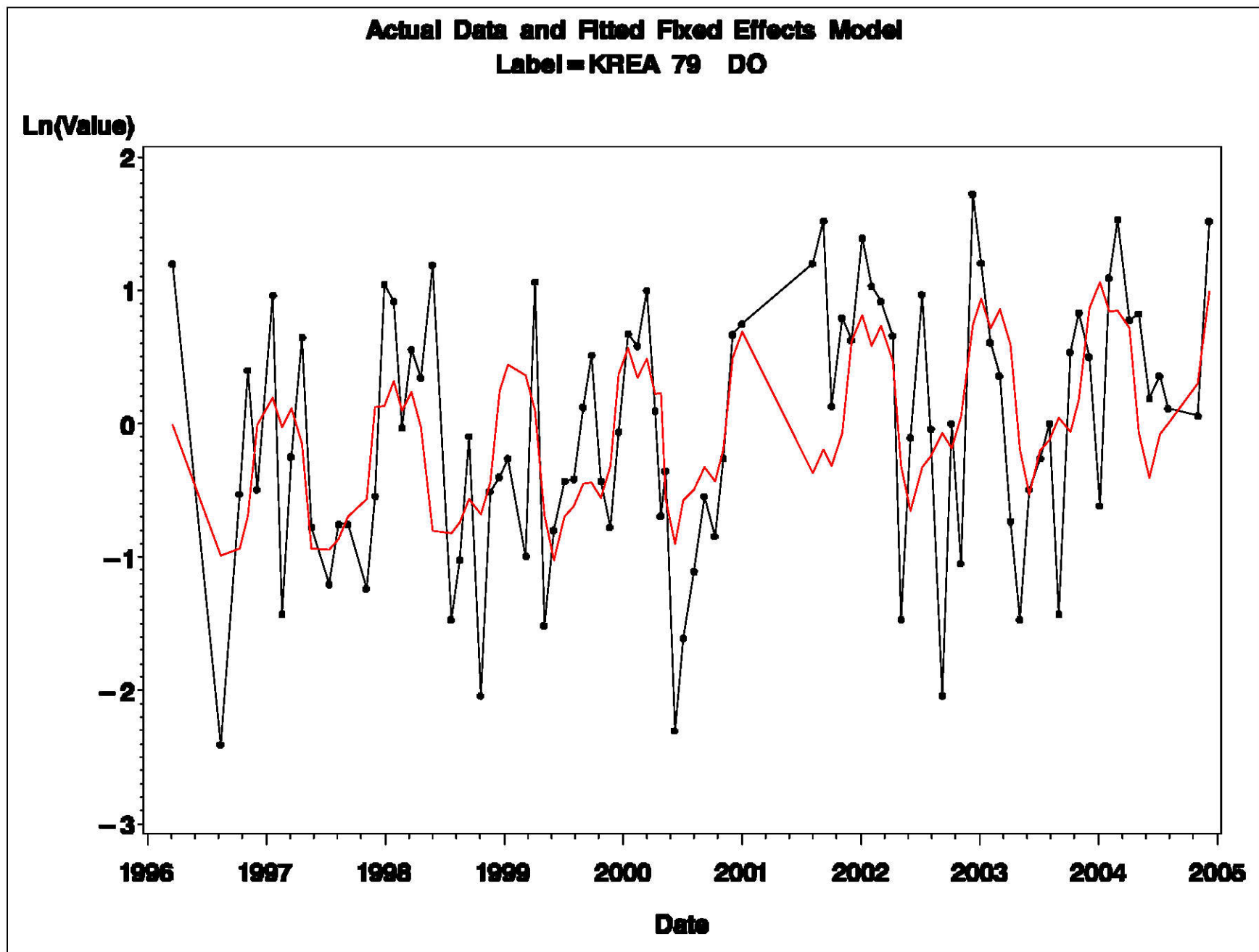


Figure A-49

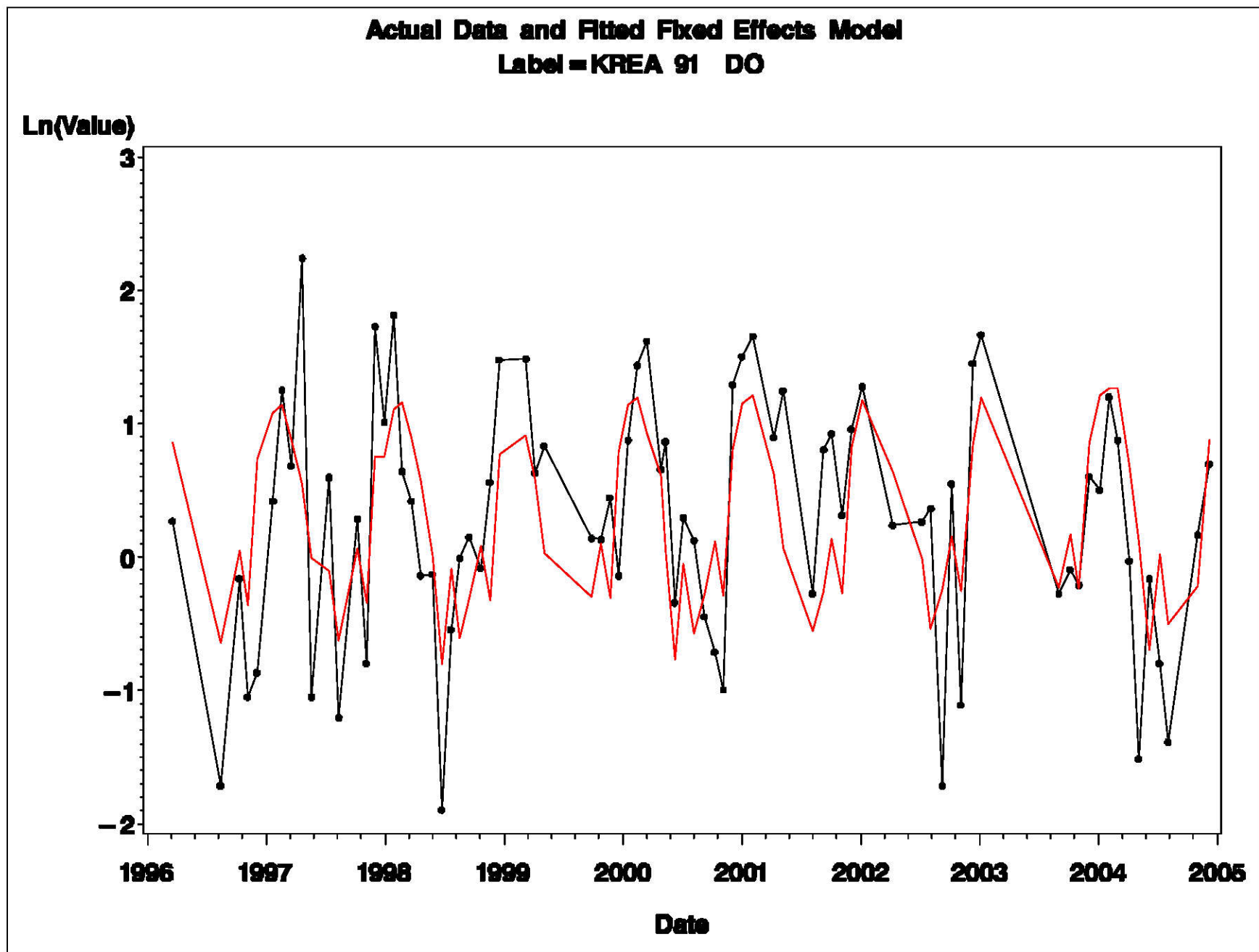


Figure A-50

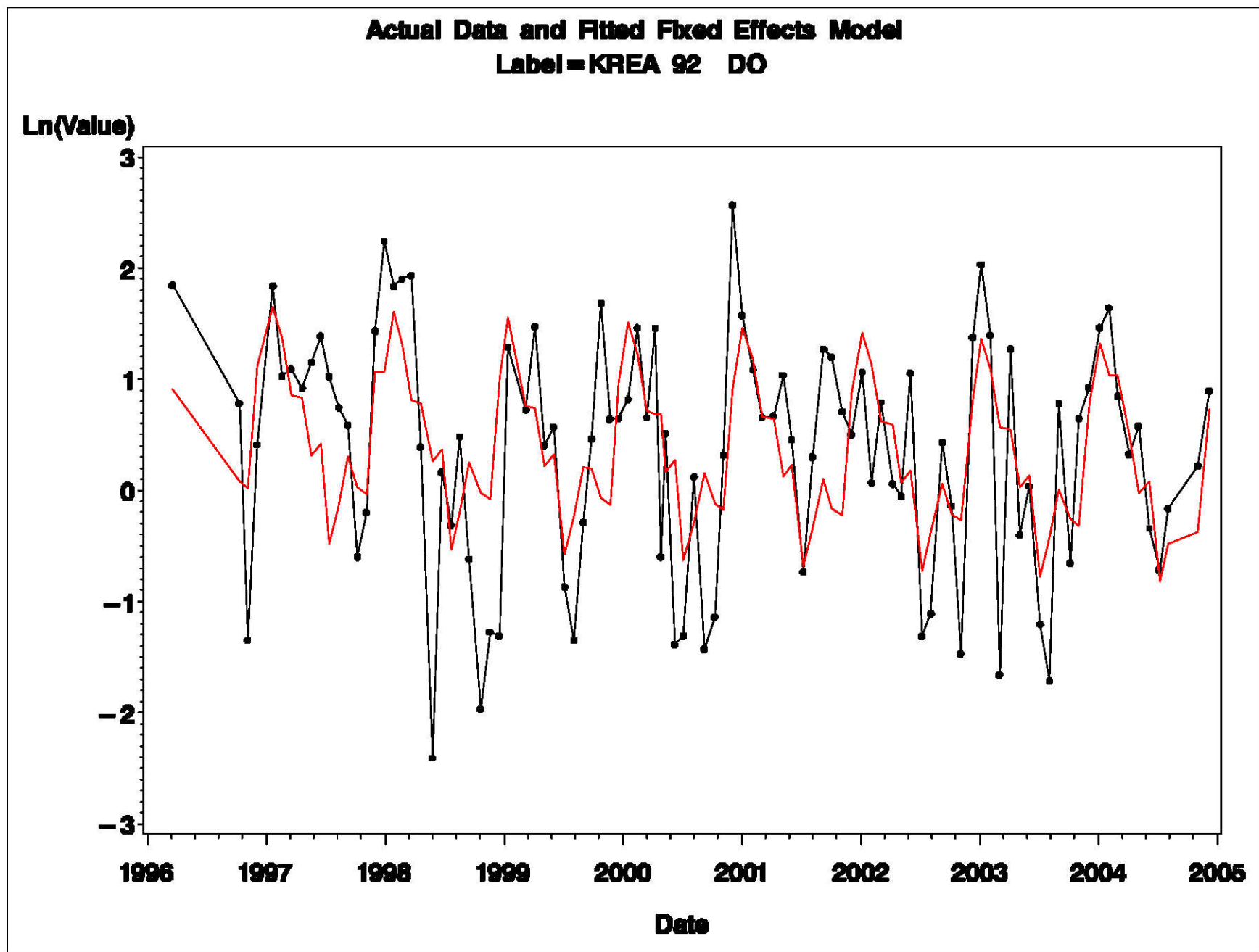


Figure A-51

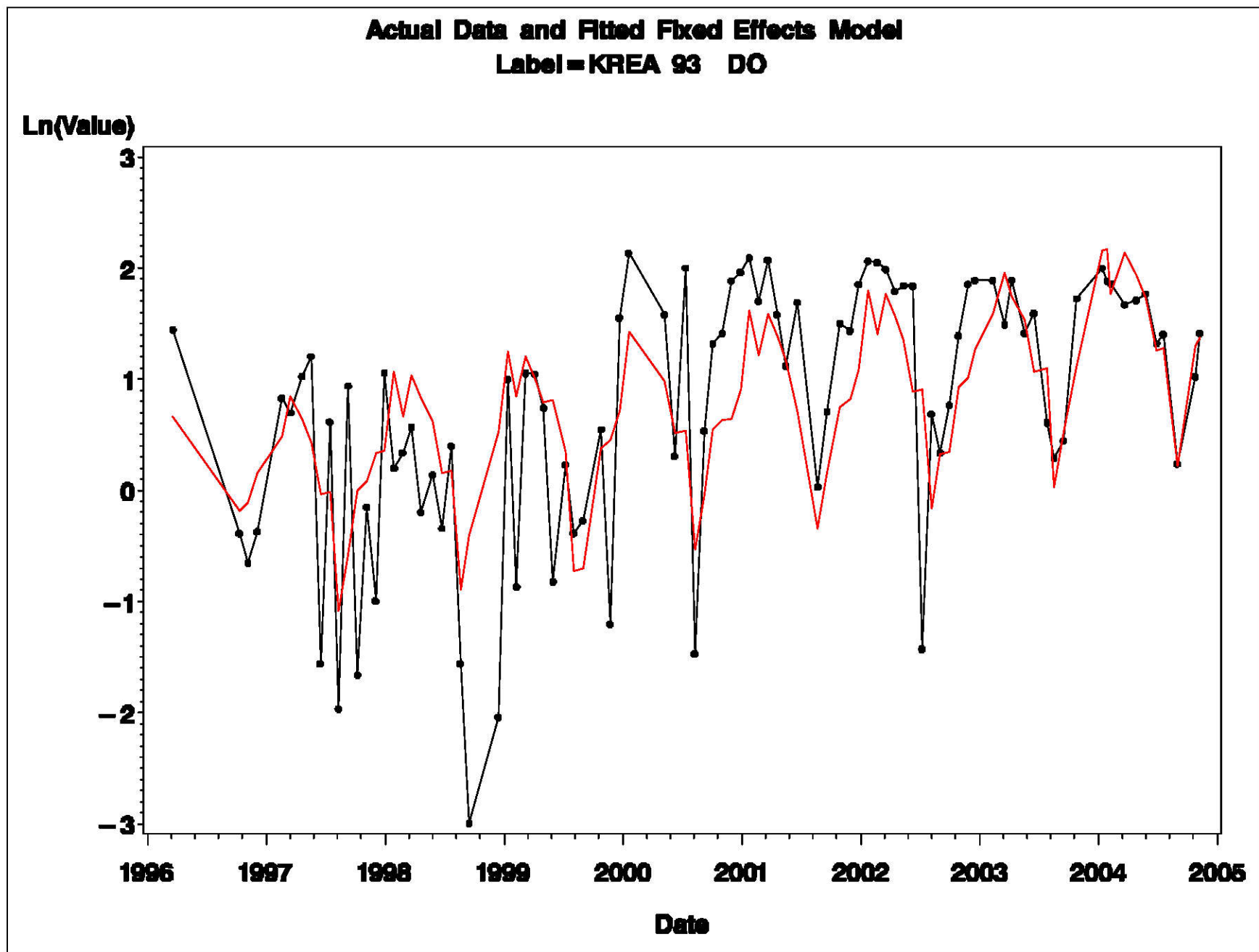


Figure A-52

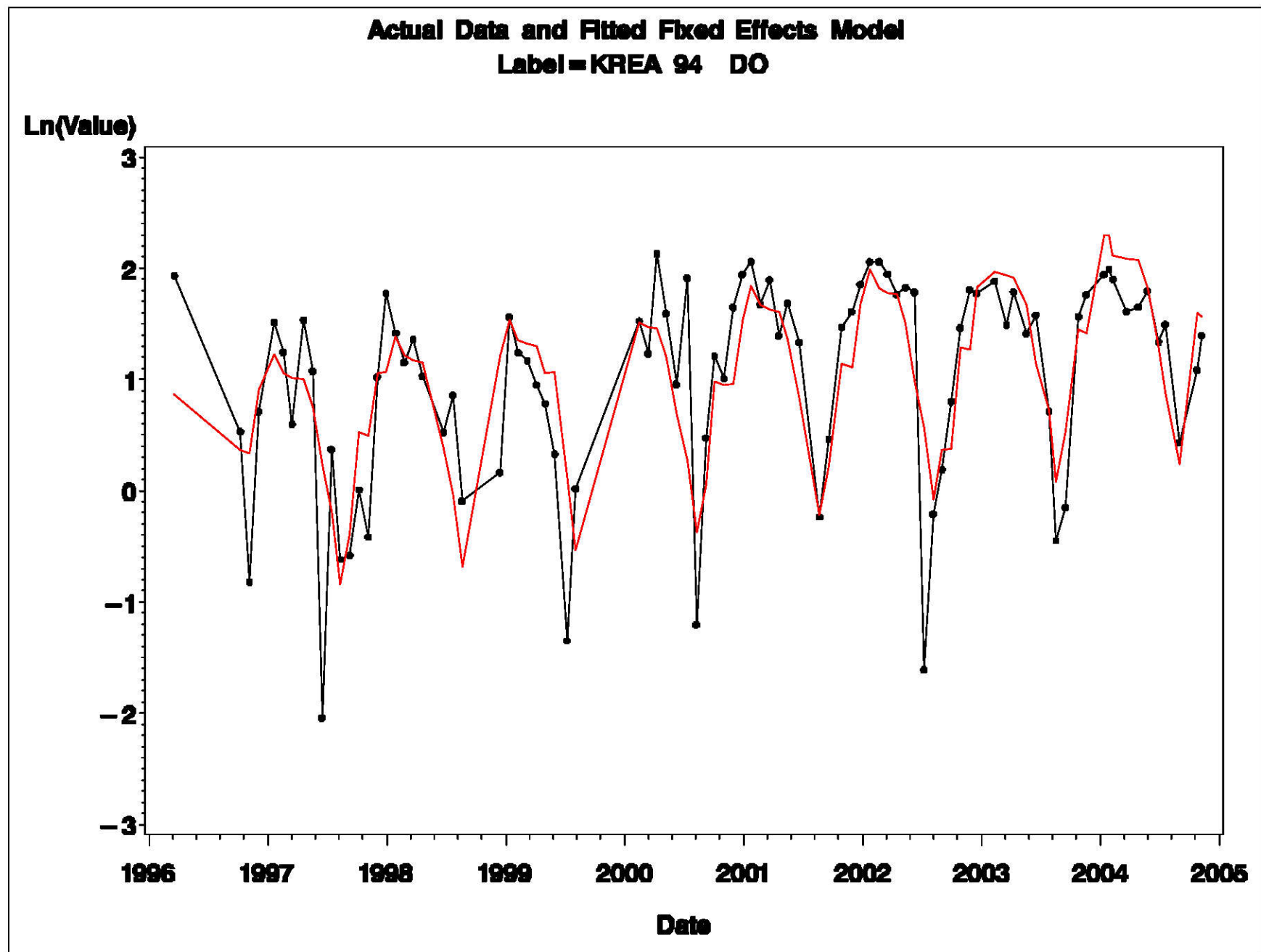


Figure A-53

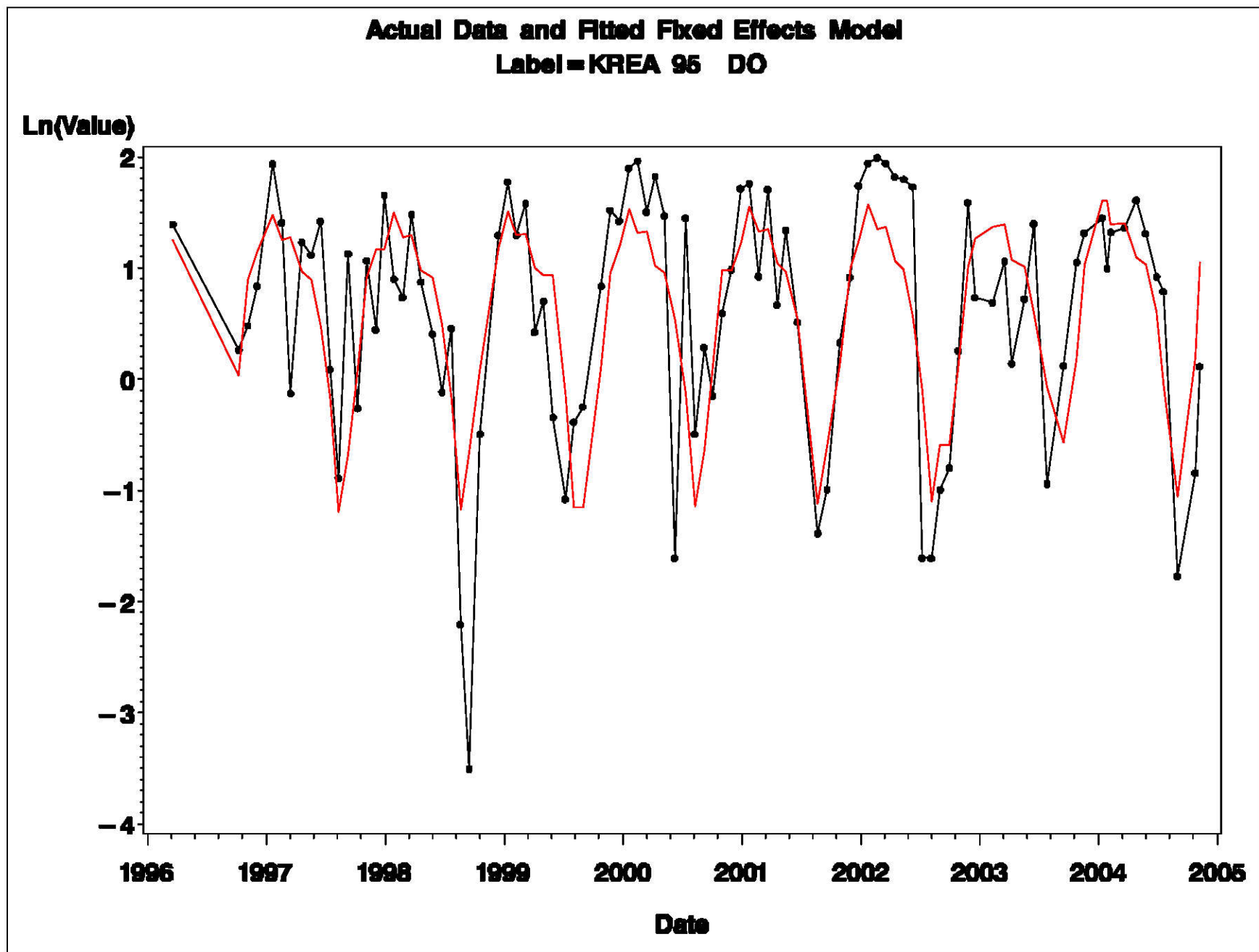


Figure A-54

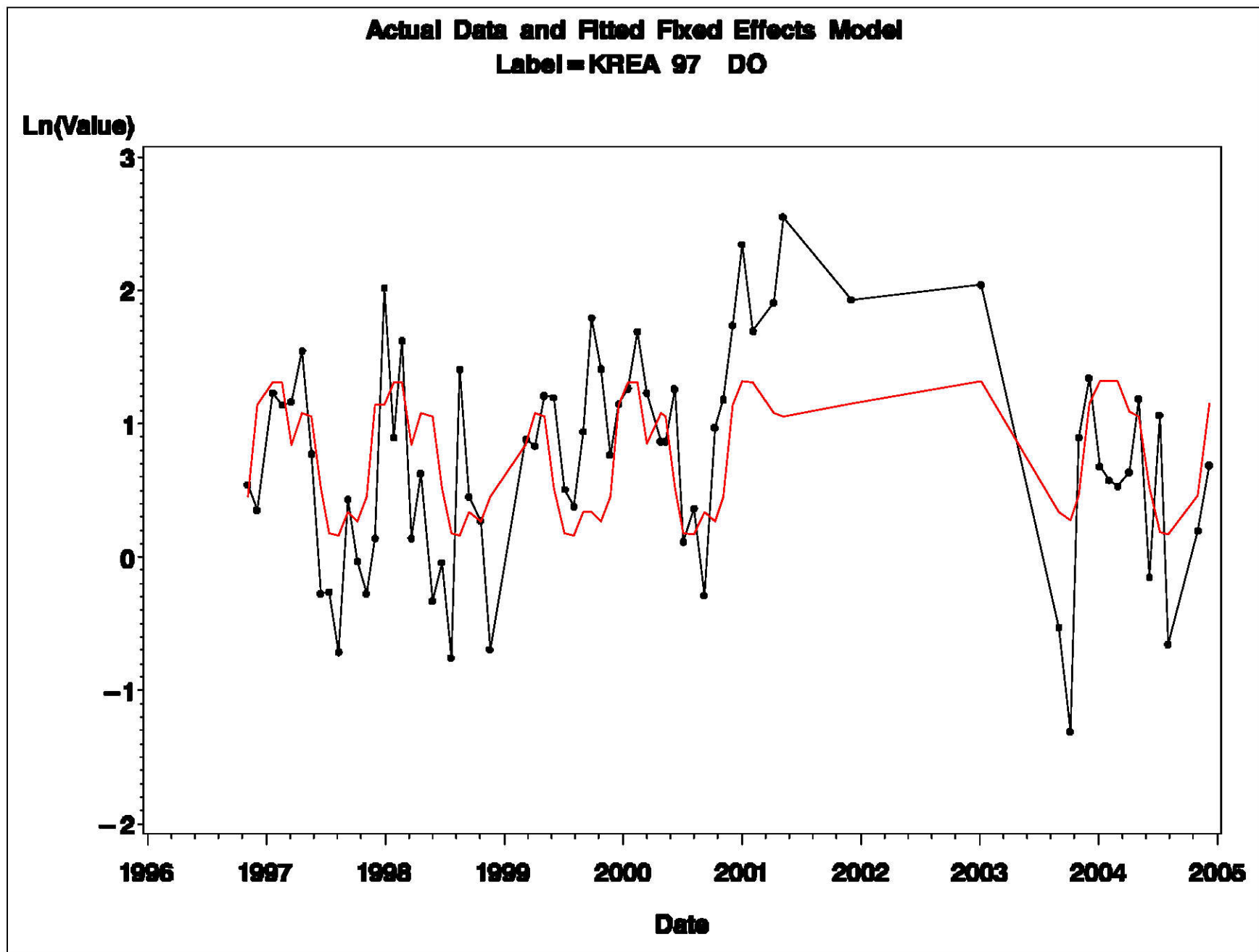


Figure A-55

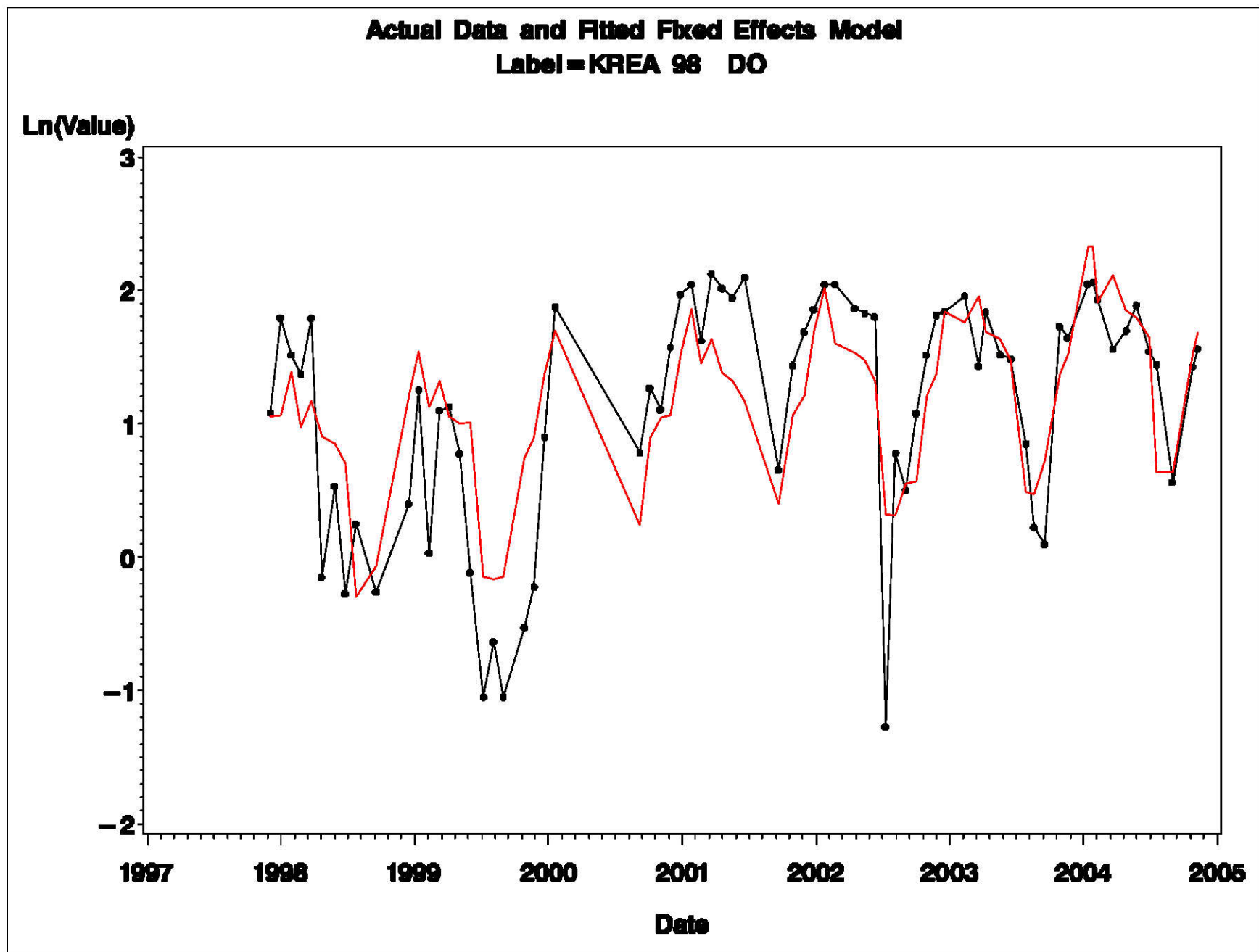


Figure A-56

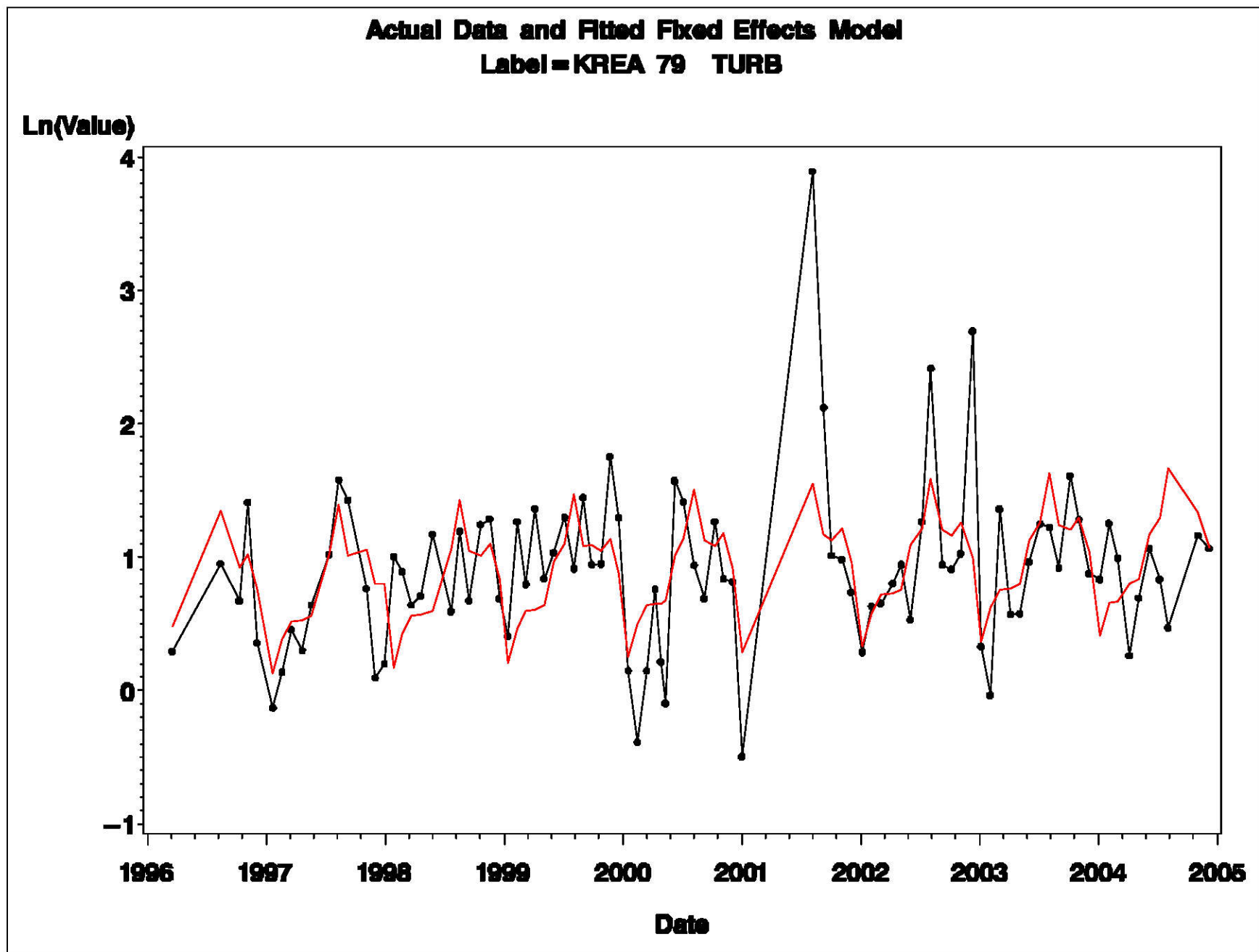


Figure A-57

Actual Data and Fitted Fixed Effects Model
Label = KREA 91 TURB

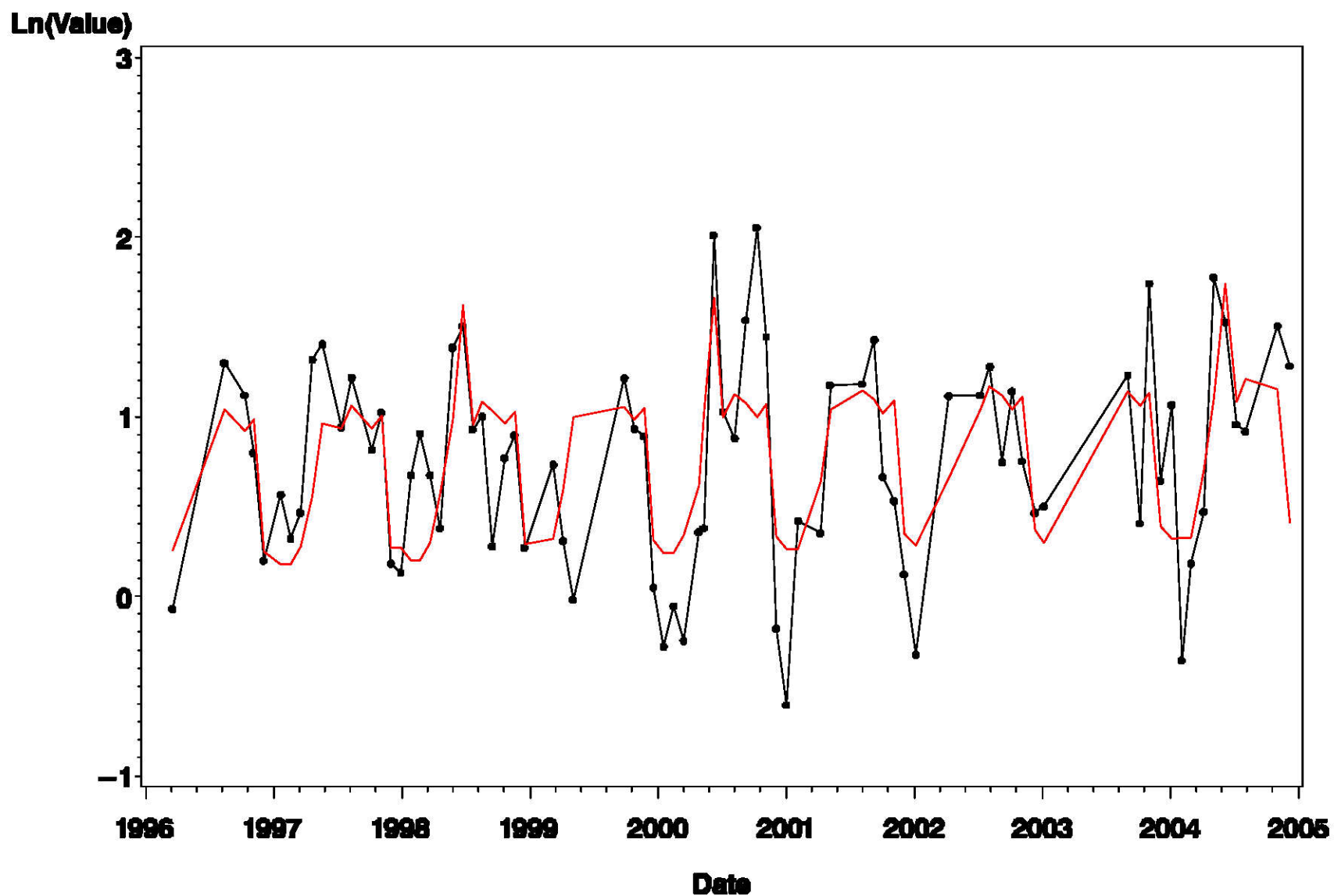


Figure A-58

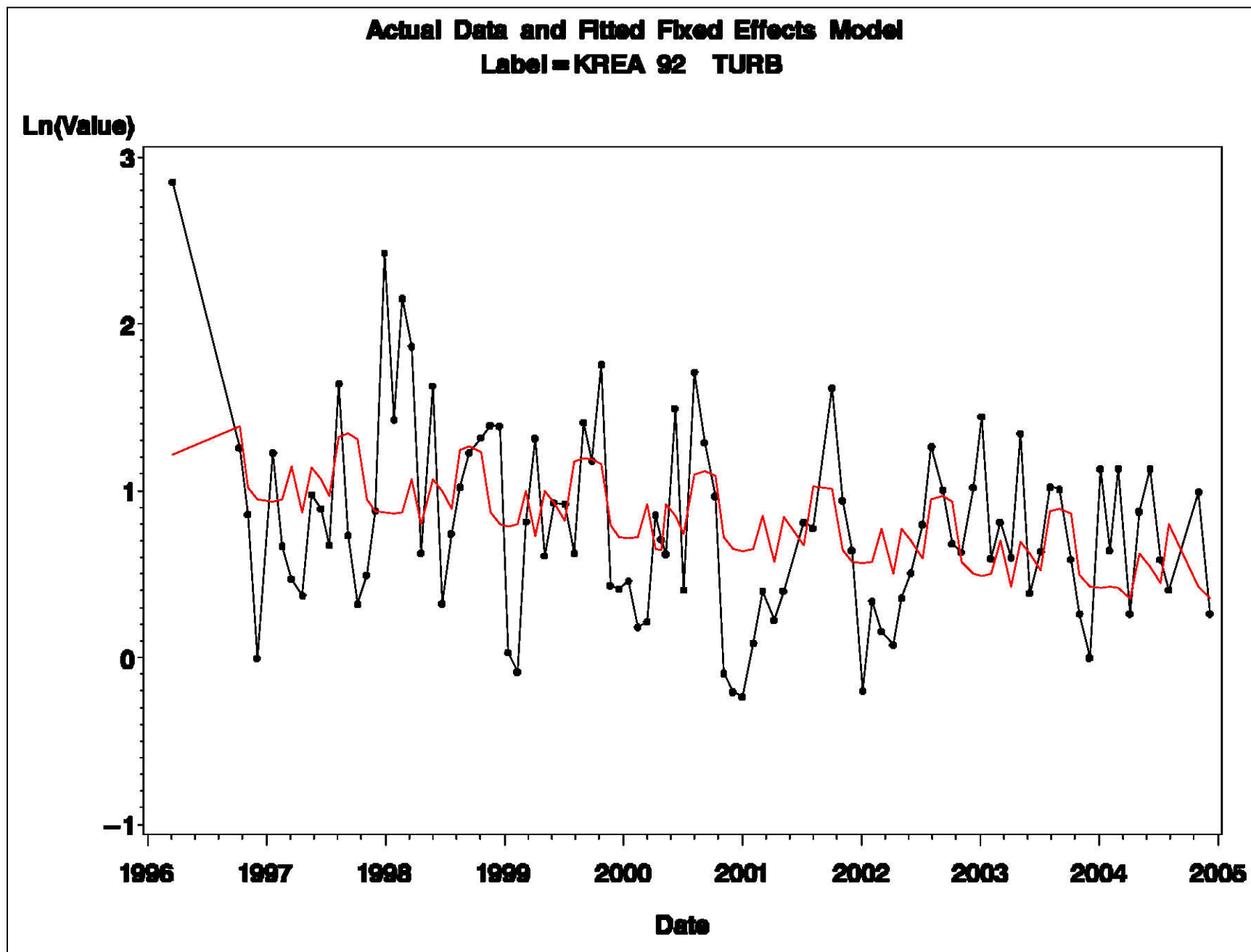


Figure A-59

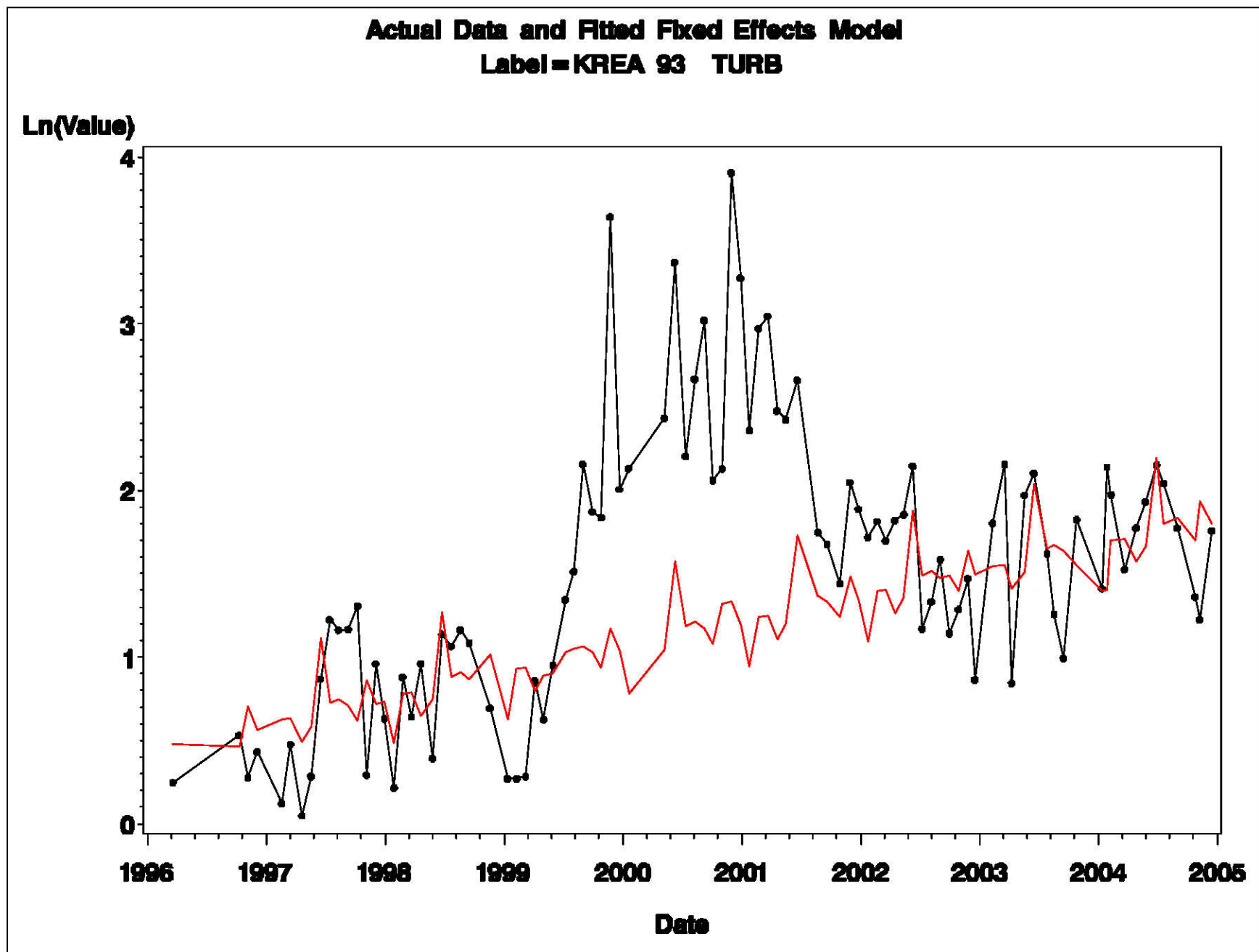


Figure A-60

Actual Data and Fitted Fixed Effects Model
Label=KREA 94 TURB

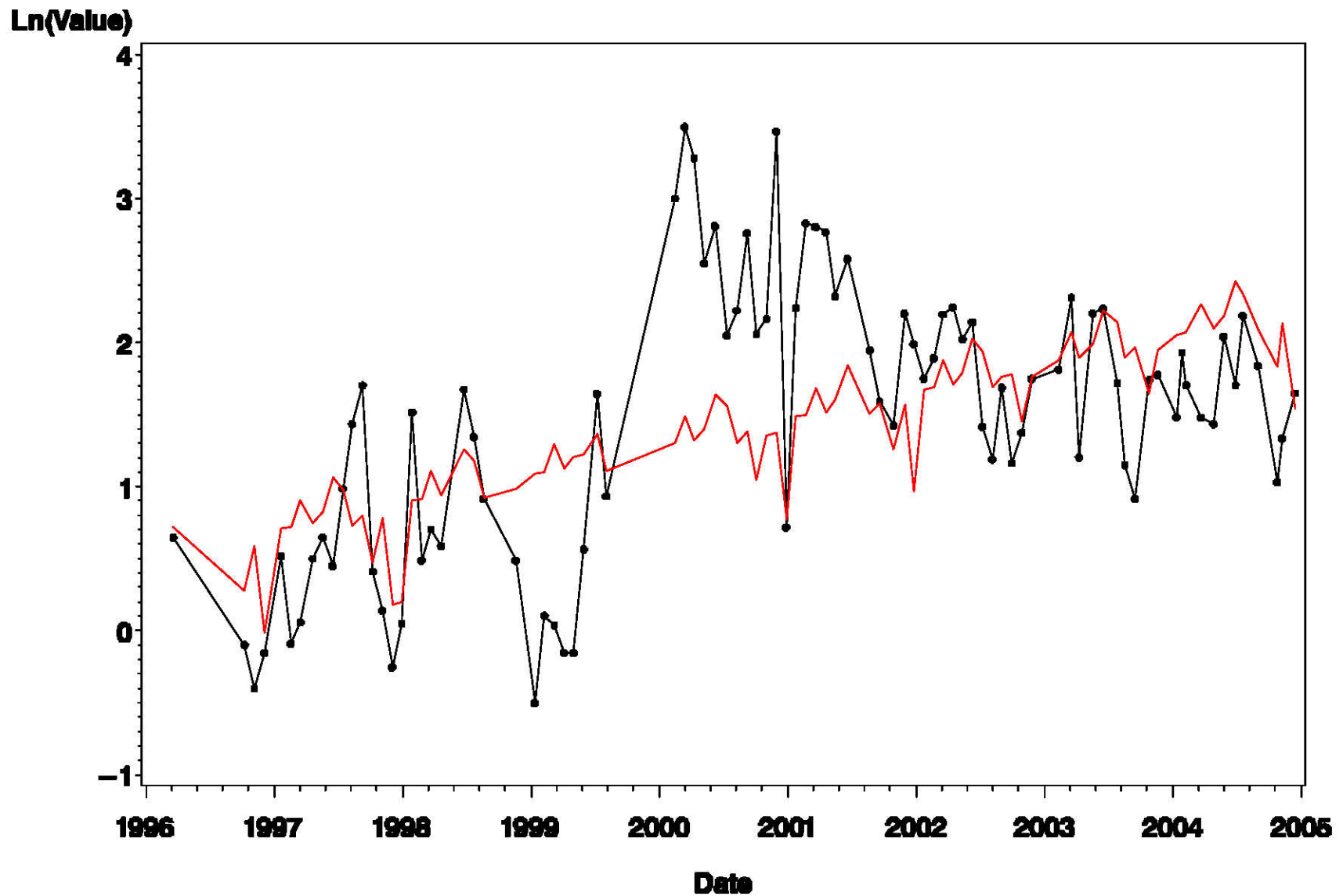


Figure A-61

Actual Data and Fitted Fixed Effects Model
Label=KREA 95 TURB

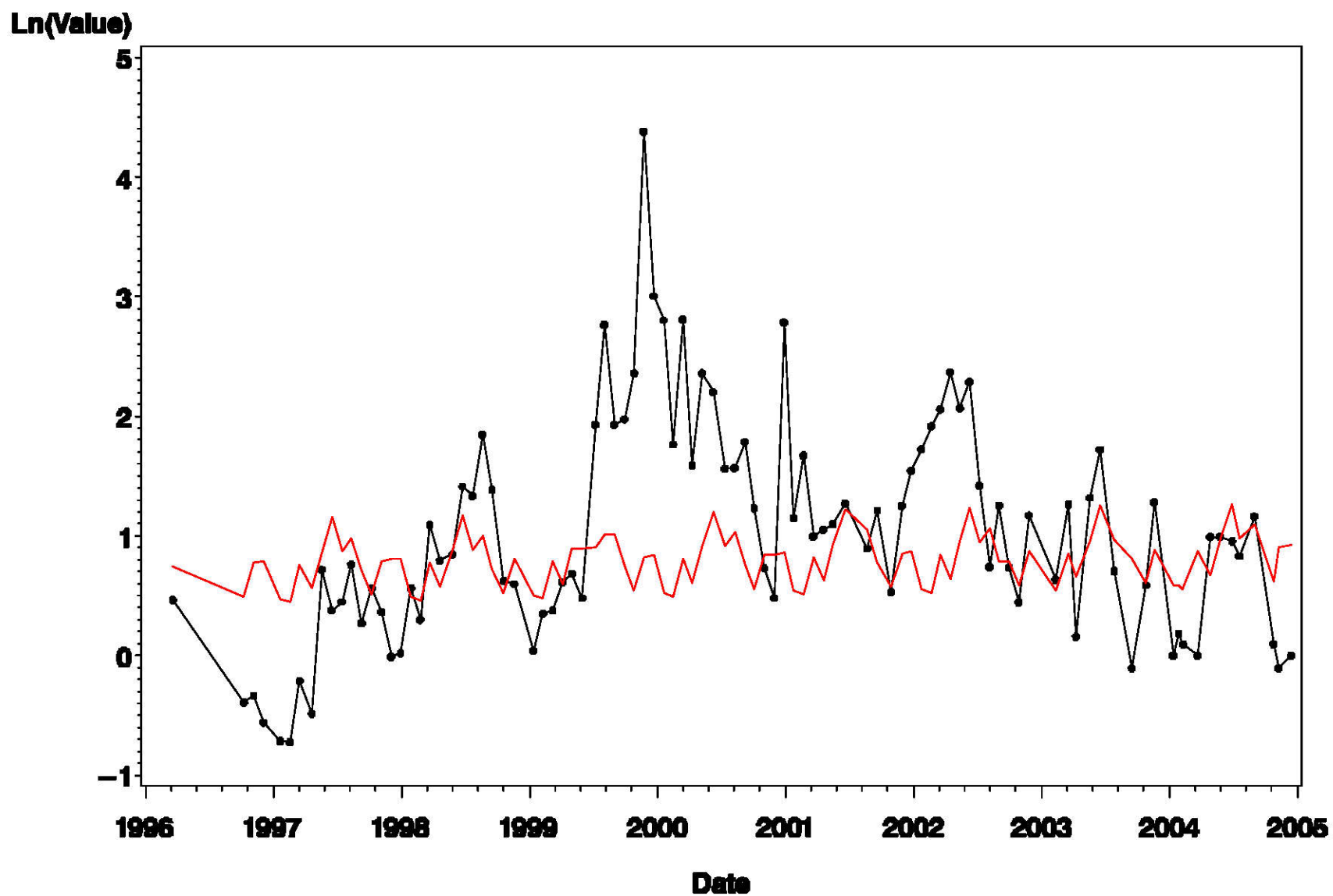


Figure A-62

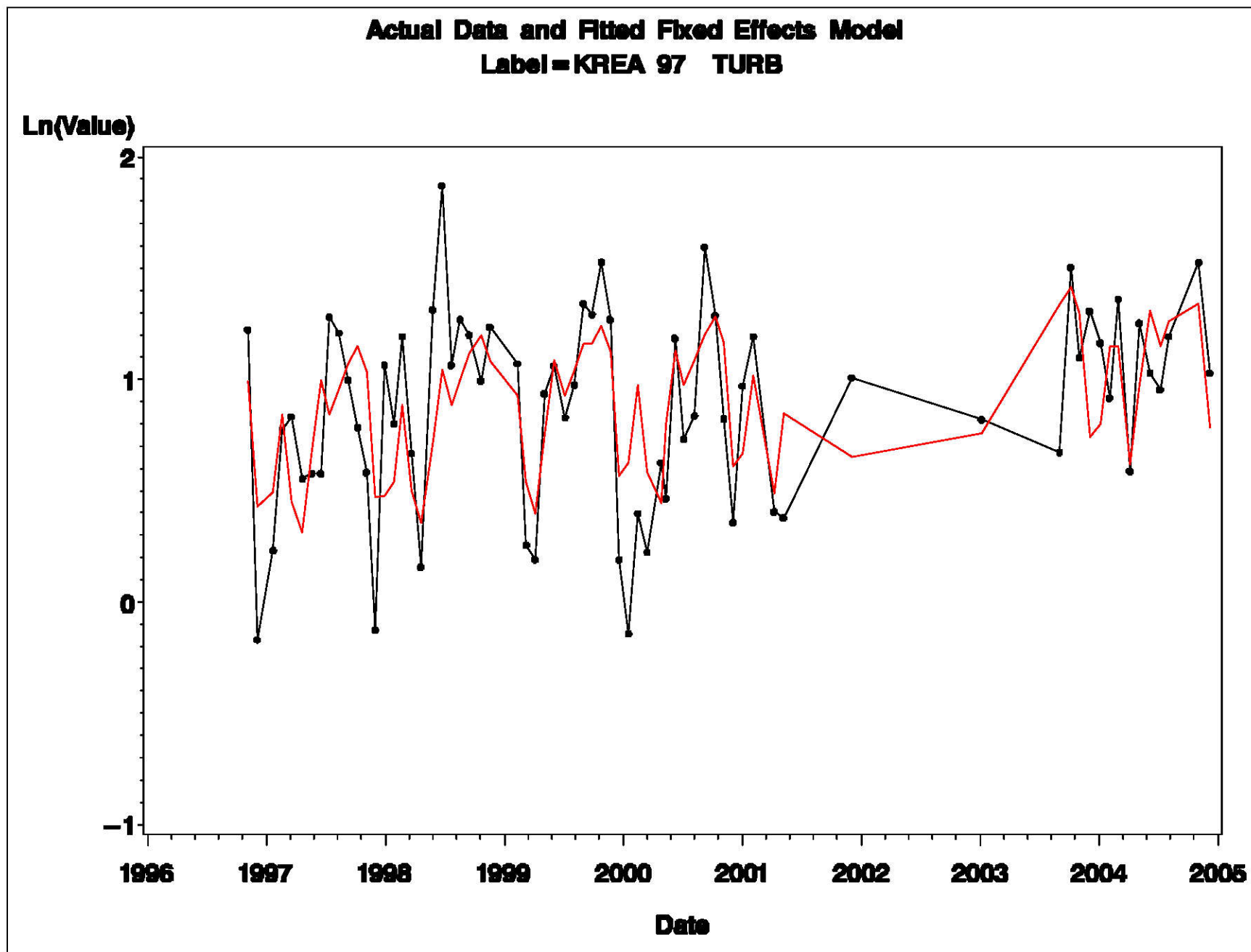


Figure A-63

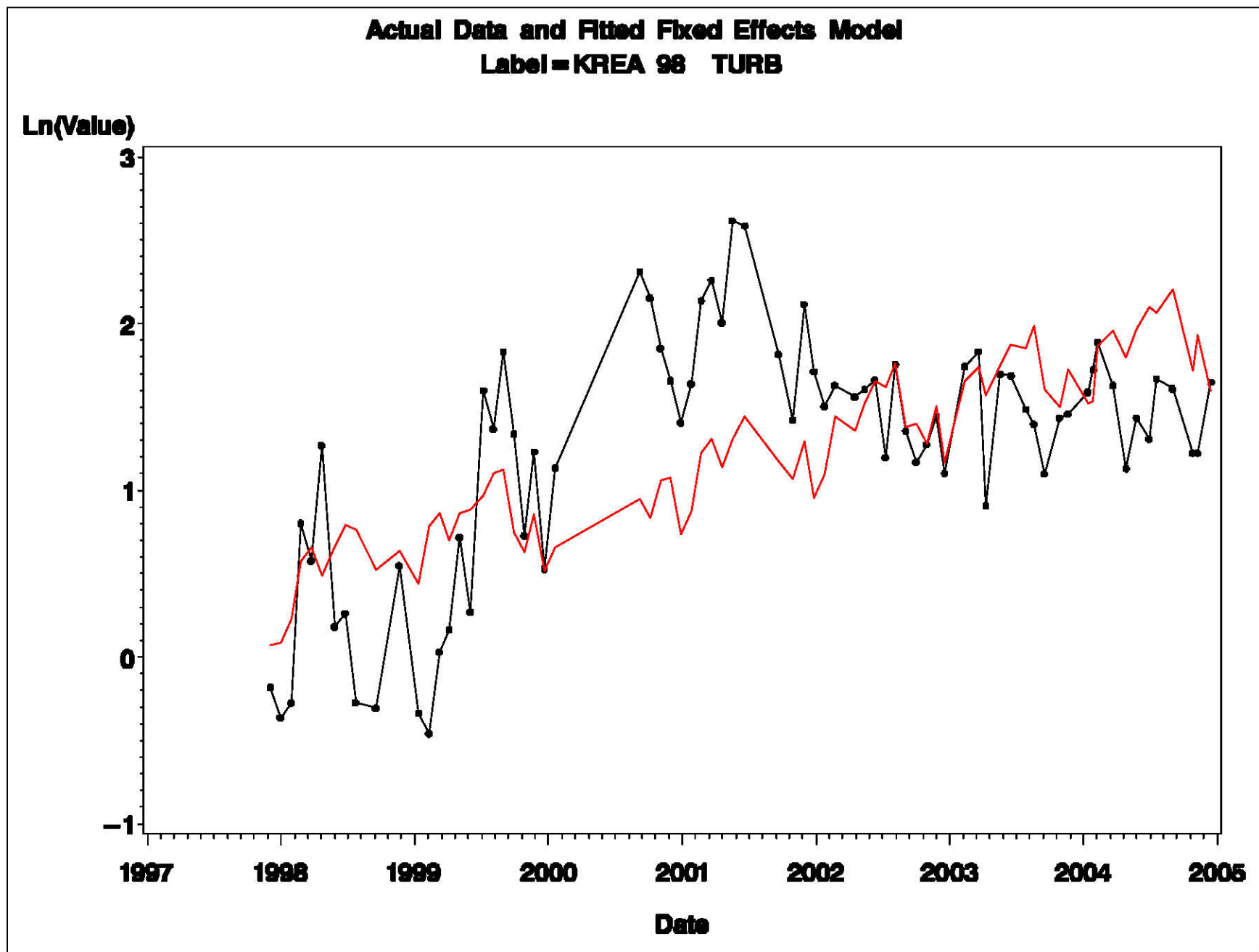


Figure A-64

Actual Data and Fitted Fixed Effects Model
Label=KREA 79 TKN

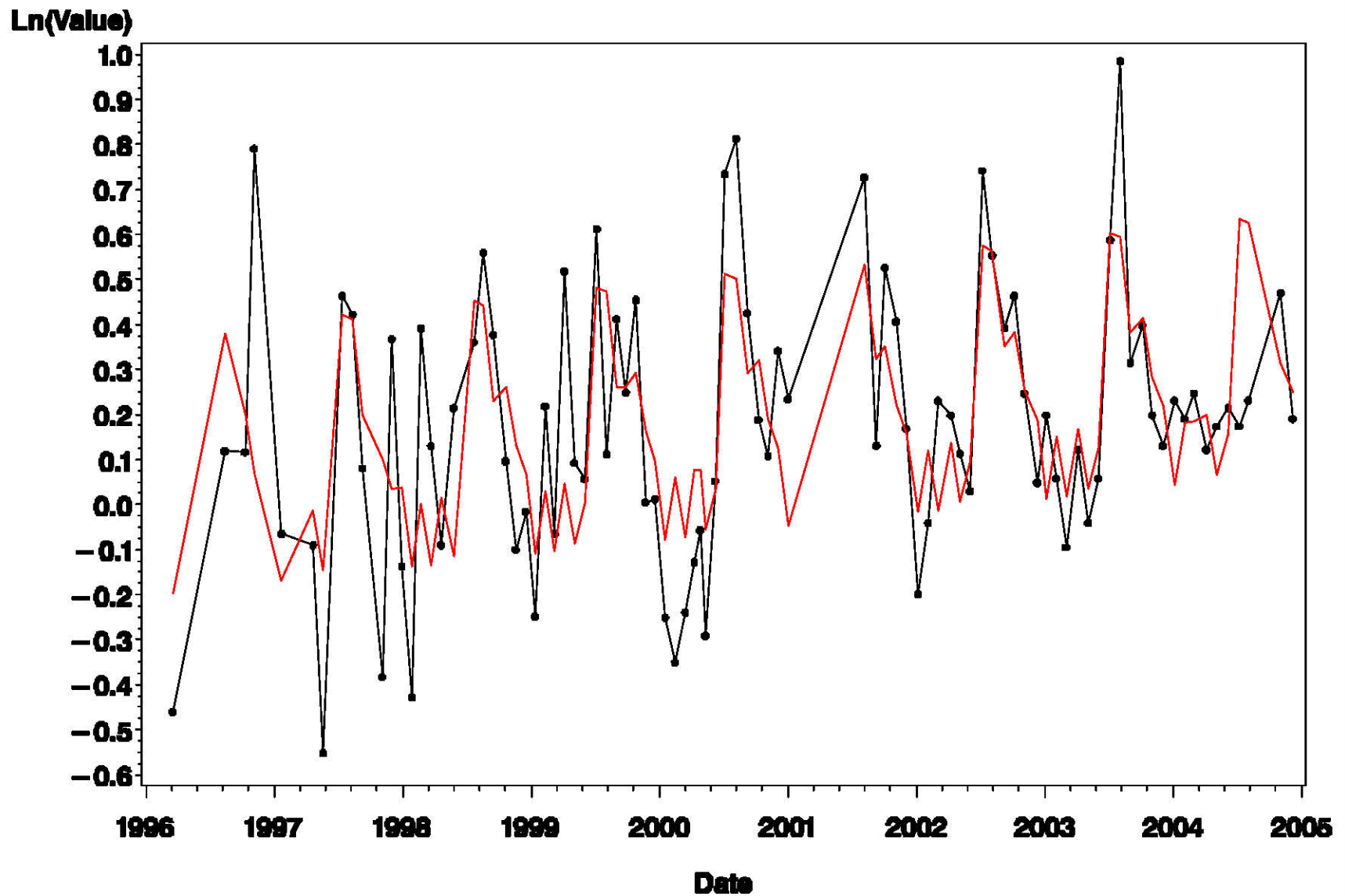


Figure A-65

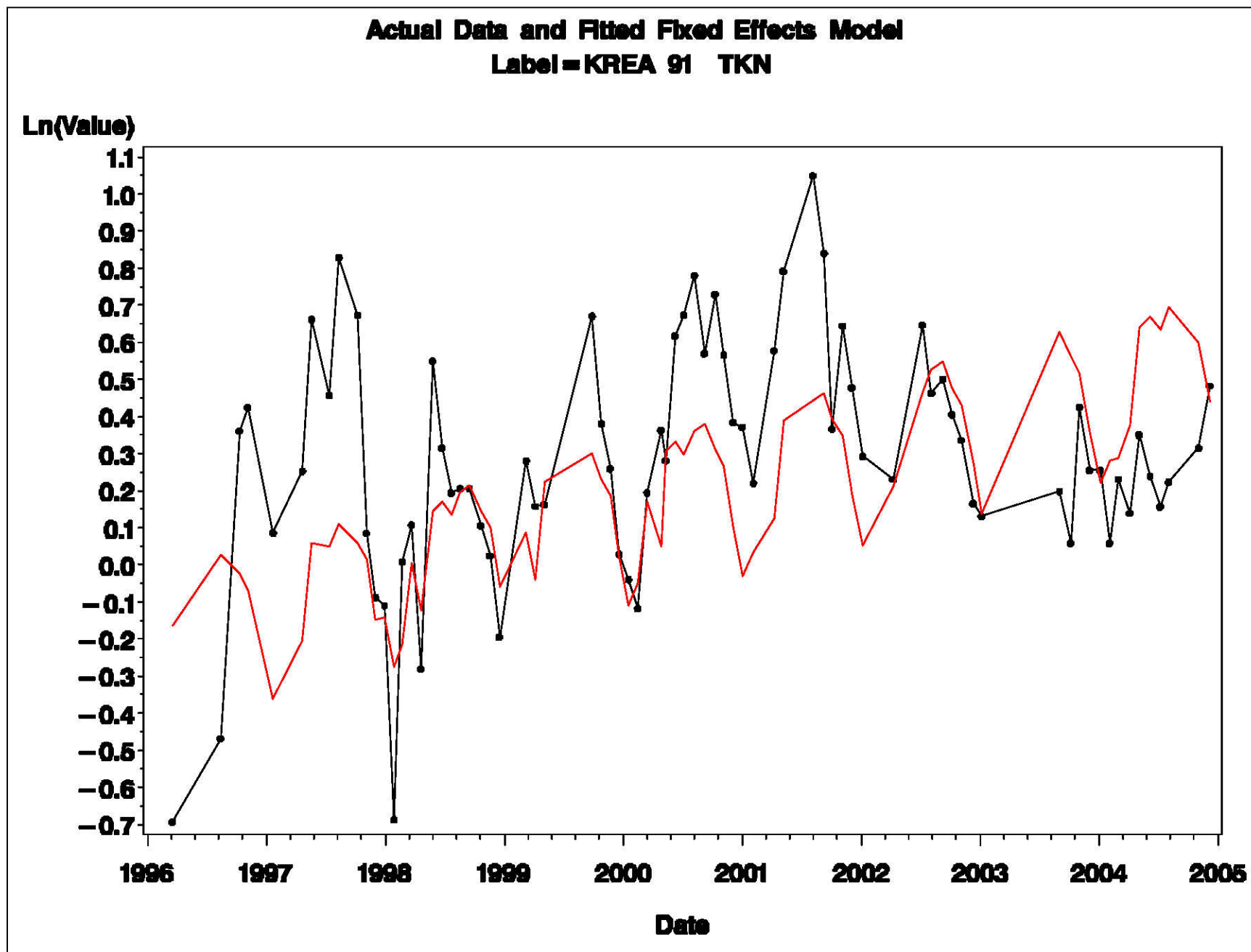


Figure A-66

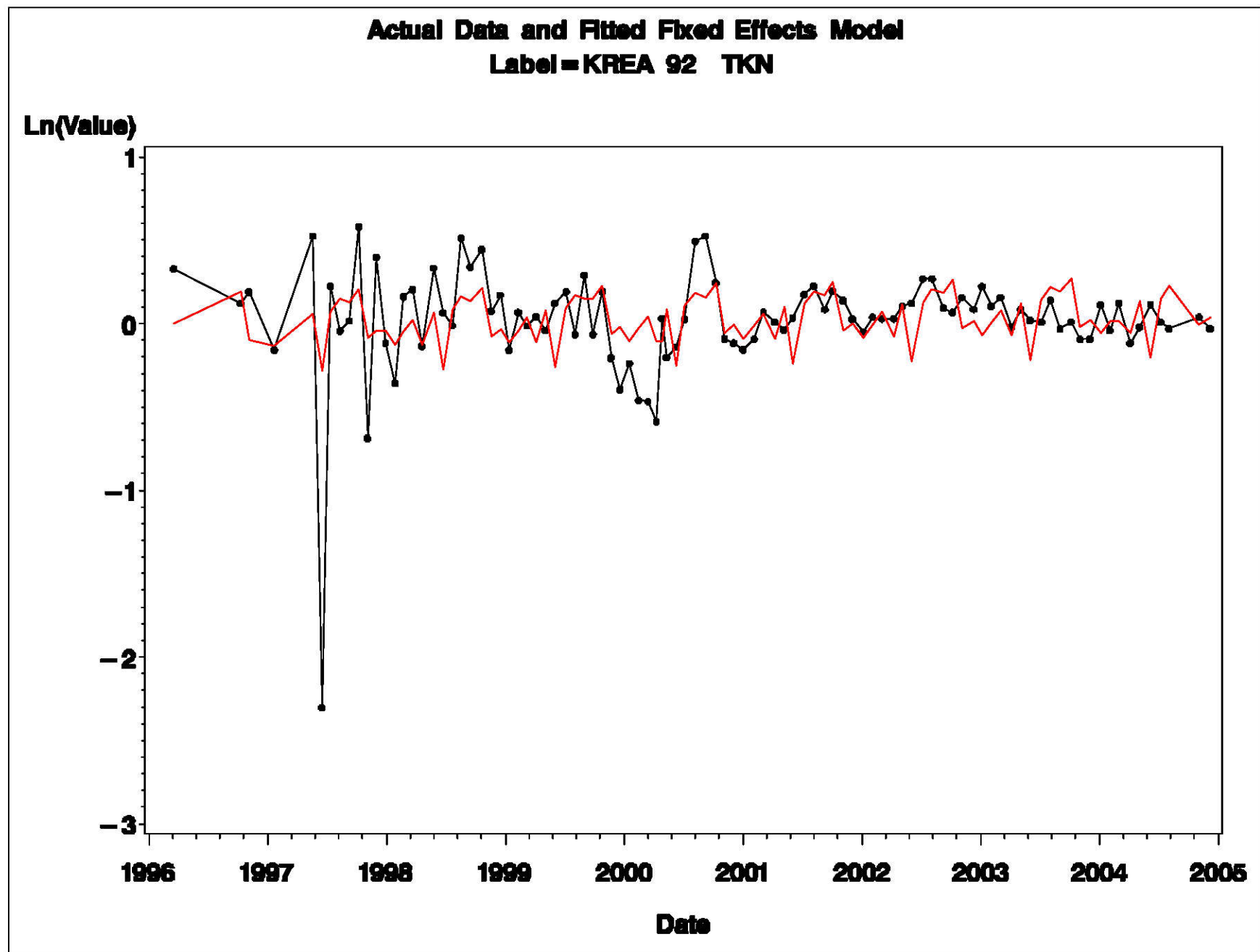


Figure A-67

Actual Data and Fitted Fixed Effects Model
Label=KREA 93 TKN

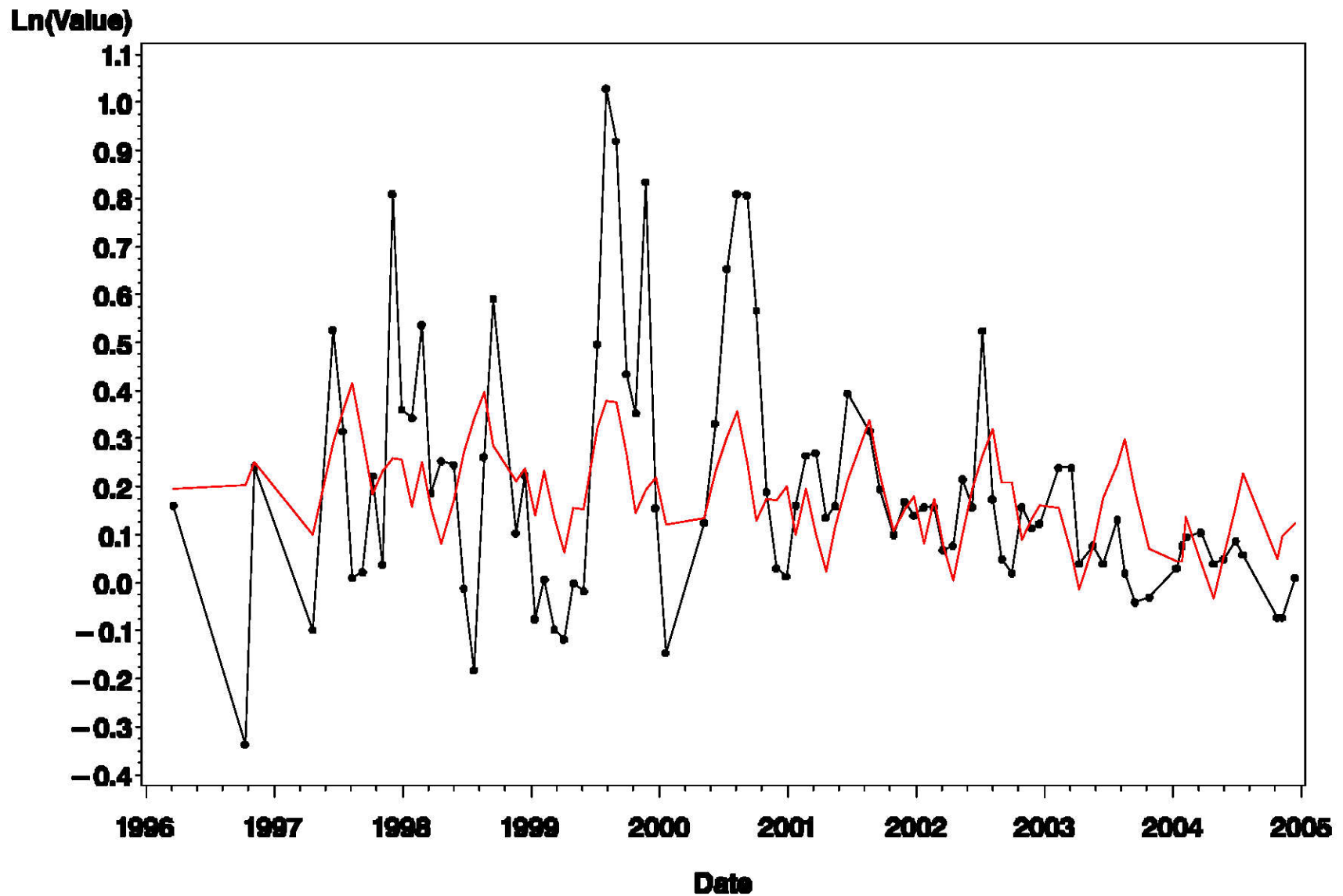


Figure A-68

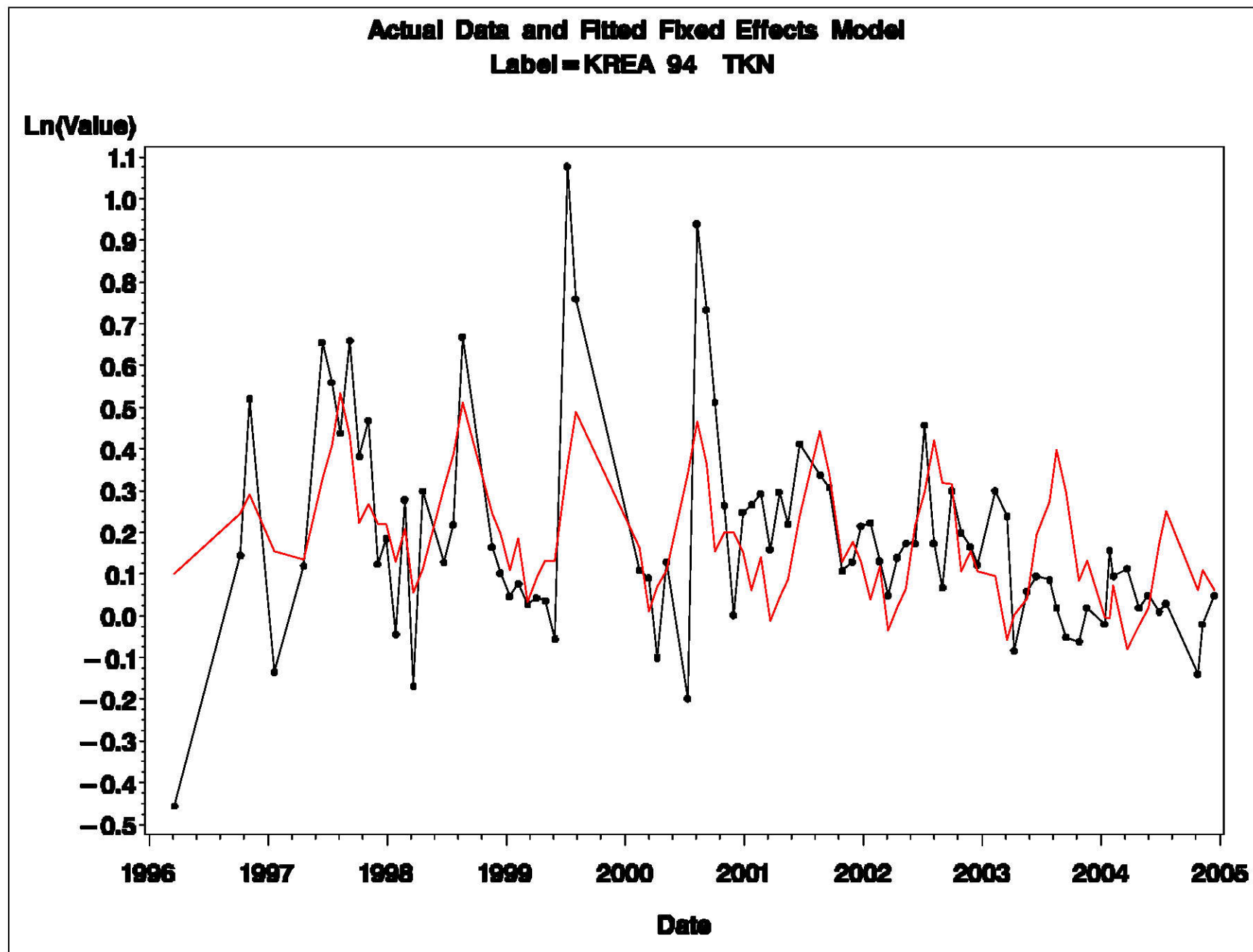


Figure A-69

Actual Data and Fitted Fixed Effects Model
Label=KREA 95 TKN

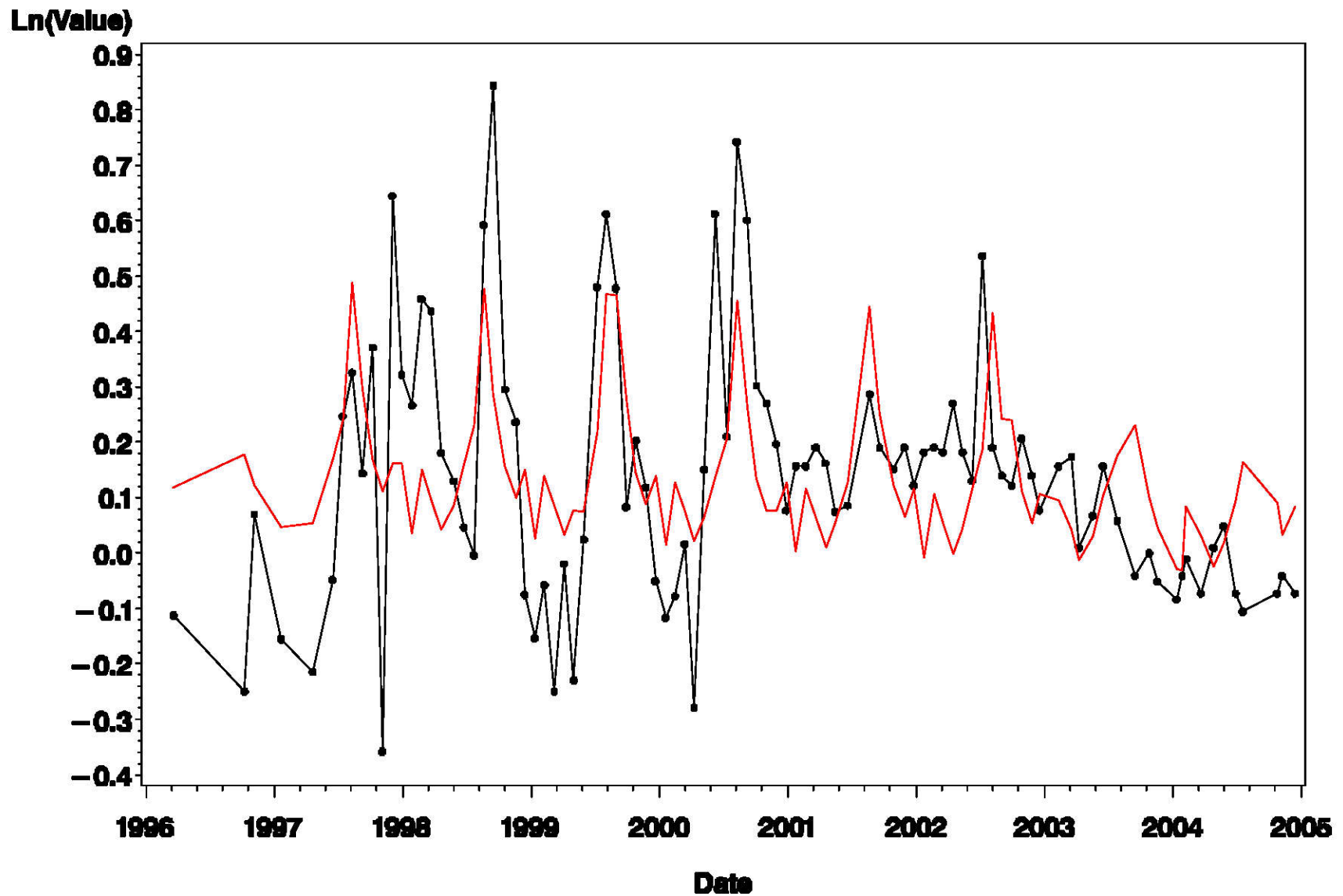


Figure A-70

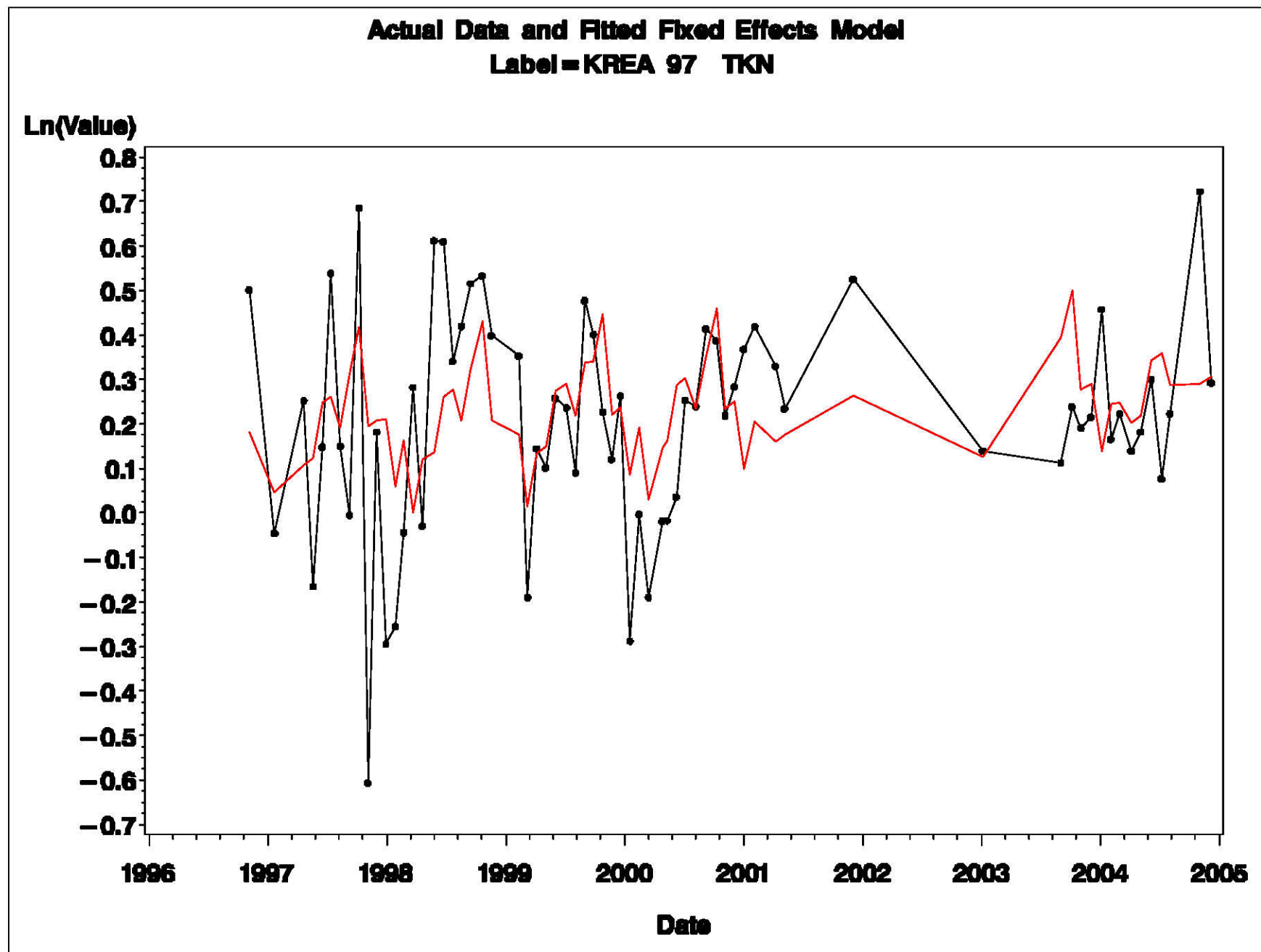


Figure A-71

Actual Data and Fitted Fixed Effects Model
Label=KREA 98 TKN

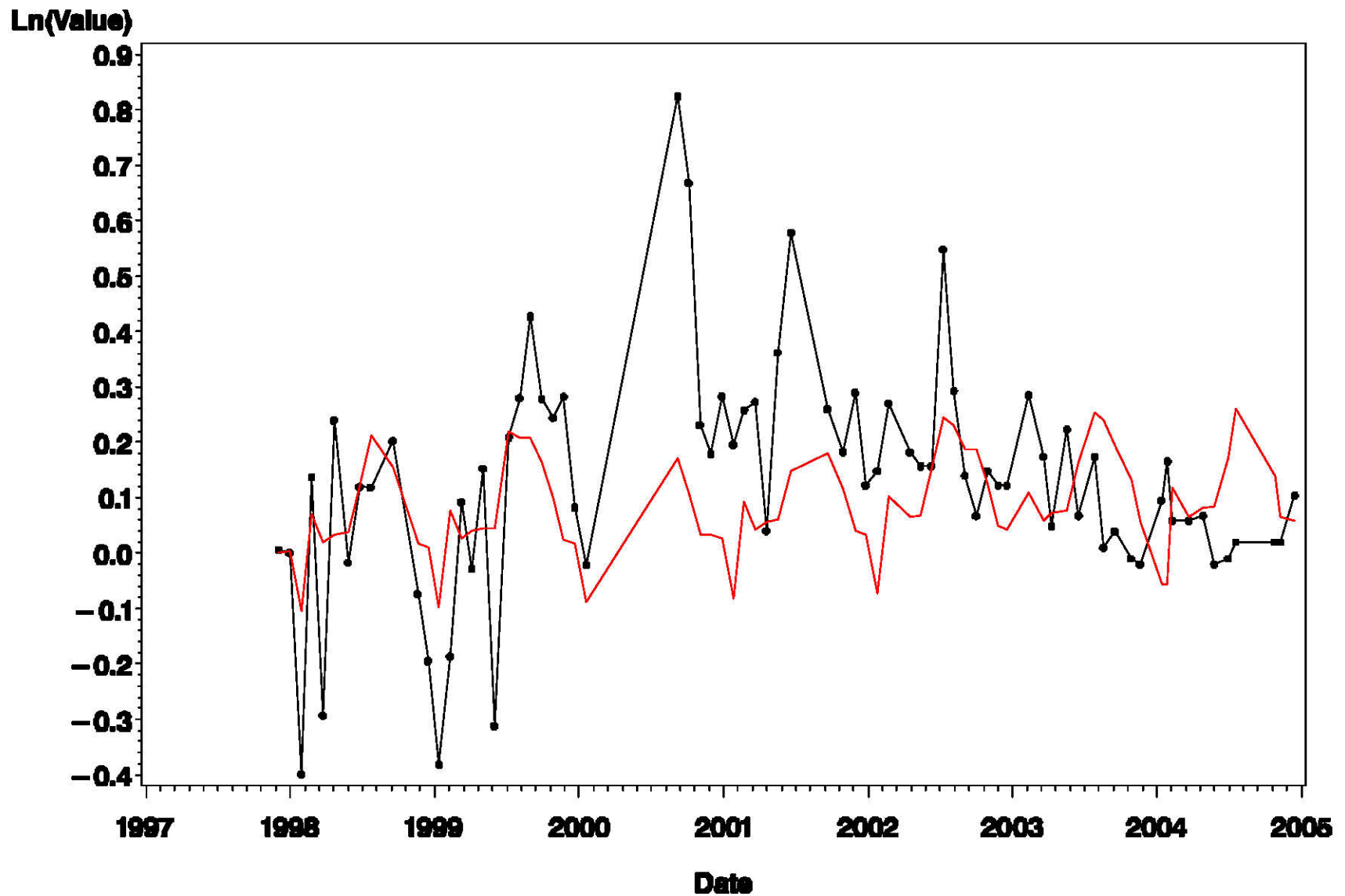


Figure A-72

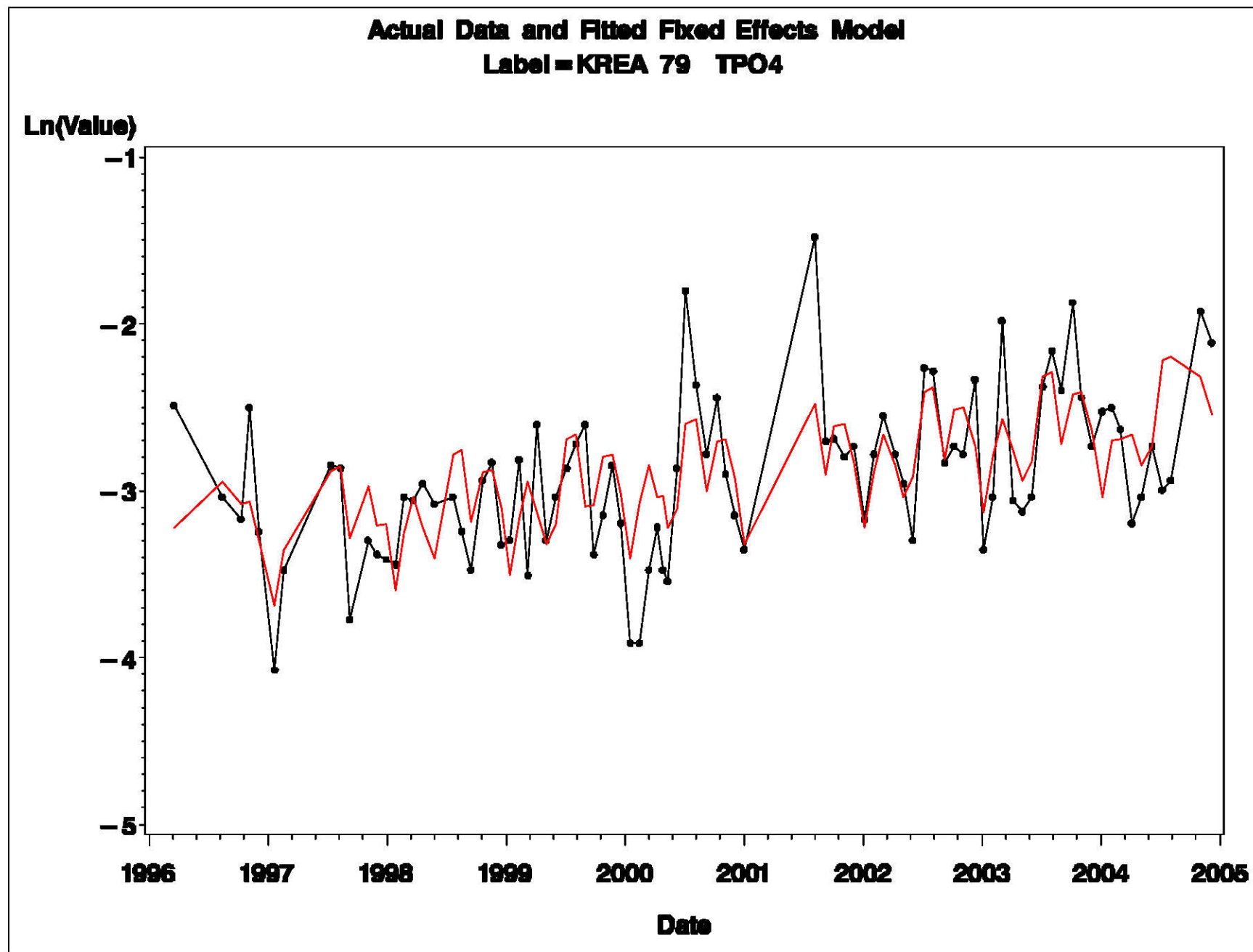


Figure A-73

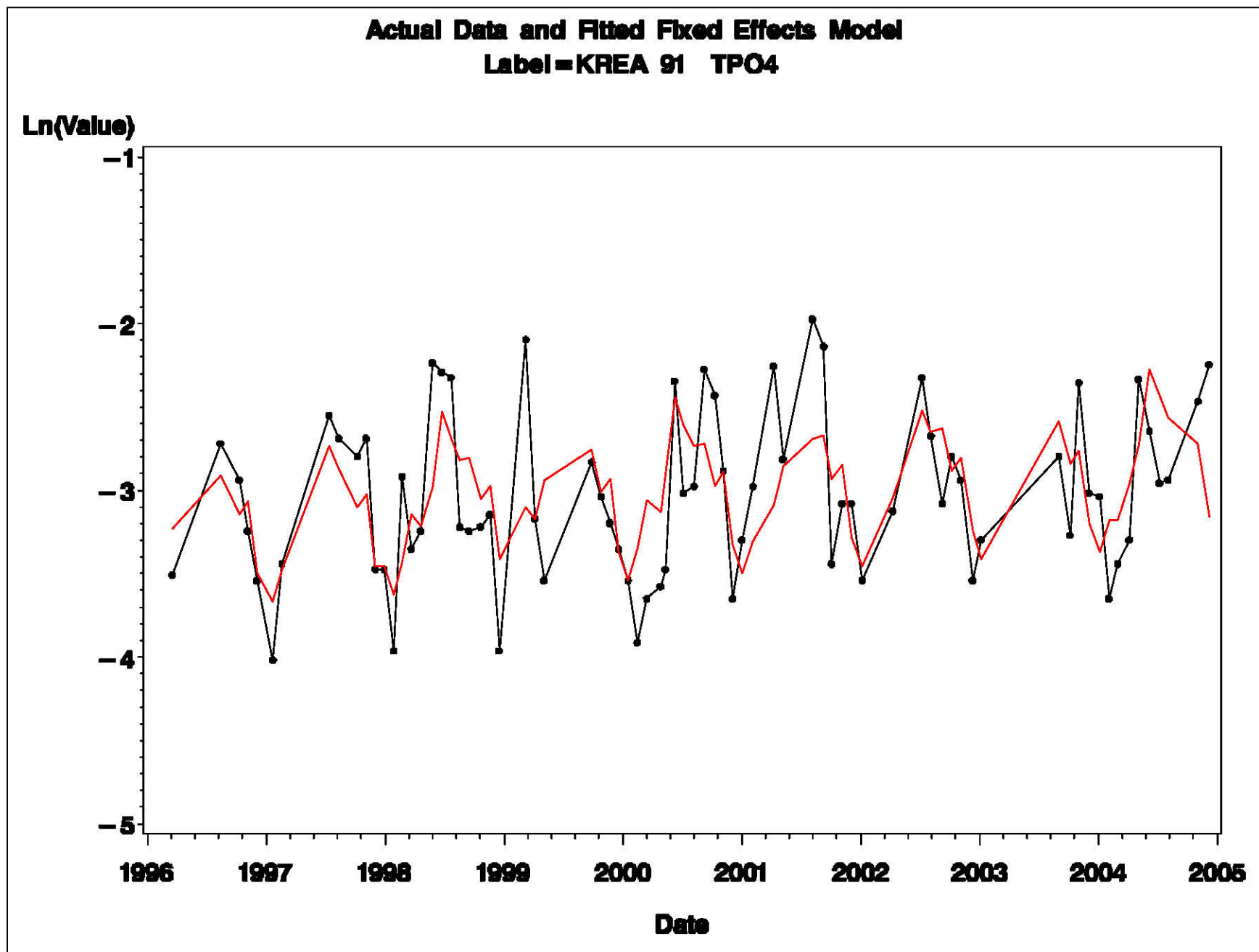


Figure A-74

Actual Data and Fitted Fixed Effects Model
Label = KREA 92 TPO4

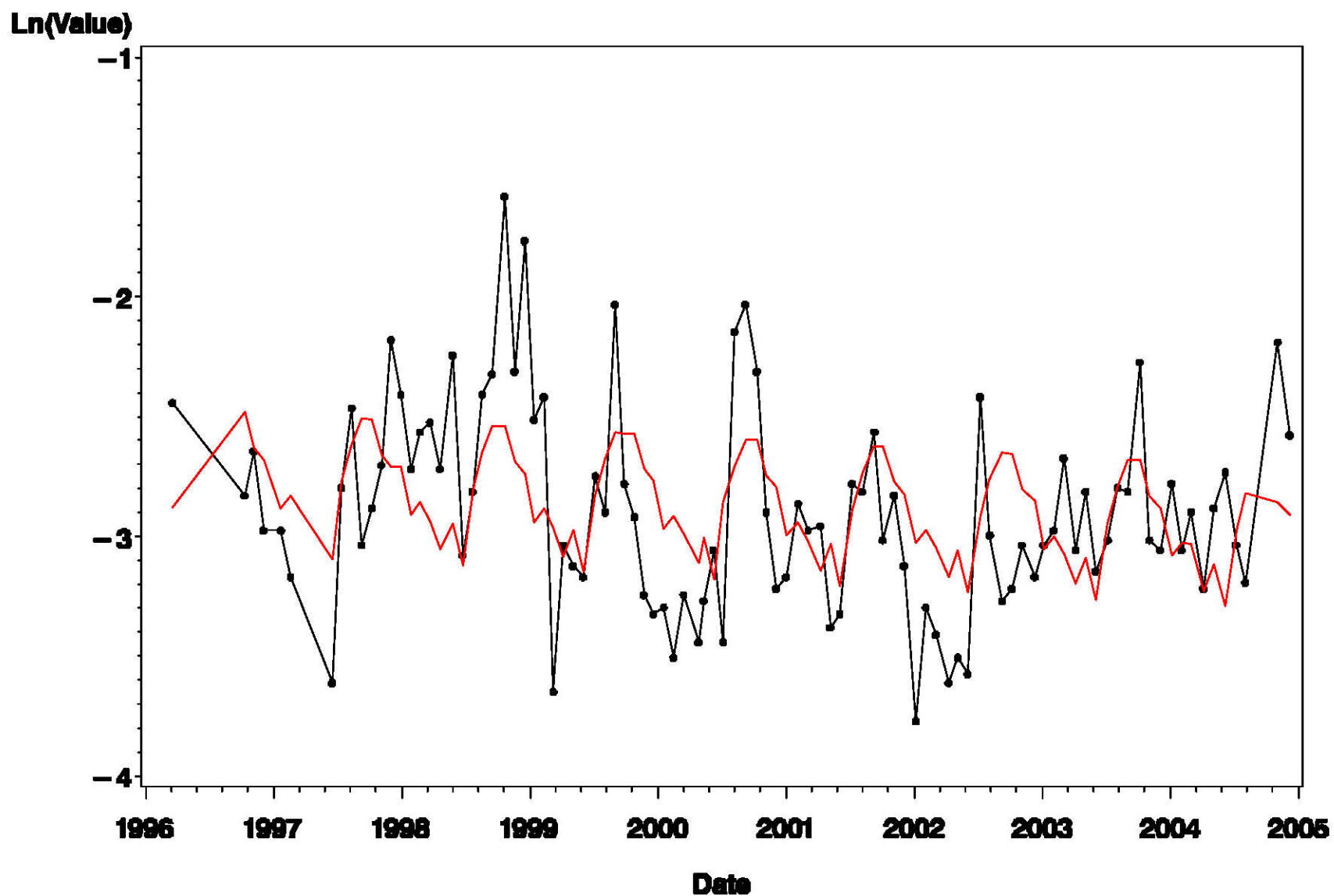


Figure A-75

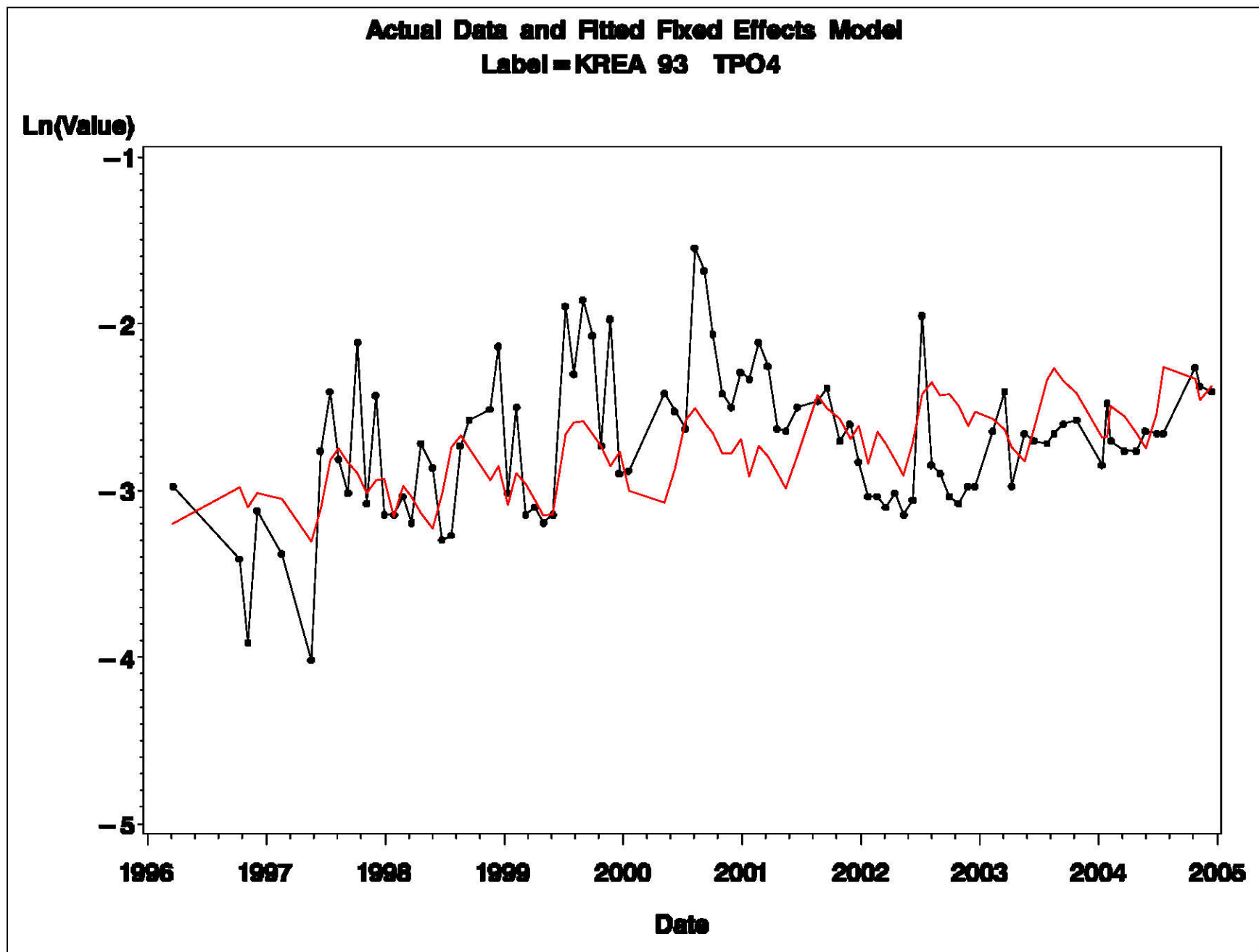


Figure A-76

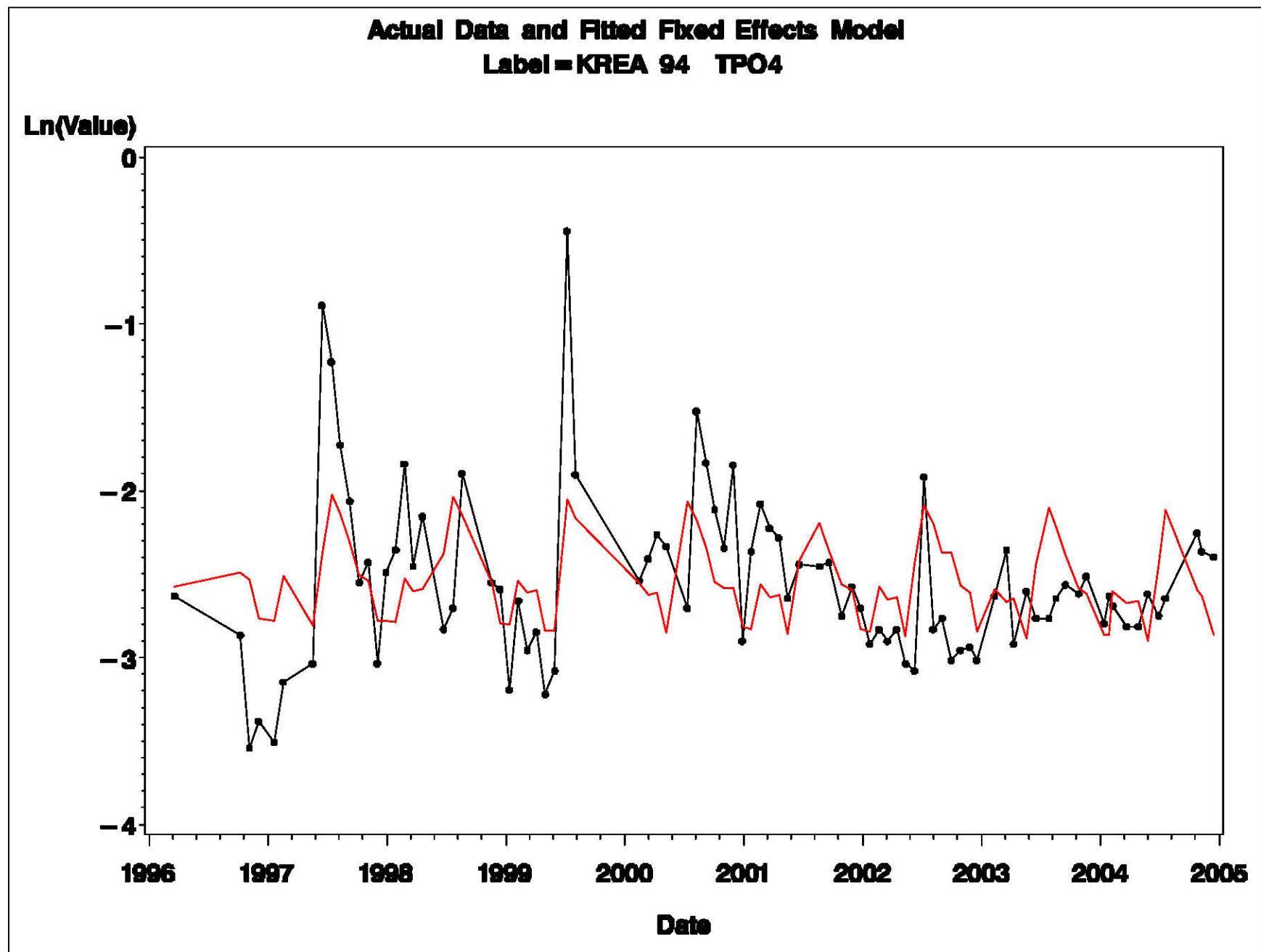


Figure A-77

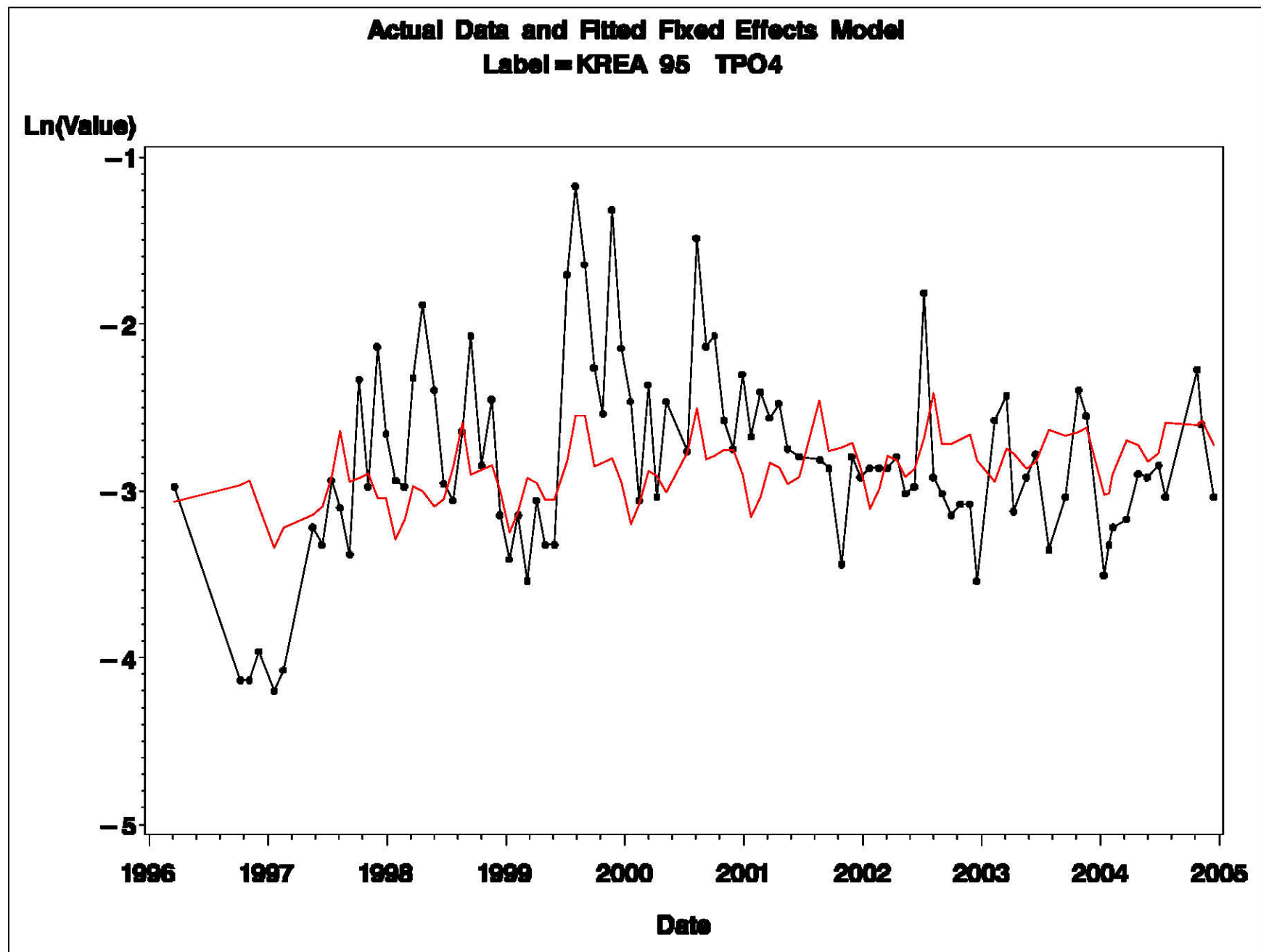


Figure A-78

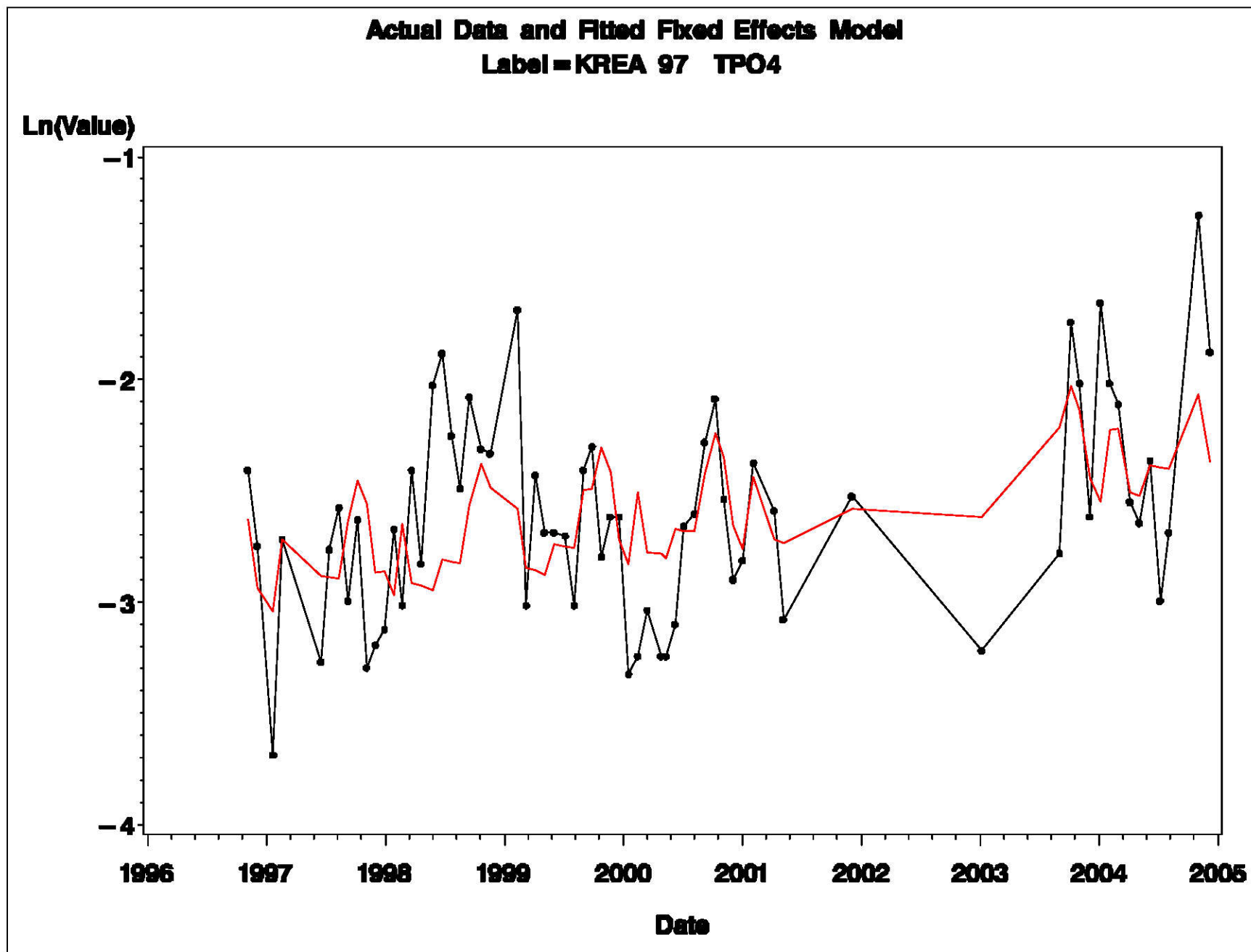


Figure A-79

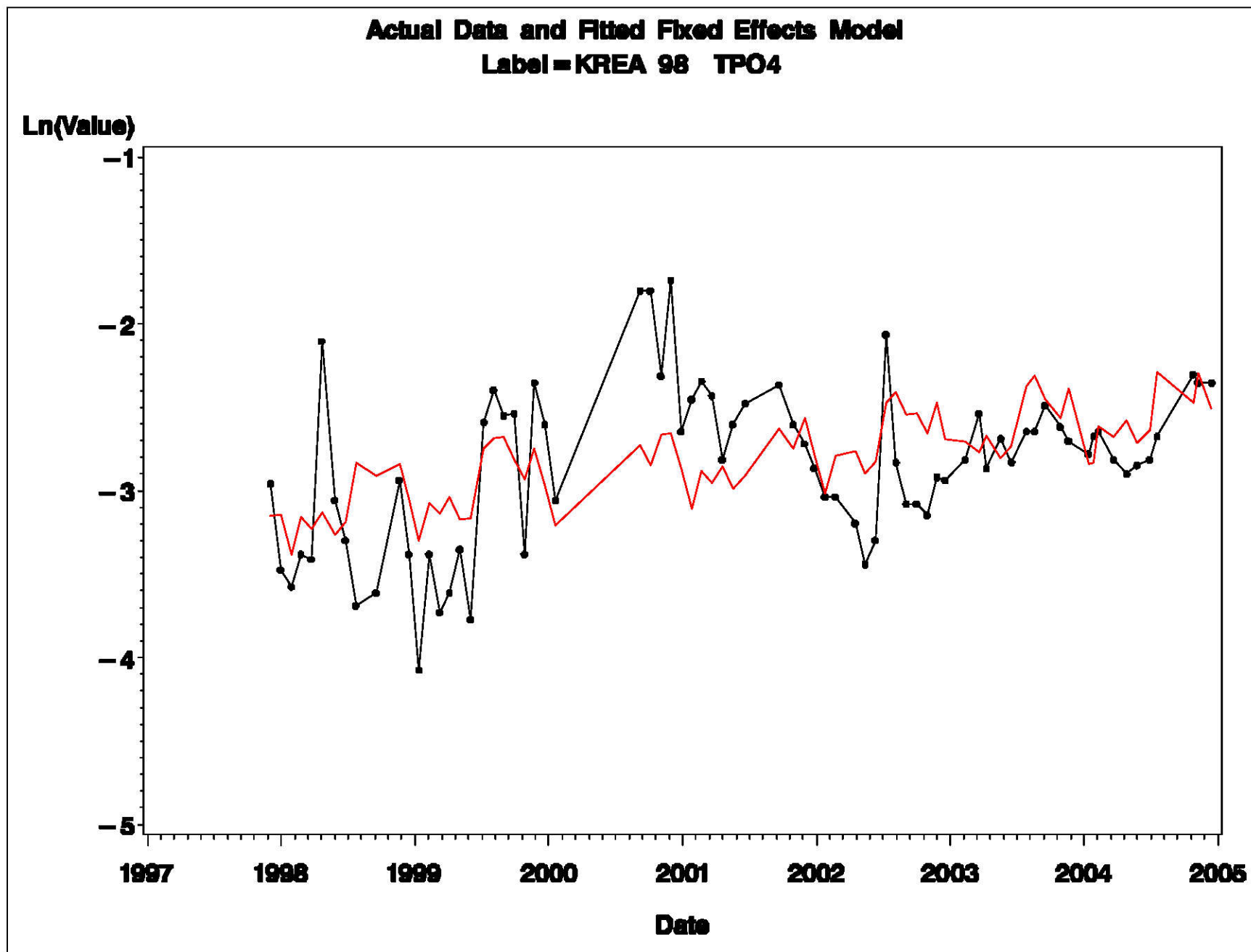


Figure A-80

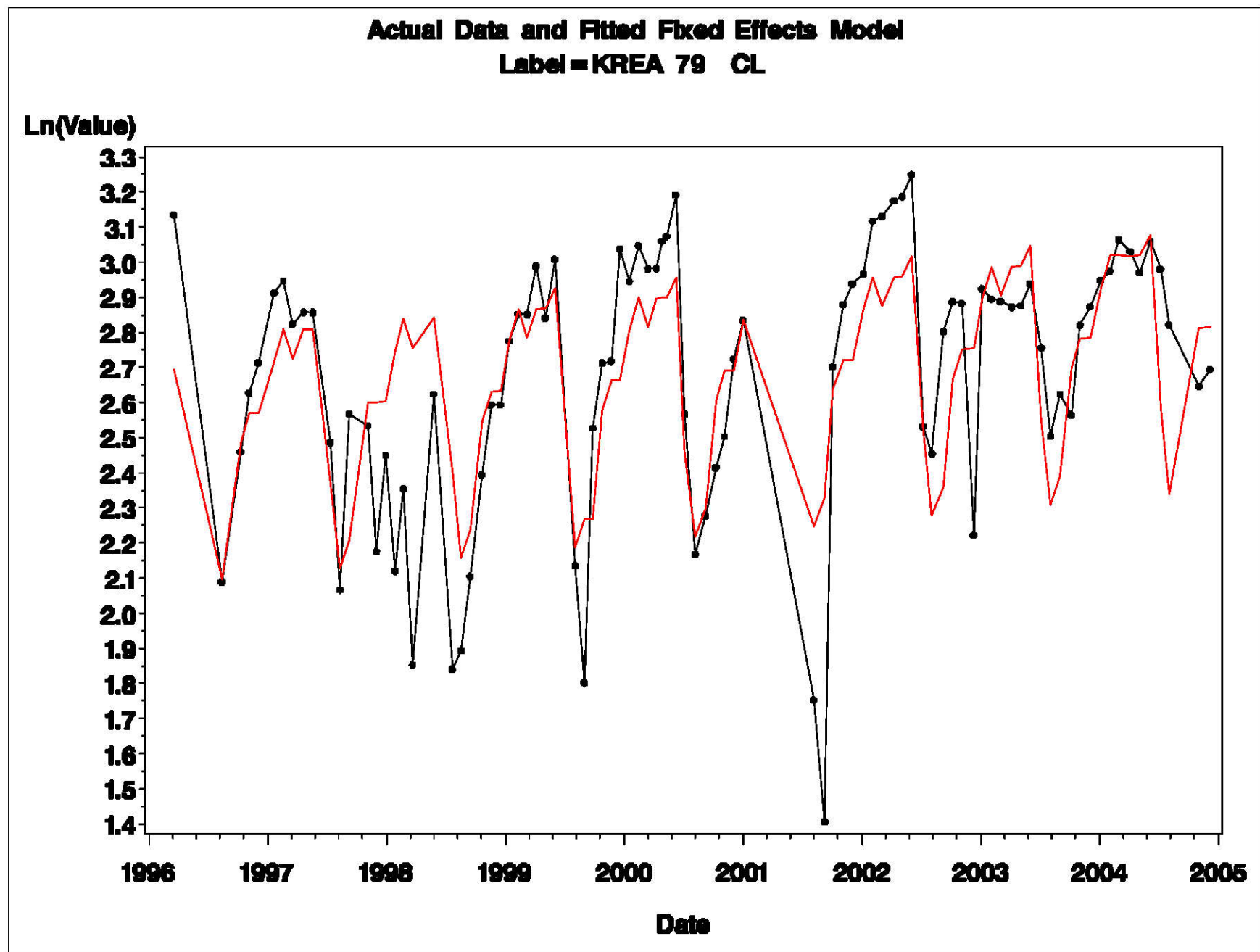


Figure A-81

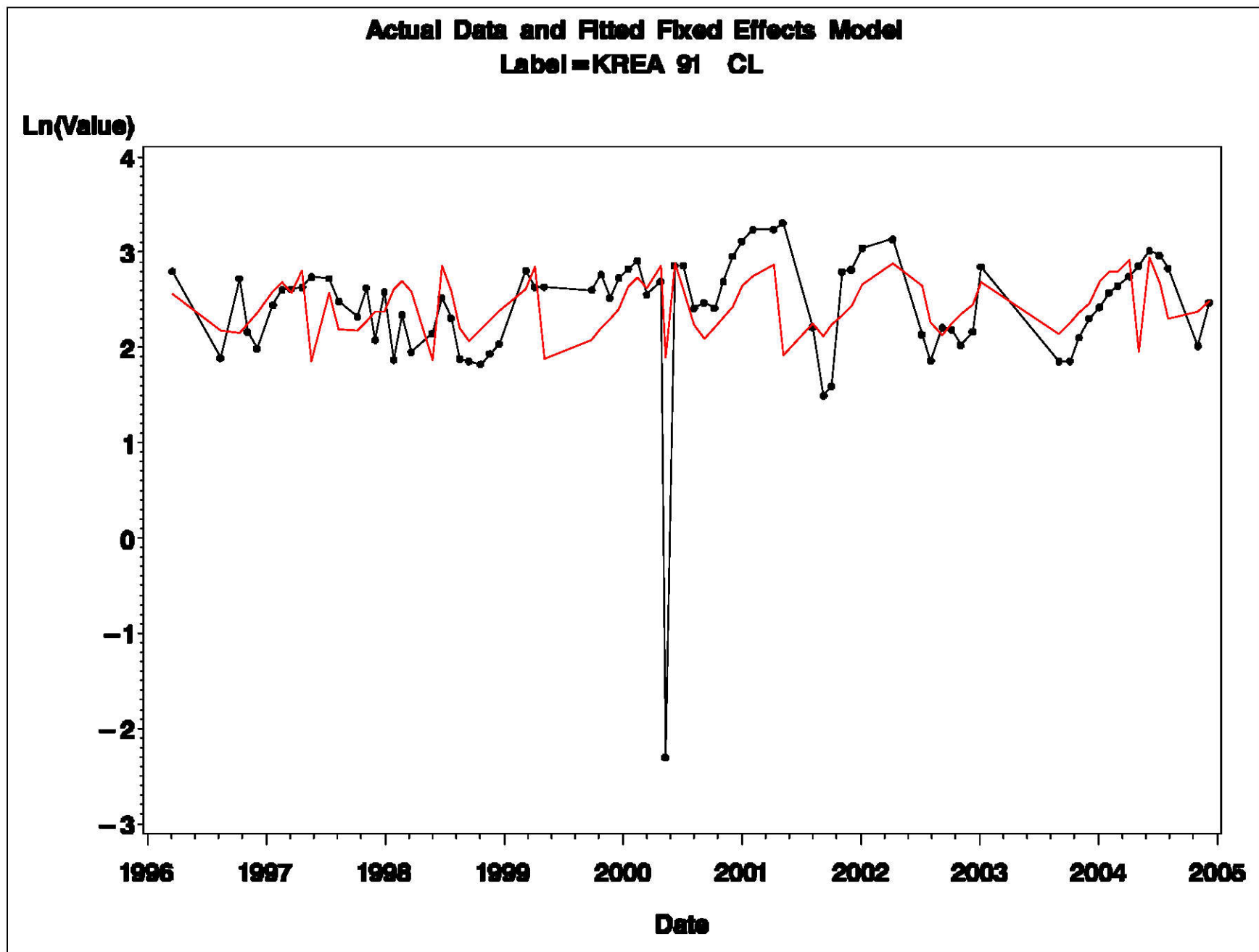


Figure A-82

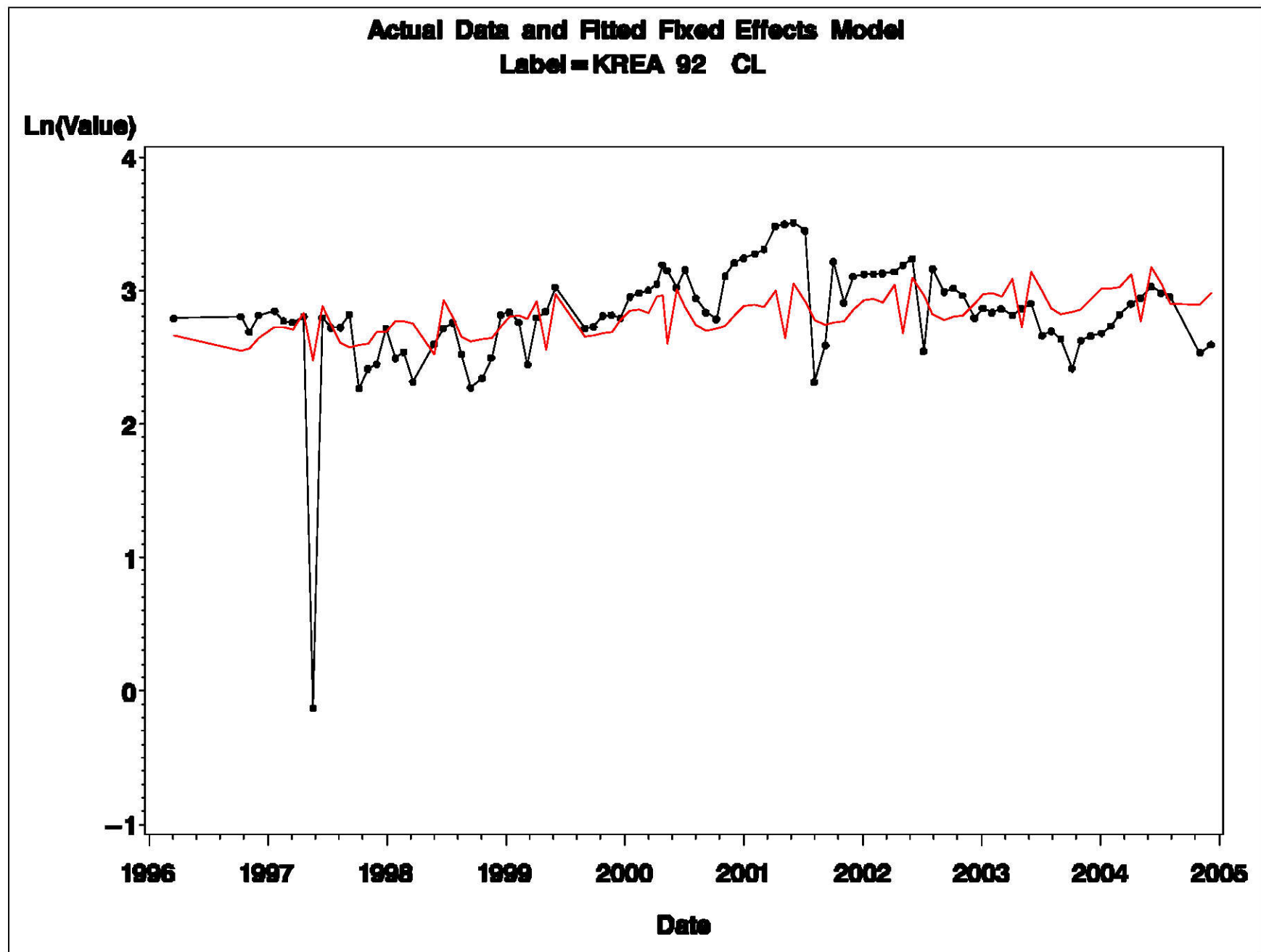


Figure A-83

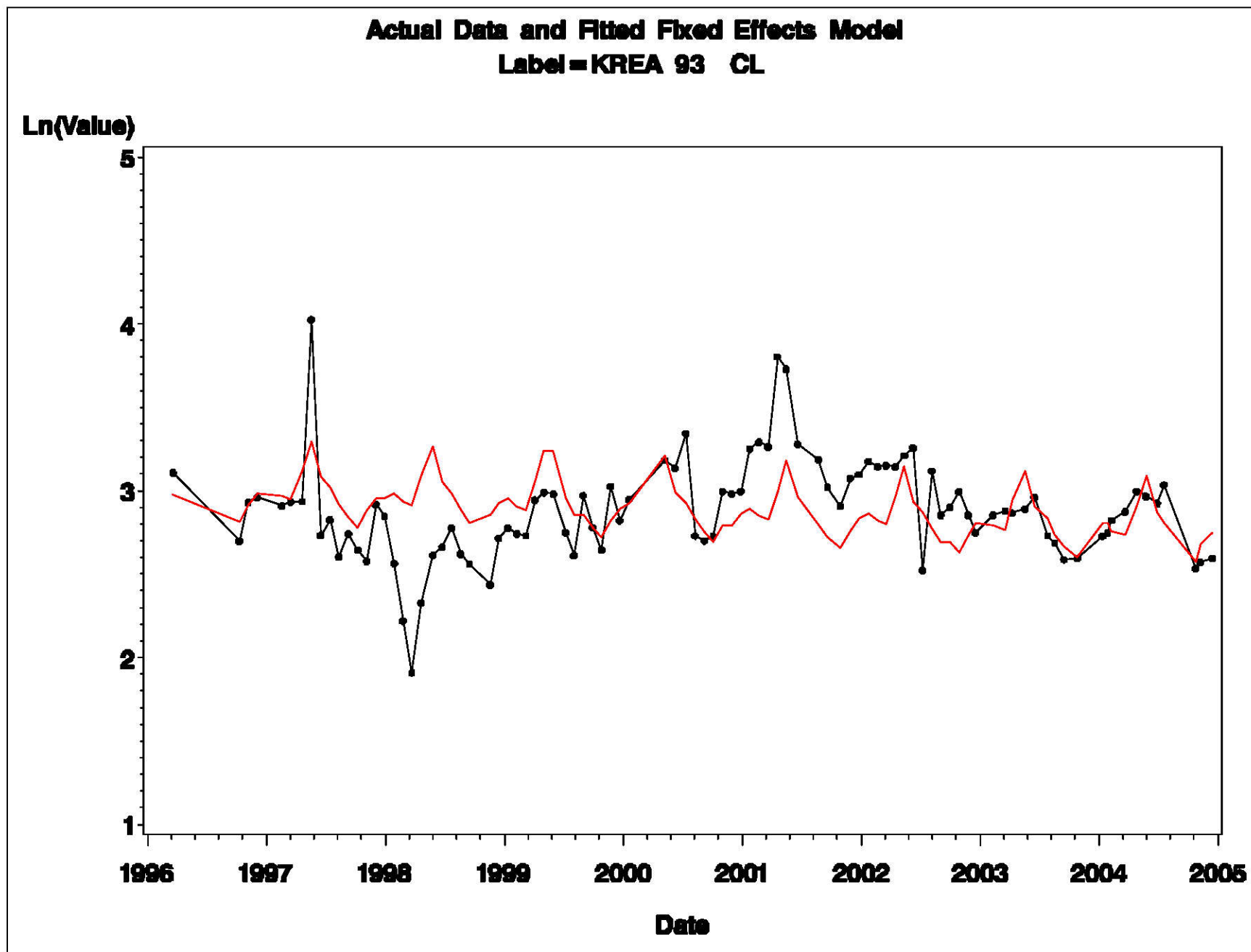


Figure A-84

Actual Data and Fitted Fixed Effects Model
Label = KREA 94 CL

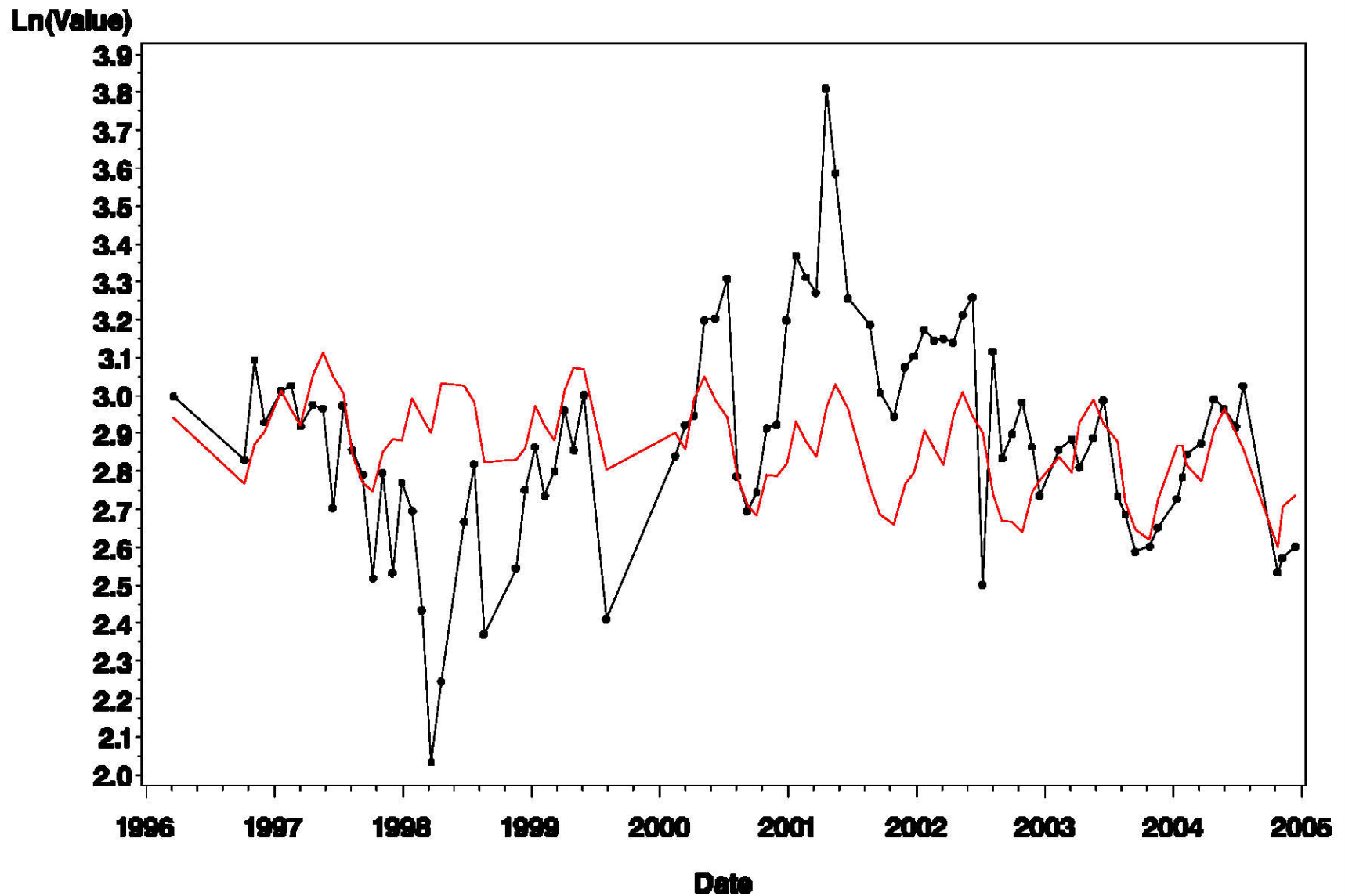


Figure A-85

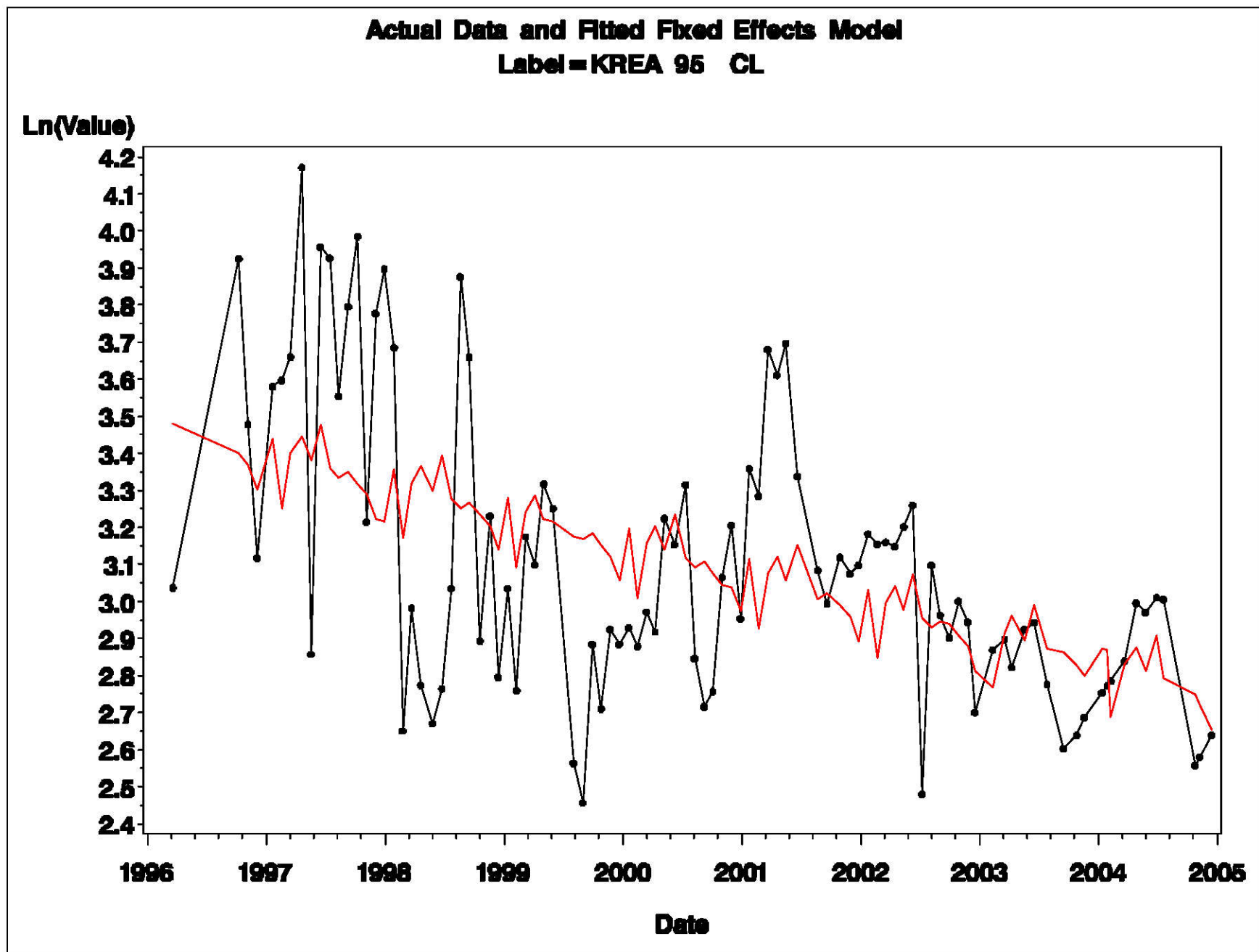


Figure A-86

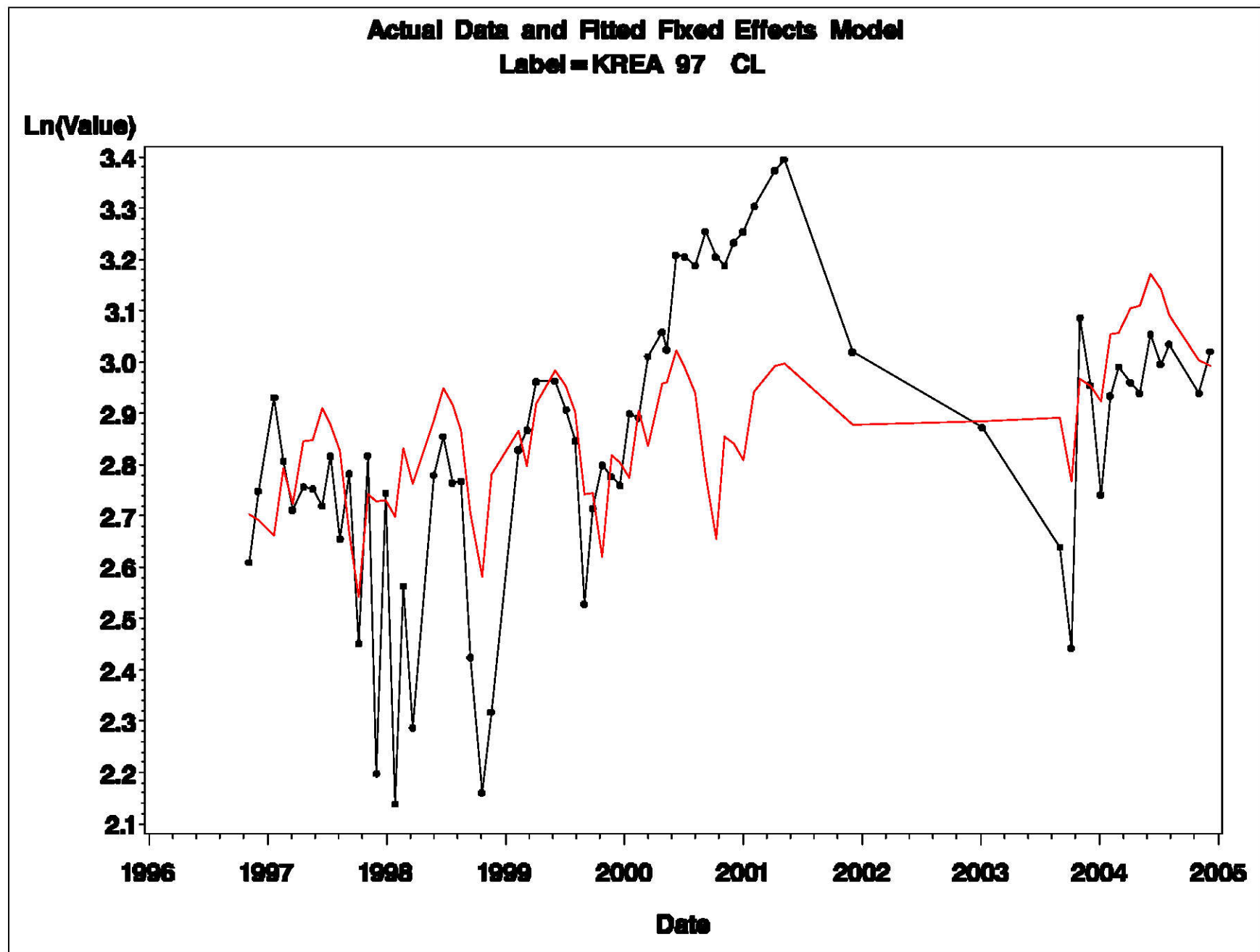


Figure A-87

Actual Data and Fitted Fixed Effects Model
Label = KREA 98 CL

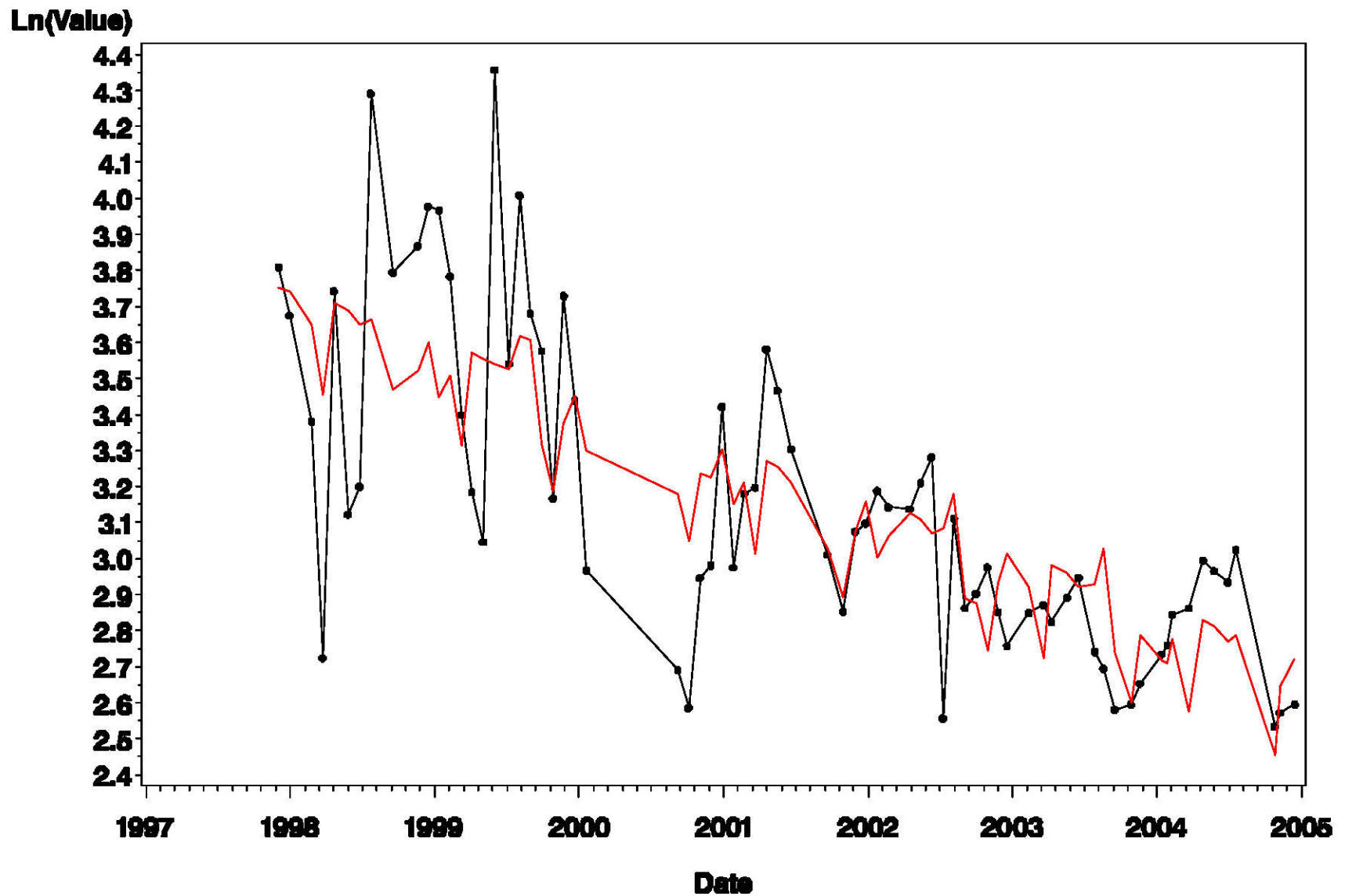


Figure A-88

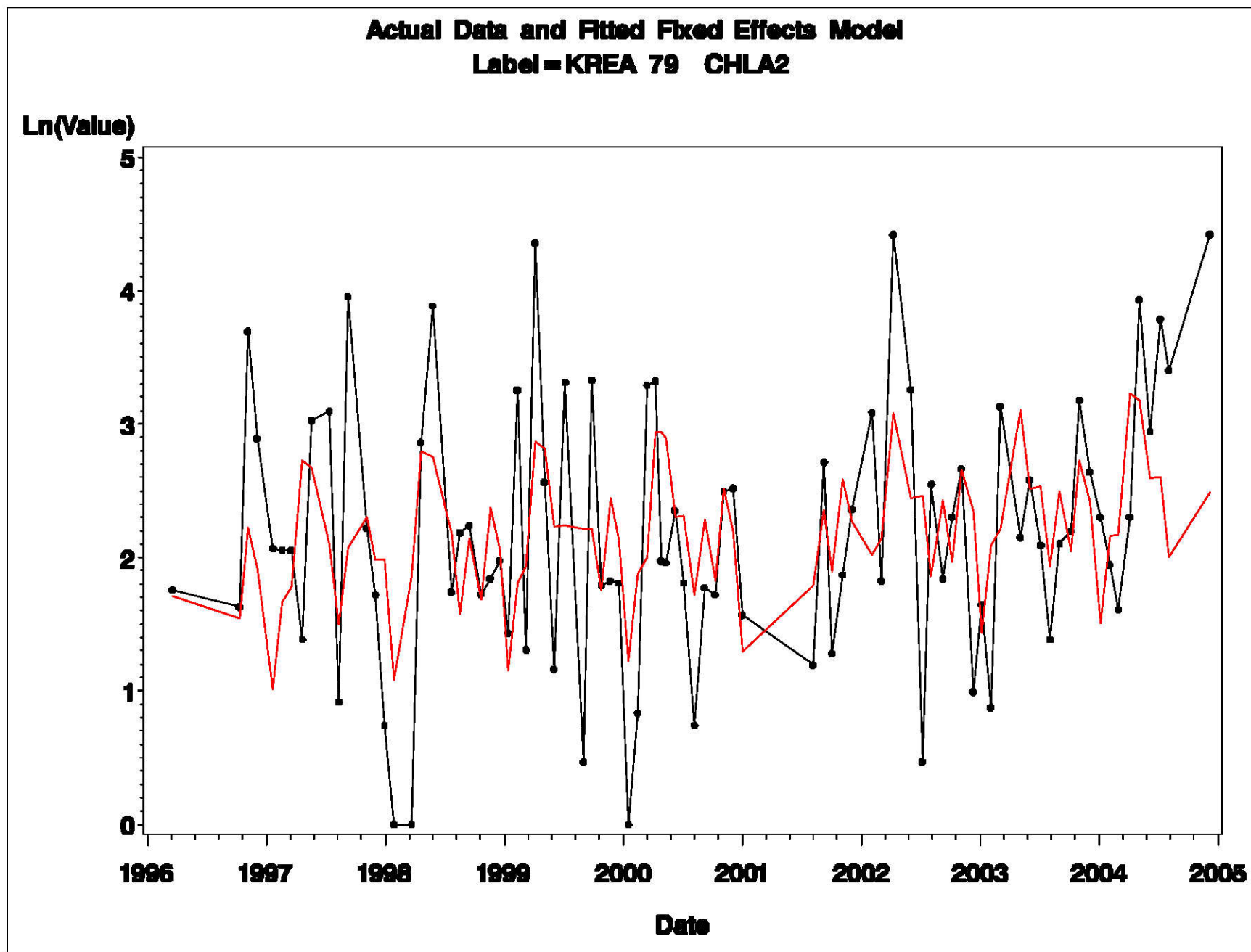


Figure A-89

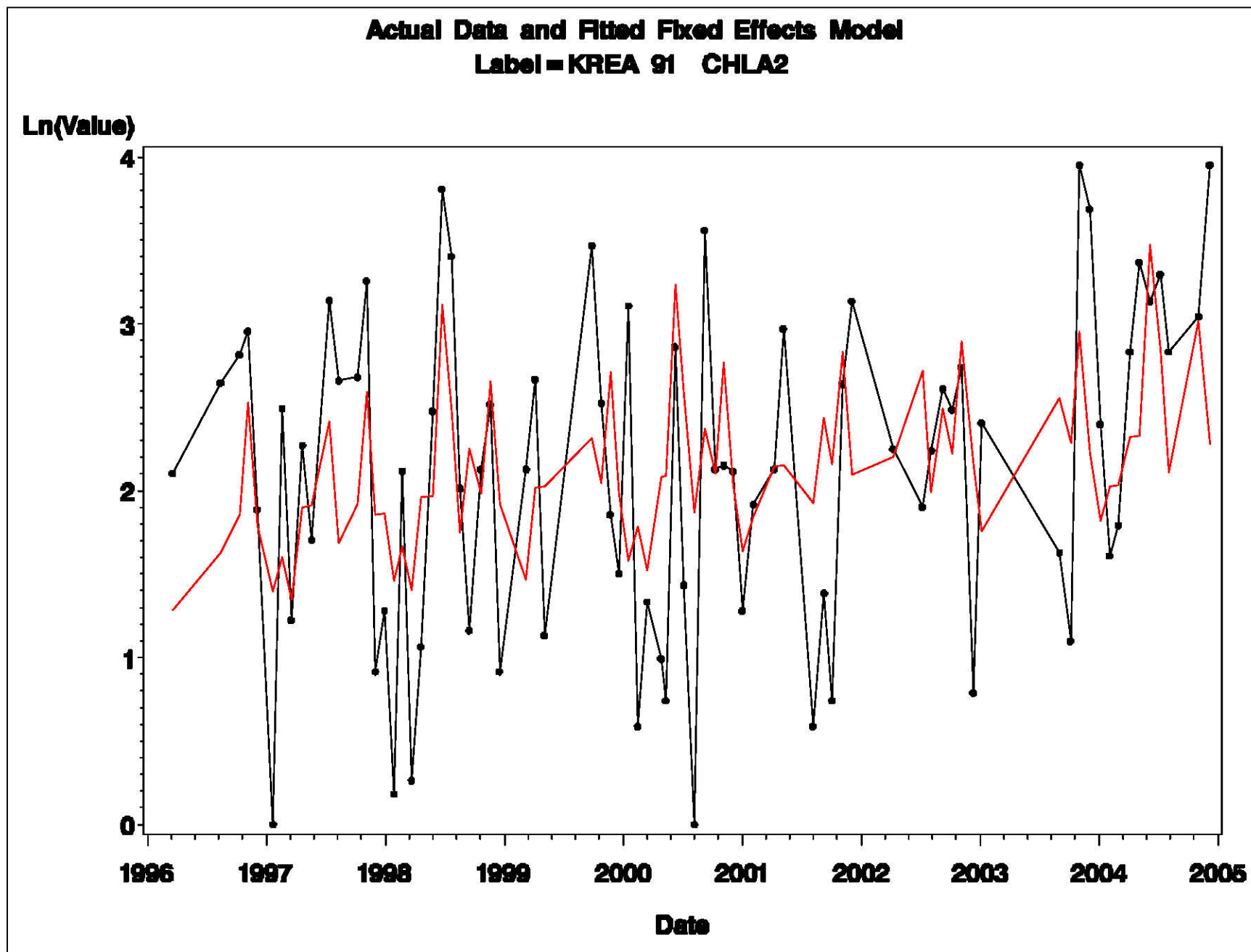


Figure A-90

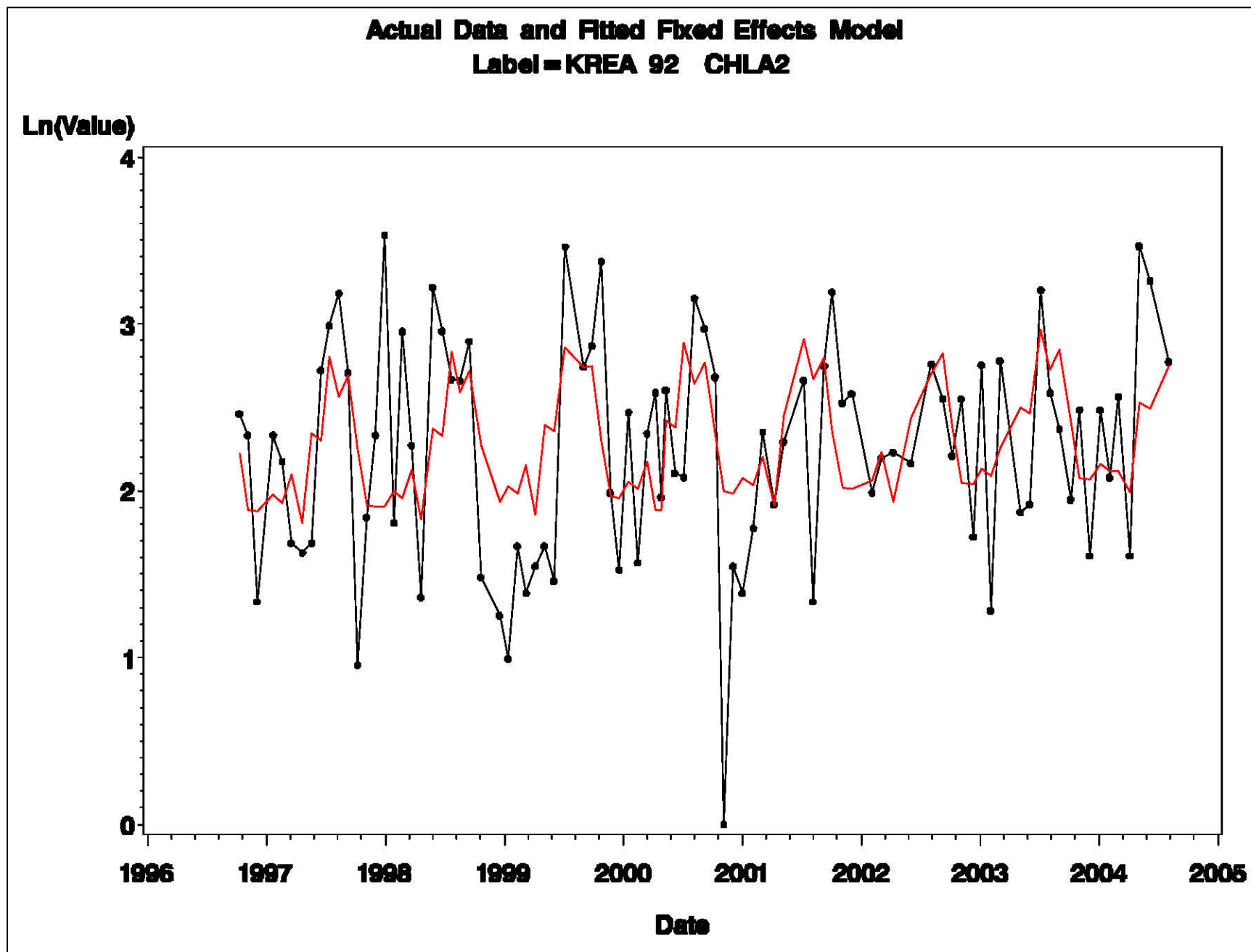


Figure A-91

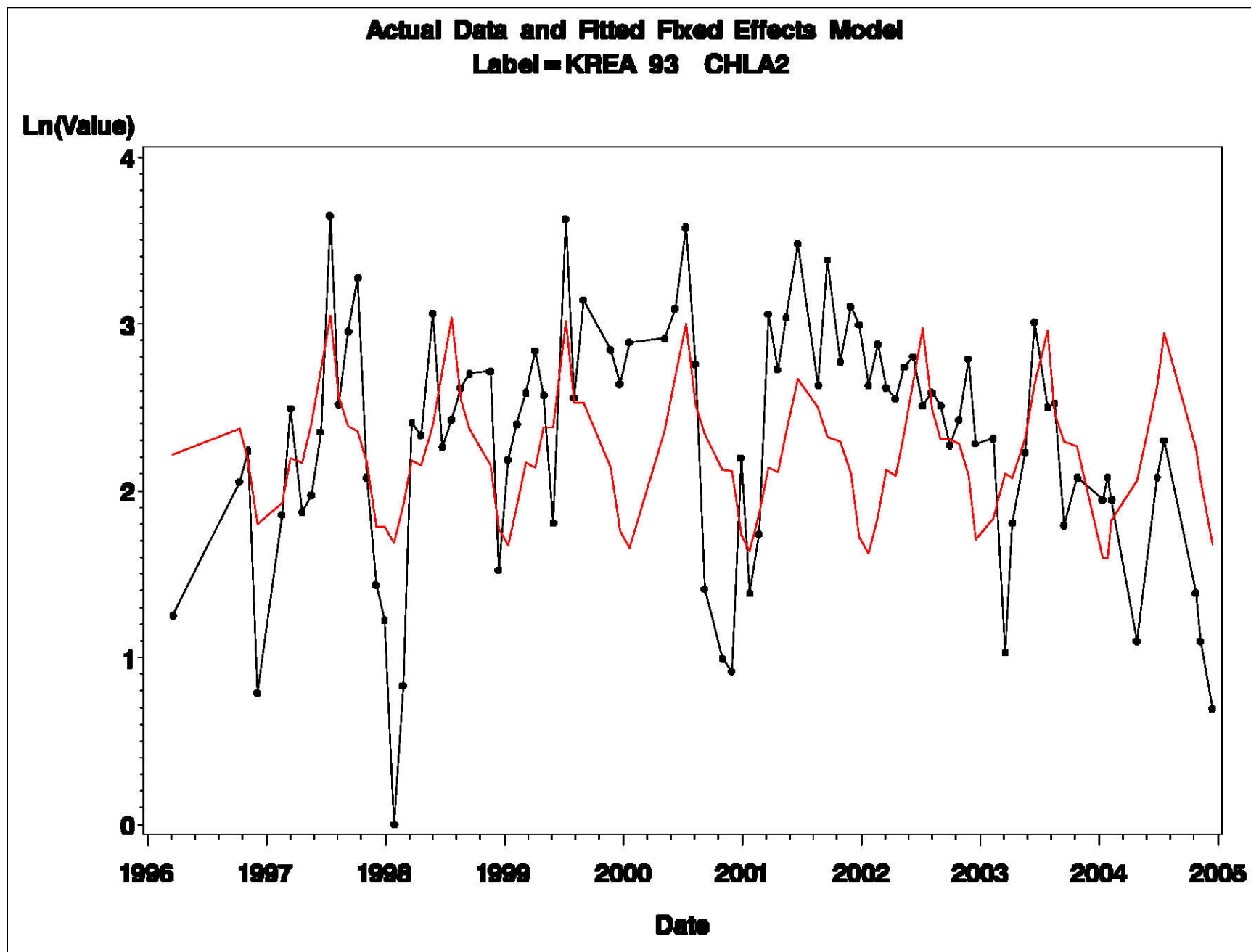


Figure A-92

Actual Data and Fitted Fixed Effects Model
Label = KREA 94 CHLA2

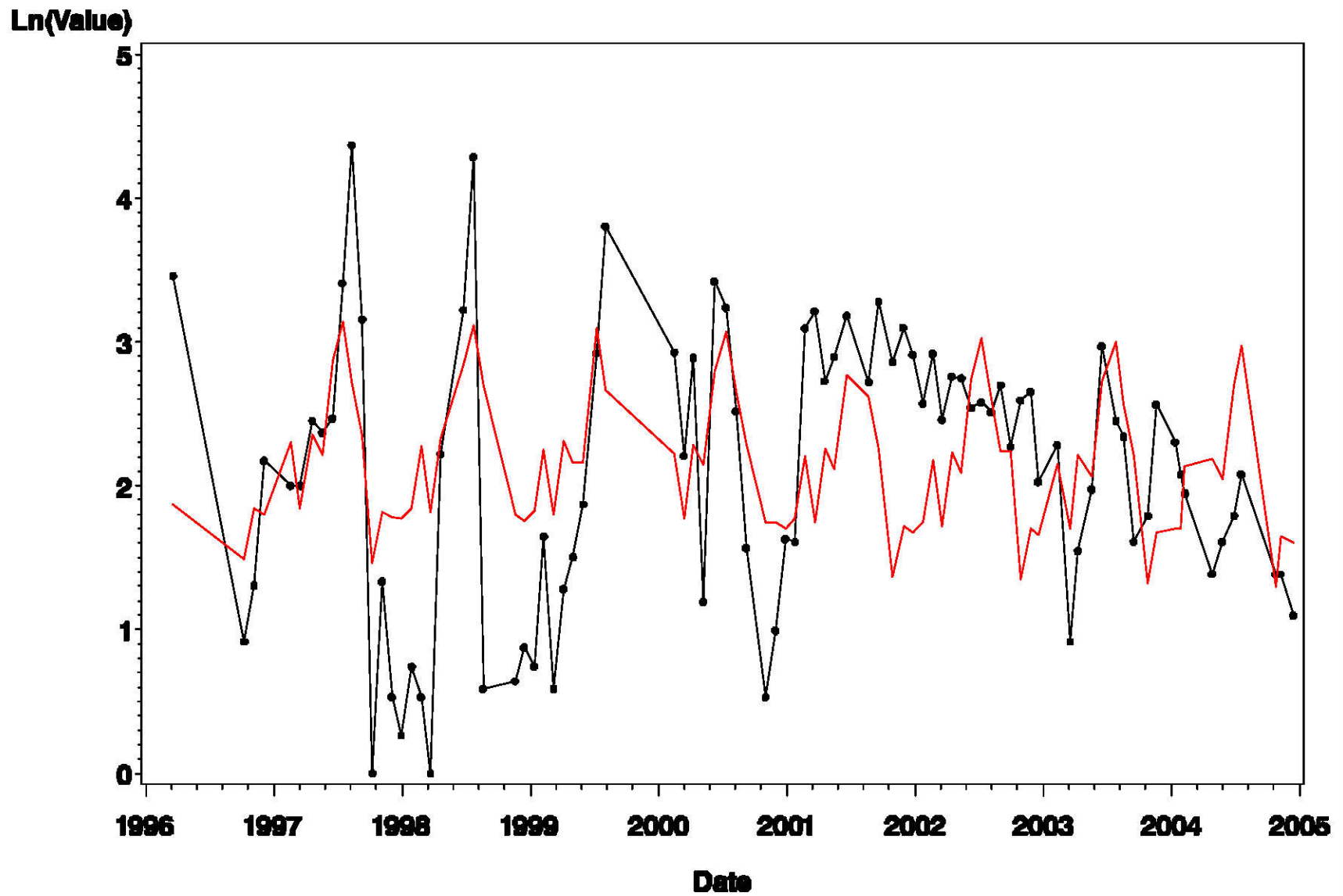


Figure A-93

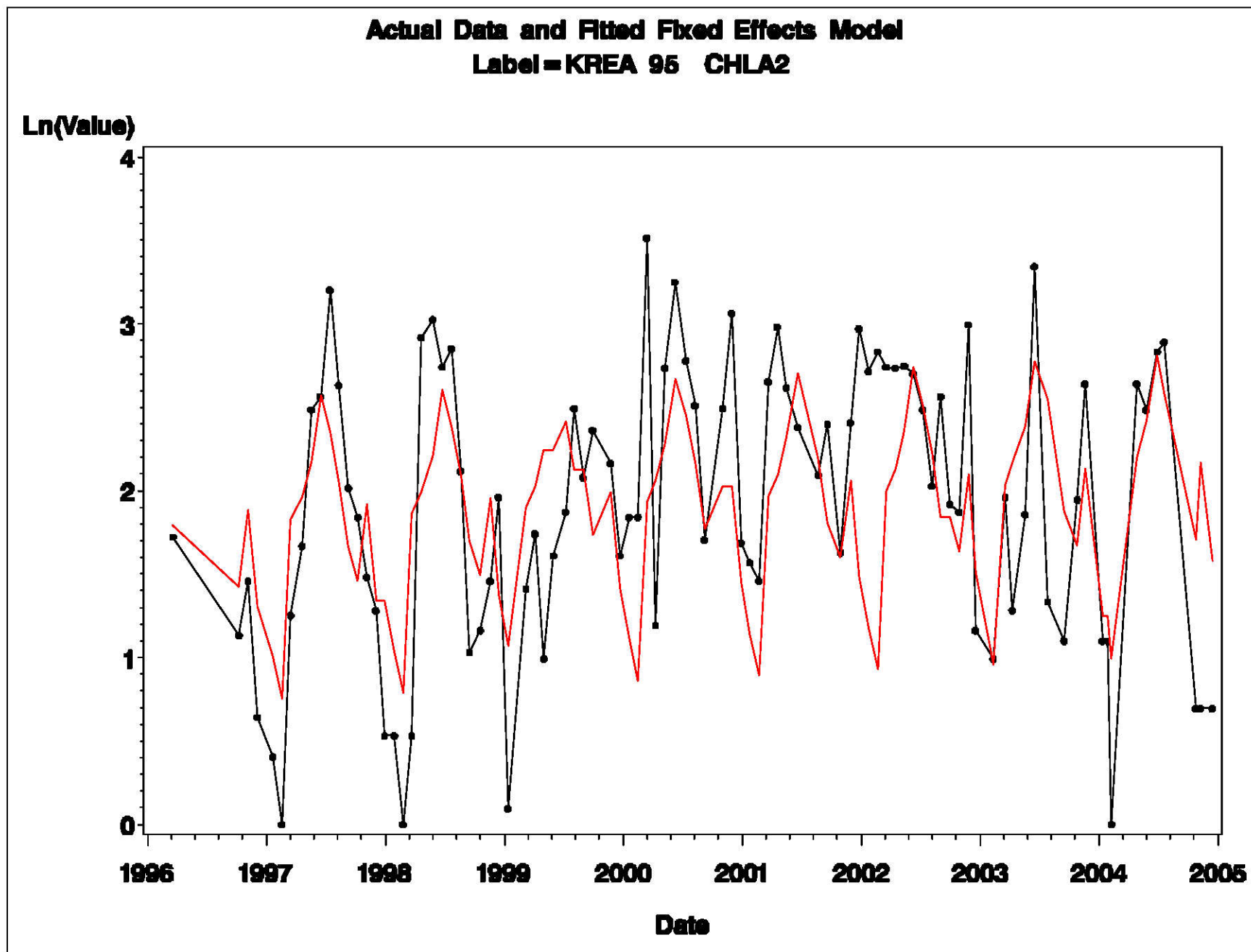


Figure A-94

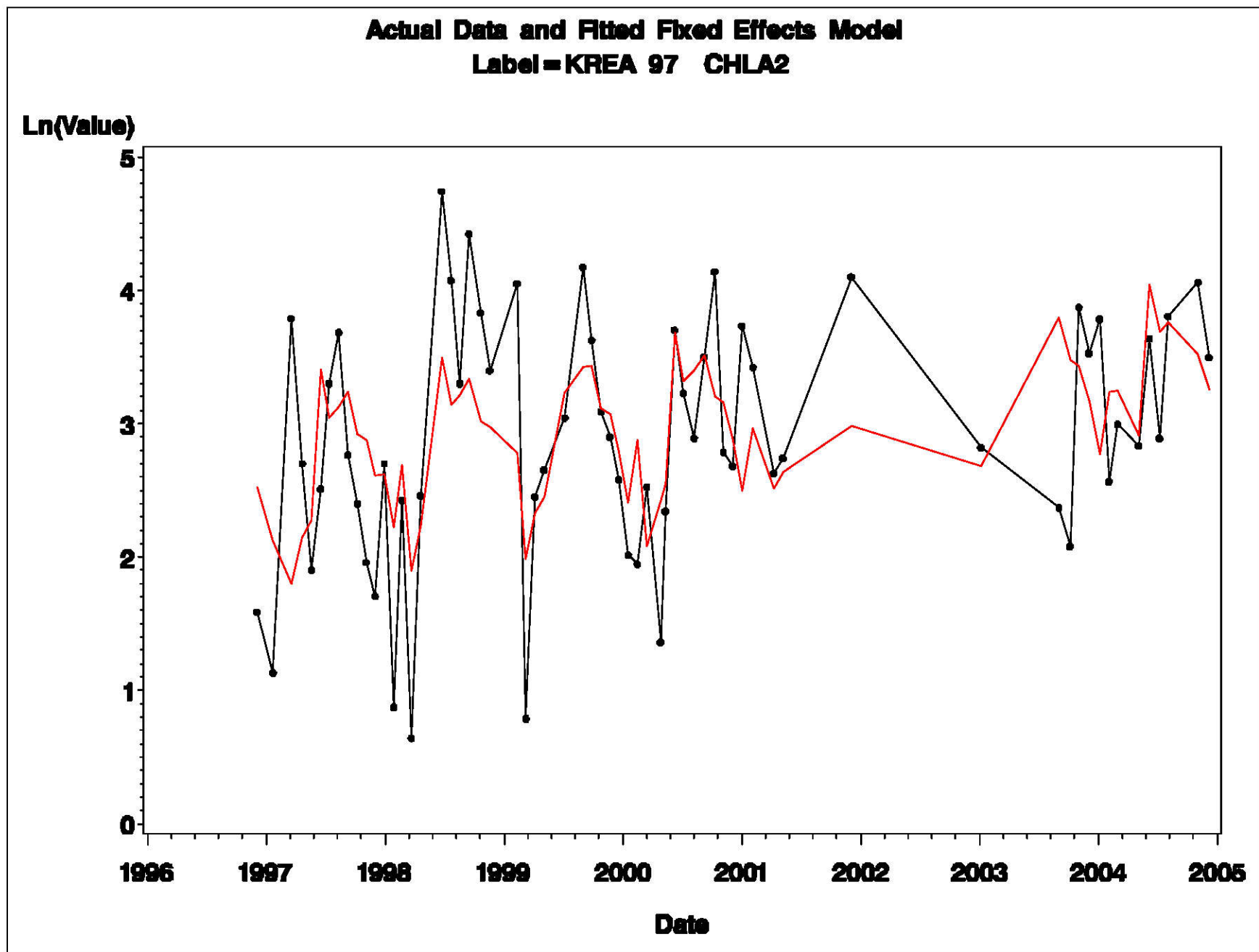


Figure A-95

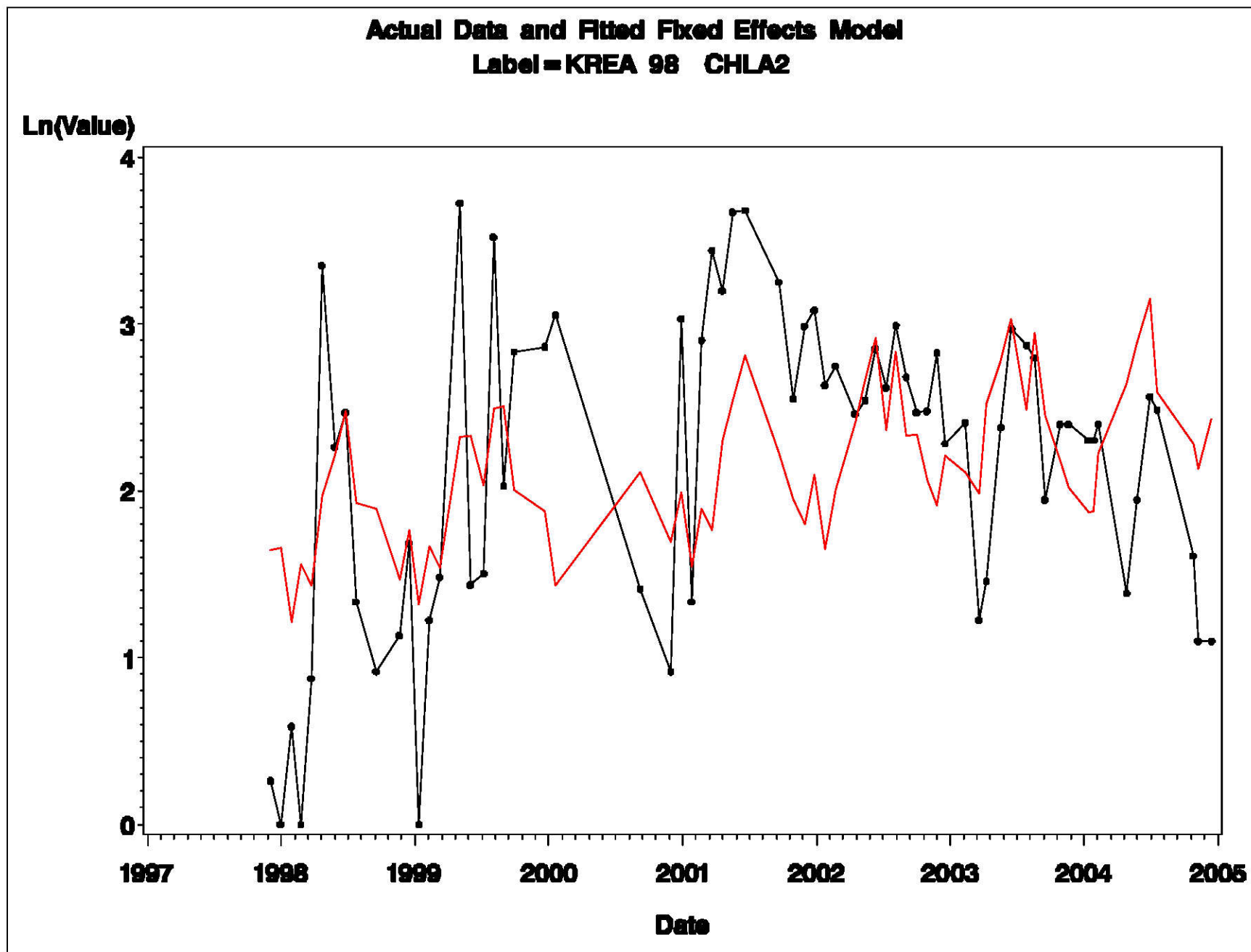


Figure A-96

APPENDIX B

SUMMARY OF POWER ANALYSIS RESULTS

Table B-1. Summary of Power Analysis Results

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 01 | CL | 0.50 | 0.67 | 12 | 28% |
| KREA 01 | CL | 0.50 | 0.67 | 24 | 26% |
| KREA 01 | CL | 0.50 | 0.67 | 52 | 25% |
| KREA 01 | DO | 0.65 | 0.53 | 12 | 46% |
| KREA 01 | DO | 0.65 | 0.53 | 24 | 42% |
| KREA 01 | DO | 0.65 | 0.53 | 52 | 41% |
| KREA 01 | TKN | 0.27 | 0.28 | 12 | 11% |
| KREA 01 | TKN | 0.27 | 0.28 | 24 | 9% |
| KREA 01 | TKN | 0.27 | 0.28 | 52 | 8% |
| KREA 01 | TPO4 | 0.76 | 0.39 | 12 | 36% |
| KREA 01 | TPO4 | 0.76 | 0.39 | 24 | 30% |
| KREA 01 | TPO4 | 0.76 | 0.39 | 52 | 26% |
| KREA 04 | CL | 0.47 | 0.40 | 12 | 34% |
| KREA 04 | CL | 0.47 | 0.40 | 24 | 27% |
| KREA 04 | CL | 0.47 | 0.40 | 52 | 24% |
| KREA 04 | DO | 0.42 | 0.07 | 12 | 27% |
| KREA 04 | DO | 0.42 | 0.07 | 24 | 20% |
| KREA 04 | DO | 0.42 | 0.07 | 52 | 16% |
| KREA 04 | TKN | 0.29 | 0.27 | 12 | 20% |
| KREA 04 | TKN | 0.29 | 0.27 | 24 | 17% |
| KREA 04 | TKN | 0.29 | 0.27 | 52 | 15% |
| KREA 04 | TPO4 | 0.53 | 0.09 | 12 | 34% |
| KREA 04 | TPO4 | 0.53 | 0.09 | 24 | 25% |
| KREA 04 | TPO4 | 0.53 | 0.09 | 52 | 18% |
| KREA 06A** | DO** | 0.44 | 0.49 | 12 | 30% |
| KREA 06A** | DO** | 0.44 | 0.49 | 24 | 27% |
| KREA 06A** | DO** | 0.44 | 0.49 | 52 | 25% |
| KREA 06A | TKN | 0.24 | 0.26 | 12 | 13% |
| KREA 06A | TKN | 0.24 | 0.26 | 24 | 11% |
| KREA 06A | TKN | 0.24 | 0.26 | 52 | 10% |
| KREA 06A | TPO4 | 0.44 | 0.37 | 12 | 27% |
| KREA 06A | TPO4 | 0.44 | 0.37 | 24 | 24% |
| KREA 06A | TPO4 | 0.44 | 0.37 | 52 | 22% |
| KREA 14 | DO | 0.67 | 0.29 | 12 | 59% |
| KREA 14 | DO | 0.67 | 0.29 | 24 | 44% |
| KREA 14 | DO | 0.67 | 0.29 | 52 | 36% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 14 | TKN | 0.29 | 0.27 | 12 | 21% |
| KREA 14 | TKN | 0.29 | 0.27 | 24 | 16% |
| KREA 14 | TKN | 0.29 | 0.27 | 52 | 13% |
| KREA 14 | TPO4 | 0.67 | 0.43 | 12 | 57% |
| KREA 14 | TPO4 | 0.67 | 0.43 | 24 | 44% |
| KREA 14 | TPO4 | 0.67 | 0.43 | 52 | 36% |
| KREA 17A | CL | 0.48 | 0.64 | 12 | 36% |
| KREA 17A | CL | 0.48 | 0.64 | 24 | 32% |
| KREA 17A | CL | 0.48 | 0.64 | 52 | 30% |
| KREA 17A | DO | 0.50 | 0.20 | 12 | 29% |
| KREA 17A | DO | 0.50 | 0.20 | 24 | 22% |
| KREA 17A | DO | 0.50 | 0.20 | 52 | 18% |
| KREA 17A | TKN | 0.24 | 0.14 | 12 | 13% |
| KREA 17A | TKN | 0.24 | 0.14 | 24 | 9% |
| KREA 17A | TKN | 0.24 | 0.14 | 52 | 7% |
| KREA 17A | TPO4 | 0.64 | 0.43 | 12 | 44% |
| KREA 17A | TPO4 | 0.64 | 0.43 | 24 | 36% |
| KREA 17A | TPO4 | 0.64 | 0.43 | 52 | 33% |
| KREA 19 | DO | 0.53 | 0.43 | 12 | 25% |
| KREA 19 | DO | 0.53 | 0.43 | 24 | 21% |
| KREA 19 | DO | 0.53 | 0.43 | 52 | 19% |
| KREA 19 | TKN | 0.46 | 0.28 | 12 | 20% |
| KREA 19 | TKN | 0.46 | 0.28 | 24 | 16% |
| KREA 19 | TKN | 0.46 | 0.28 | 52 | 13% |
| KREA 19 | TPO4 | 0.95 | 0.30 | 12 | 44% |
| KREA 19 | TPO4 | 0.95 | 0.30 | 24 | 35% |
| KREA 19 | TPO4 | 0.95 | 0.30 | 52 | 29% |
| KREA 20 | CL | 0.71 | 0.63 | 24 | 100% |
| KREA 20 | CL | 0.71 | 0.63 | 52 | 82% |
| KREA 20 | DO | 0.69 | 0.34 | 24 | 95% |
| KREA 20 | DO | 0.69 | 0.34 | 52 | 67% |
| KREA 20 | TKN | 0.39 | 0.42 | 24 | 48% |
| KREA 20 | TKN | 0.39 | 0.42 | 52 | 35% |
| KREA 20** | TPO4** | 0.72 | 0.40 | 24 | 101% |
| KREA 20** | TPO4** | 0.72 | 0.40 | 52 | 70% |
| KREA 22 | CL | 0.39 | 0.47 | 12 | 24% |
| KREA 22 | CL | 0.39 | 0.47 | 24 | 22% |
| KREA 22 | CL | 0.39 | 0.47 | 52 | 21% |
| KREA 22 | DO | 0.44 | 0.44 | 12 | 23% |
| KREA 22 | DO | 0.44 | 0.44 | 24 | 21% |
| KREA 22 | DO | 0.44 | 0.44 | 52 | 20% |
| KREA 22 | TKN | 0.22 | 0.45 | 12 | 11% |
| KREA 22 | TKN | 0.22 | 0.45 | 24 | 10% |
| KREA 22 | TKN | 0.22 | 0.45 | 52 | 10% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 22 | TPO4 | 0.56 | 0.15 | 12 | 27% |
| KREA 22 | TPO4 | 0.56 | 0.15 | 24 | 22% |
| KREA 22 | TPO4 | 0.56 | 0.15 | 52 | 19% |
| KREA 23 | CL | 0.42 | 0.55 | 12 | 36% |
| KREA 23 | CL | 0.42 | 0.55 | 24 | 33% |
| KREA 23 | CL | 0.42 | 0.55 | 52 | 32% |
| KREA 23 | DO | 0.58 | 0.51 | 12 | 50% |
| KREA 23 | DO | 0.58 | 0.51 | 24 | 47% |
| KREA 23 | DO | 0.58 | 0.51 | 52 | 45% |
| KREA 23 | TKN | 0.26 | 0.27 | 12 | 16% |
| KREA 23 | TKN | 0.26 | 0.27 | 24 | 14% |
| KREA 23 | TKN | 0.26 | 0.27 | 52 | 13% |
| KREA 23 | TPO4 | 0.75 | 0.45 | 12 | 56% |
| KREA 23 | TPO4 | 0.75 | 0.45 | 24 | 50% |
| KREA 23 | TPO4 | 0.75 | 0.45 | 52 | 47% |
| KREA 25 | CL | 0.59 | 0.77 | 24 | 90% |
| KREA 25 | CL | 0.59 | 0.77 | 52 | 74% |
| KREA 25 | DO | 0.65 | 0.10 | 24 | 76% |
| KREA 25 | DO | 0.65 | 0.10 | 52 | 48% |
| KREA 25 | TKN | 0.28 | 0.54 | 24 | 31% |
| KREA 25 | TKN | 0.28 | 0.54 | 52 | 25% |
| KREA 25 | TPO4 | 0.61 | 0.55 | 24 | 84% |
| KREA 25 | TPO4 | 0.61 | 0.55 | 52 | 65% |
| KREA 28 | CL | 0.38 | 0.56 | 12 | 33% |
| KREA 28 | CL | 0.38 | 0.56 | 24 | 27% |
| KREA 28 | CL | 0.38 | 0.56 | 52 | 23% |
| KREA 28 | DO | 0.60 | 0.34 | 12 | 52% |
| KREA 28 | DO | 0.60 | 0.34 | 24 | 37% |
| KREA 28 | DO | 0.60 | 0.34 | 52 | 30% |
| KREA 28 | TKN | 0.30 | 0.24 | 12 | 24% |
| KREA 28 | TKN | 0.30 | 0.24 | 24 | 18% |
| KREA 28 | TKN | 0.30 | 0.24 | 52 | 14% |
| KREA 28 | TPO4 | 0.48 | 0.42 | 12 | 39% |
| KREA 28 | TPO4 | 0.48 | 0.42 | 24 | 30% |
| KREA 28 | TPO4 | 0.48 | 0.42 | 52 | 25% |
| KREA 30A | CL | 0.62 | 0.56 | 24 | 74% |
| KREA 30A | CL | 0.62 | 0.56 | 52 | 46% |
| KREA 30A* | DO* | 0.41 | -0.09 | 24 | 43% |
| KREA 30A* | DO* | 0.41 | -0.09 | 52 | 25% |
| KREA 30A | TKN | 0.25 | 0.36 | 24 | 25% |
| KREA 30A | TKN | 0.25 | 0.36 | 52 | 17% |
| KREA 30A | TPO4 | 0.59 | 0.57 | 24 | 73% |
| KREA 30A | TPO4 | 0.59 | 0.57 | 52 | 46% |
| KREA 41A | DO | 0.70 | 0.52 | 12 | 44% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 41A | DO | 0.70 | 0.52 | 24 | 36% |
| KREA 41A | DO | 0.70 | 0.52 | 52 | 32% |
| KREA 41A | TKN | 0.34 | 0.37 | 12 | 19% |
| KREA 41A | TKN | 0.34 | 0.37 | 24 | 16% |
| KREA 41A | TKN | 0.34 | 0.37 | 52 | 14% |
| KREA 41A | TPO4 | 0.86 | 0.39 | 12 | 52% |
| KREA 41A | TPO4 | 0.86 | 0.39 | 24 | 39% |
| KREA 41A | TPO4 | 0.86 | 0.39 | 52 | 33% |
| KREA 79* | CHLA2* | 0.94 | -0.08 | 6 | 54% |
| KREA 79* | CHLA2* | 0.94 | -0.08 | 12 | 33% |
| KREA 79* | CHLA2* | 0.94 | -0.08 | 24 | 20% |
| KREA 79 | CL | 0.29 | 0.57 | 6 | 20% |
| KREA 79 | CL | 0.29 | 0.57 | 12 | 19% |
| KREA 79 | CL | 0.29 | 0.57 | 24 | 18% |
| KREA 79 | DO | 1.37 | 0.62 | 6 | 46% |
| KREA 79 | DO | 1.37 | 0.62 | 12 | 31% |
| KREA 79 | DO | 1.37 | 0.62 | 24 | 21% |
| KREA 79 | TKN | 0.23 | 0.07 | 6 | 11% |
| KREA 79 | TKN | 0.23 | 0.07 | 12 | 8% |
| KREA 79 | TKN | 0.23 | 0.07 | 24 | 7% |
| KREA 79 | TPO4 | 0.38 | 0.31 | 6 | 20% |
| KREA 79 | TPO4 | 0.38 | 0.31 | 12 | 16% |
| KREA 79 | TPO4 | 0.38 | 0.31 | 24 | 15% |
| KREA 79 | TURB | 0.56 | 0.22 | 6 | 30% |
| KREA 79 | TURB | 0.56 | 0.22 | 12 | 23% |
| KREA 79 | TURB | 0.56 | 0.22 | 24 | 20% |
| KREA 91 | CHLA2 | 0.93 | 0.14 | 6 | 64% |
| KREA 91 | CHLA2 | 0.93 | 0.14 | 12 | 44% |
| KREA 91 | CHLA2 | 0.93 | 0.14 | 24 | 35% |
| KREA 91** | CL** | 0.68 | 0.11 | 6 | 45% |
| KREA 91** | CL** | 0.68 | 0.11 | 12 | 31% |
| KREA 91** | CL** | 0.68 | 0.11 | 24 | 24% |
| KREA 91 | DO | 0.75 | 0.10 | 6 | 48% |
| KREA 91 | DO | 0.75 | 0.10 | 12 | 34% |
| KREA 91 | DO | 0.75 | 0.10 | 24 | 26% |
| KREA 91 | TKN | 0.41 | 0.81 | 6 | 45% |
| KREA 91 | TKN | 0.41 | 0.81 | 12 | 43% |
| KREA 91 | TKN | 0.41 | 0.81 | 24 | 42% |
| KREA 91 | TPO4 | 0.42 | 0.21 | 6 | 25% |
| KREA 91 | TPO4 | 0.42 | 0.21 | 12 | 19% |
| KREA 91 | TPO4 | 0.42 | 0.21 | 24 | 16% |
| KREA 91 | TURB | 0.45 | 0.21 | 6 | 27% |
| KREA 91 | TURB | 0.45 | 0.21 | 12 | 20% |
| KREA 91 | TURB | 0.45 | 0.21 | 24 | 17% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 92 | CHLA2 | 1.15 | 0.71 | 6 | 32% |
| KREA 92 | CHLA2 | 1.15 | 0.71 | 12 | 24% |
| KREA 92 | CHLA2 | 1.15 | 0.71 | 24 | 18% |
| KREA 92** | CL ** | 0.40 | 0.25 | 6 | 18% |
| KREA 92** | CL ** | 0.40 | 0.25 | 12 | 15% |
| KREA 92** | CL ** | 0.40 | 0.25 | 24 | 14% |
| KREA 92 | DO | 0.91 | 0.20 | 6 | 47% |
| KREA 92 | DO | 0.91 | 0.20 | 12 | 38% |
| KREA 92 | DO | 0.91 | 0.20 | 24 | 32% |
| KREA 92** | TKN** | 0.50 | 0.59 | 6 | 14% |
| KREA 92** | TKN** | 0.50 | 0.59 | 12 | 10% |
| KREA 92** | TKN** | 0.50 | 0.59 | 24 | 7% |
| KREA 92 | TPO4 | 0.40 | 0.43 | 6 | 26% |
| KREA 92 | TPO4 | 0.40 | 0.43 | 12 | 23% |
| KREA 92 | TPO4 | 0.40 | 0.43 | 24 | 22% |
| KREA 92 | TURB | 0.57 | 0.37 | 6 | 31% |
| KREA 92 | TURB | 0.57 | 0.37 | 12 | 27% |
| KREA 92 | TURB | 0.57 | 0.37 | 24 | 24% |
| KREA 93 | CHLA2 | 0.73 | 0.61 | 6 | 57% |
| KREA 93 | CHLA2 | 0.73 | 0.61 | 12 | 52% |
| KREA 93 | CHLA2 | 0.73 | 0.61 | 24 | 51% |
| KREA 93 | CL | 0.37 | 0.75 | 6 | 36% |
| KREA 93 | CL | 0.37 | 0.75 | 12 | 34% |
| KREA 93 | CL | 0.37 | 0.75 | 24 | 34% |
| KREA 93 | DO | 1.09 | 0.49 | 6 | 89% |
| KREA 93 | DO | 1.09 | 0.49 | 12 | 79% |
| KREA 93 | DO | 1.09 | 0.49 | 24 | 75% |
| KREA 93 | TKN | 0.24 | 0.45 | 6 | 13% |
| KREA 93 | TKN | 0.24 | 0.45 | 12 | 11% |
| KREA 93 | TKN | 0.24 | 0.45 | 24 | 11% |
| KREA 93 | TPO4 | 0.51 | 0.61 | 6 | 44% |
| KREA 93 | TPO4 | 0.51 | 0.61 | 12 | 42% |
| KREA 93 | TPO4 | 0.51 | 0.61 | 24 | 41% |
| KREA 93 | TURB | 1.41 | 0.92 | 6 | 156% |
| KREA 93 | TURB | 1.41 | 0.92 | 12 | 151% |
| KREA 93 | TURB | 1.41 | 0.92 | 24 | 151% |
| KREA 94 | CHLA2 | 0.94 | 0.59 | 6 | 70% |
| KREA 94 | CHLA2 | 0.94 | 0.59 | 12 | 65% |
| KREA 94 | CHLA2 | 0.94 | 0.59 | 24 | 63% |
| KREA 94 | CL | 0.34 | 0.81 | 6 | 34% |
| KREA 94 | CL | 0.34 | 0.81 | 12 | 33% |
| KREA 94 | CL | 0.34 | 0.81 | 24 | 33% |
| KREA 94* | DO* | 0.63 | -0.03 | 6 | 30% |
| KREA 94* | DO* | 0.63 | -0.03 | 12 | 20% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 94* | DO* | 0.63 | -0.03 | 24 | 12% |
| KREA 94 | TKN | 0.22 | 0.28 | 6 | 10% |
| KREA 94 | TKN | 0.22 | 0.28 | 12 | 8% |
| KREA 94 | TKN | 0.22 | 0.28 | 24 | 8% |
| KREA 94 | TPO4 | 0.49 | 0.41 | 6 | 28% |
| KREA 94 | TPO4 | 0.49 | 0.41 | 12 | 25% |
| KREA 94 | TPO4 | 0.49 | 0.41 | 24 | 23% |
| KREA 94 | TURB | 0.89 | 0.76 | 6 | 109% |
| KREA 94 | TURB | 0.89 | 0.76 | 12 | 108% |
| KREA 94 | TURB | 0.89 | 0.76 | 24 | 106% |
| KREA 95 | CHLA2 | 0.73 | 0.47 | 6 | 50% |
| KREA 95 | CHLA2 | 0.73 | 0.47 | 12 | 46% |
| KREA 95 | CHLA2 | 0.73 | 0.47 | 24 | 43% |
| KREA 95 | CL | 0.35 | 0.49 | 6 | 21% |
| KREA 95 | CL | 0.35 | 0.49 | 12 | 19% |
| KREA 95 | CL | 0.35 | 0.49 | 24 | 18% |
| KREA 95 | DO | 0.78 | 0.17 | 6 | 39% |
| KREA 95 | DO | 0.78 | 0.17 | 12 | 30% |
| KREA 95 | DO | 0.78 | 0.17 | 24 | 26% |
| KREA 95 | TKN | 0.21 | 0.00 | 6 | 9% |
| KREA 95 | TKN | 0.21 | 0.00 | 12 | 6% |
| KREA 95 | TKN | 0.21 | 0.00 | 24 | 4% |
| KREA 95 | TPO4 | 0.60 | 0.62 | 6 | 53% |
| KREA 95 | TPO4 | 0.60 | 0.62 | 12 | 51% |
| KREA 95 | TPO4 | 0.60 | 0.62 | 24 | 50% |
| KREA 95 | TURB | 1.09 | 0.82 | 6 | 162% |
| KREA 95 | TURB | 1.09 | 0.82 | 12 | 154% |
| KREA 95 | TURB | 1.09 | 0.82 | 24 | 154% |
| KREA 97 | CHLA2 | 0.84 | 0.20 | 6 | 84% |
| KREA 97 | CHLA2 | 0.84 | 0.20 | 12 | 55% |
| KREA 97 | CHLA2 | 0.84 | 0.20 | 24 | 41% |
| KREA 97 | CL | 0.32 | 0.79 | 6 | 33% |
| KREA 97 | CL | 0.32 | 0.79 | 12 | 30% |
| KREA 97 | CL | 0.32 | 0.79 | 24 | 30% |
| KREA 97 | DO | 0.77 | 0.30 | 6 | 75% |
| KREA 97 | DO | 0.77 | 0.30 | 12 | 51% |
| KREA 97 | DO | 0.77 | 0.30 | 24 | 40% |
| KREA 97 | TKN | 0.25 | 0.25 | 6 | 21% |
| KREA 97 | TKN | 0.25 | 0.25 | 12 | 16% |
| KREA 97 | TKN | 0.25 | 0.25 | 24 | 13% |
| KREA 97 | TPO4 | 0.45 | 0.41 | 6 | 43% |
| KREA 97 | TPO4 | 0.45 | 0.41 | 12 | 33% |
| KREA 97 | TPO4 | 0.45 | 0.41 | 24 | 28% |
| KREA 97 | TURB | 0.37 | 0.23 | 6 | 30% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| KREA 97 | TURB | 0.37 | 0.23 | 12 | 21% |
| KREA 97 | TURB | 0.37 | 0.23 | 24 | 16% |
| KREA 98 | CHLA2 | 0.94 | 0.54 | 6 | 68% |
| KREA 98 | CHLA2 | 0.94 | 0.54 | 12 | 60% |
| KREA 98 | CHLA2 | 0.94 | 0.54 | 24 | 55% |
| KREA 98 | CL | 0.31 | 0.30 | 6 | 18% |
| KREA 98 | CL | 0.31 | 0.30 | 12 | 15% |
| KREA 98 | CL | 0.31 | 0.30 | 24 | 13% |
| KREA 98 | DO | 0.69 | 0.51 | 6 | 67% |
| KREA 98 | DO | 0.69 | 0.51 | 12 | 61% |
| KREA 98 | DO | 0.69 | 0.51 | 24 | 59% |
| KREA 98 | TKN | 0.33 | 0.80 | 6 | 26% |
| KREA 98 | TKN | 0.33 | 0.80 | 12 | 25% |
| KREA 98 | TKN | 0.33 | 0.80 | 24 | 25% |
| KREA 98 | TPO4 | 0.53 | 0.65 | 6 | 53% |
| KREA 98 | TPO4 | 0.53 | 0.65 | 12 | 51% |
| KREA 98 | TPO4 | 0.53 | 0.65 | 24 | 50% |
| KREA 98 | TURB | 0.82 | 0.86 | 6 | 110% |
| KREA 98 | TURB | 0.82 | 0.86 | 12 | 107% |
| KREA 98 | TURB | 0.82 | 0.86 | 24 | 107% |

* Model assumptions may be violated for these stations

** Time series data may contain overly influential outliers

Lower Kissimmee River
Optimization Leader: Steve Rust, Battelle
Statistician: Steve Rust, Battelle

Project Code: LKR

Type: Type II

Mandate or Permit:

- Lake Okeechobee Protection Act (LOPA)
- Lake Okeechobee Operating Permit (LOOP)
- Surface Water Improvement and Management Act (SWIM)
- WRDA 2000
- Florida Watershed Restoration Act (TMDLs/MFLs/PLRGs)
- Safe Drinking Water Act
- Clean Water Act

Project Start Date: 1987

Division Manager: Okeechobee Division: Susan Gray

Program Manager: Brad Jones

Points of Contact: Steffany Gornack, Brad Jones, Patrick Davis

Field Point of Contact: Patrick Davis

Spatial Description

Sampling for Project LKR is via autosampler only at several of the structures located along the Kissimmee River in Polk and Okeechobee counties from Lake Kissimmee to Lake Okeechobee. Five of the stations from Project LKR are also sampled using grab samples as part of Project V. These 5 stations include: S65, the structure at the southern end of Lake Kissimmee where the lake drains into the Kissimmee River, the S65A structure, downstream of S65, the S65C structure, downstream of the confluence of the Kissimmee River with the Lake Istopoga Canal, and the S65D and S65E structures, downstream of S65C above the confluence of the Kissimmee River with the C41A canal. The two additional locations sampled as part of Project LKR are the S154 and S191 structures. The S154 drains to the LD-4. The S191 is located at the confluence of Nubbin Slough to Lake Okeechobee.

Discussions with District staff familiar with the project mentioned that Stations S154, S191 and S65E overlap with Project X. These stations are considered Type 1 for Project X and are listed as Type 1 for Project LKR (*mandate spreadsheet from Linda Crean*) but may be considered Type II for Project LKR because they are sampled via time proportional autosamplers. It was suggested that the autosamplers at these three stations should be flow proportional since these locations are direct inflows into Lake Okeechobee. It is also unclear how the data from the time proportional autosamplers are used for this project.

District staff also suggested the potential addition of a station. Flow is to be diverted to the structure S65DX. Eventually, the culvert will be removed from S65D and S65DX will take its place. Future monitoring may need to be conducted at the new structure (i.e., S65DX).

District staff have indicated that the following mandates and permits are relevant to this monitoring project:

Project Purpose, Goals and Objectives

The primary purpose of Project LKR is to assess tributary and basin loading and concentration inputs to the Kissimmee River and Lake Okeechobee and to identify trends in total phosphorus over time. Specific objectives of the project are to:

- A. Assess inputs to Lake Okeechobee by:
 1. Providing concentration measurements from inflows to Lake Okeechobee to compare with the 0.18 mg/l total phosphorus SWIM standard, and for use in basin loading calculations.
 2. Providing concentration measurements that will help evaluate the efficacy of the Kissimmee River restoration project.
 3. Providing data to evaluate compliance with Lake Okeechobee Total Maximum Daily Loads (TMDL).
- B. Develop basin and spatial scale models to predict changes in loads to Lake Okeechobee as a function of land use by:
 1. Providing data for determining statistical or mechanistic relationships between rainfall, land use (or land type), and nutrient runoff.
 2. Providing data to help identify the reason for high episodic phosphorus events.

Sampling Frequency and Parameters Sampled

Samples are collected on a weekly basis via time proportional autosamplers (ACT) at seven stations: S154, S191, S65, S65A, S65C, S65D and S65E. The station locations are illustrated on the map in Figure 1. The collected samples are analyzed for TPO4 concentration. The relevance of the seven stations is described below.

On the Kissimmee River

- S65 – located at the southern end of Lake Kissimmee where it drains into the Kissimmee River
- S65A – located on the Kissimmee River south of station S65 at southern end of drainage basin S65A
- S65C – located on the Kissimmee River south of station S65A at southern end of drainage basin S65C; also south of the confluence of the Lake Istokpoga Canal and the Kissimmee River
- S65D – located on the Kissimmee River south of station S65C at southern end of drainage basin S65D
- S65E – located on the Kissimmee River south of station S65D at southern end of drainage basin S65E; also just north of the confluence of the C41A Canal with the Kissimmee River

Not on the Kissimmee River

- S154 – located at the southern end of drainage basin S154 where it drains to the LD-4
- S191 – located at the confluence of Nubbin Slough to Lake Okeechobee

While stations S154, S191, and S65E are considered Type I stations for Project X, all seven stations monitored for project LKR are considered to be Type II stations.

The geographical domains that can be associated with LKR monitoring stations are noted in Table 1. Since sampling is performed via time proportional autosampler, the concentration data is of questionable value when computing phosphorous loads.

Table 1. Geographical Domain of Monitoring Stations

| Station | Geographical Domain |
|-----------------|-------------------------------|
| S65 | Lake Kissimmee |
| S65A minus S65 | S65A Drainage Basin |
| S65C minus S65A | S65B and S65C Drainage Basins |
| S65D minus S65C | S65D Drainage Basin |
| S65E minus S65D | S65E Drainage Basin |
| S154 | S154 Drainage Basin |
| S191 | Nubbin Slough Drainage Basin |

Project LKR has been monitoring TPO4 in grab samples during CY2004 at S191, S65, S65A, S65C, and S65D. Since this data is not part of the current monitoring plan, it has been ignored.

Project V monitors TPO4 in grab samples collected at stations S65, S65A, S65C, S65D and S65E on a bi-weekly basis.

Project X monitors TPO4 in grab samples collected at stations S154, S191 and S65E. Over the past 13 years samples have been collected at the following average rates: S154 (~40 per year), S191 (~45 per year), and S65E (~8 per year).

Current and Future Data Uses

The LKR data are used in several District reports including the South Florida Environmental Report, and all reports pertaining to the Kissimmee River Restoration. The Lake Okeechobee watershed modeling activities (CREAMS and FHANTM models) may also use this information. In the future, this data will be used for TMDL development in cooperation with DEP. Additionally, The CERP RECOVER Monitoring and Assessment Plan may use several sites from Project X which are sampled for Project LKR (S191, S154, and S65E) as long-term monitoring stations

Optimization Analyses

Perhaps the most significant water quality monitoring objective that motivates LKR monitoring is detection of an increasing or decreasing trend in TPO4 concentrations over time. The Lake Okeechobee Protection Plan (LOPP) calls for a 70% reduction in the TPO4 load to Lake Okeechobee by 2015 and a near-shore TPO4 concentration of less than 40 ppb (µg/L). The LOPP also specifies construction projects, management projects, and a myriad of best management practices that are designed to achieve these TPO4 goals. Over the next decade, the

District will use its LKR monitoring data and statistical trend analysis procedures to assess the effectiveness of LOPP implementation toward meeting the 2015 TPO4 goals.

A key question related to the LKR monitoring project is whether or not the monitoring data collected will be sufficient to assess the effectiveness of projects and practices implemented to control and improve water quality and determine whether or not sufficient progress is being made toward water quality goals and objectives. One way to address this question is to perform statistical power analyses to determine the smallest water quality trends that will be detectable with high probability based on water quality data collected according to current monitoring plans. Using the resulting detectable trends, District staff will be able to determine whether the trends necessary to achieve long-term goals will be discernable from trends that fail to achieve the long-term goals. The same statistical power analysis procedures can be used to identify detectable water quality trends for alternatives to the current monitoring design. With power analysis results for both the current and alternative monitoring designs in hand, District staff will be able to optimize the LKR monitoring design for achievement of long-term goals and objectives.

Optimization Analysis Procedures

Power analyses were performed for the TPO4 concentration data (DBHYDRO code 25) from each of the seven LKR monitoring stations by carrying out the following power analysis steps:

- Fit a statistical model to the water quality parameter data in order to have a basis for generating simulated data to support a Monte Carlo based power analysis procedure
- Generate multiple replicate simulated water quality time series data sets; for all power analyses reported here, each time series generated was for a 5-year monitoring period
- Perform a Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) for each simulated time series data set; in particular, obtain a point estimate of the slope vs. time for the log-transformed water quality parameter values
- Estimate the *annual proportion change* (APC) in water quality parameter values that is detectable with 80% power using a simple two-sided test based on the Seasonal Kendall's Tau slope estimate performed at a 5% significance level

The TPO4 concentration data were natural log-transformed for statistical modeling because the log-transformed data was more nearly normally distributed than were the untransformed data. The fitted statistical model contains the following components:

- Fixed seasonal effects that repeat themselves in an annual cycle
- A long-term linear trend in the log-transformed parameter concentrations; this corresponds to a fixed percentage increase or decrease in the water quality parameter each year
- A random error term representing temporal variability in true water quality parameter values; these error terms are allowed to be correlated from one time point to the next in order to capture any serial autocorrelation that is present in the monitoring data
- A random error term representing sampling and chemical analysis variability; these error terms are assumed to be stochastically independent from one time point to the next

The fitted statistical model is used to perform a Monte Carlo simulation analysis in which multiple TPO4 time series data sets are simulated and used to determine the anticipated statistical properties of trend detection procedures that will be used by the District. All statistical trend analyses performed on the simulated data were based on the Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) preferred by the District.

In the course of performing the power analyses for the District, it was determined that the basic Seasonal Kendall's Tau trend detection procedures do not necessarily control the true significance level of the hypothesis test for trend when there is serial autocorrelation exhibited in the data. This was found to be true even for procedures that attempt to correct for serial autocorrelation. For this reason, all power analysis results reported here are for a simple hypothesis test procedure based on the median slope estimator that accompanies the Seasonal Kendall's Tau test procedure. The median slope estimator is assumed to follow a normal distribution and power results are obtained by performing a simple z-test with this estimator.

For each of the seven LKR stations, the following three monitoring designs were simulated:

- The current monitoring frequency of weekly samples (52 samples per year)
- An alternative reduced sampling design of semi-monthly samples (24 samples per year)
- A second alternative reduced sampling design of monthly samples (12 samples per year)

For each of the three monitoring designs, an estimate was obtained of the minimum annual percentage change (APC) in TPO4 concentration that is detectable with 80% power using the median slope estimator z-test procedure performed at a two-sided significance level of 0.05.

Analysis of the data from DBHYDRO indicates that it was sometimes not possible to obtain one of the weekly autosamples called for by the current monitoring design. By analyzing TPO4 records from DBHYDRO along with "No Bottle Sample" records, it was possible to estimate the proportion of attempted sampling occasions for which no sample was obtained. This procedure was carried out for sampling dates during the period from January 1, 2000 through September 30, 2004 in order to estimate the proportion of the time that no sample was obtained. In the Monte Carlo procedure used to generate simulated monitoring data, sampling results were set equal to missing values with probability equal to the proportion of "No Bottle Samples".

Rust (2005) describes the power analysis procedure and underlying statistical model employed here in detail. Rust (2005) also documents the SAS program used to carry out the power analyses for which results are reported here.

Optimization Analysis Results

Appendix A contains a figure corresponding to each of the TPO4 time series data sets for which power analyses were performed. For the LKR project, that is a single TPO4 time series data set per station. The table at the beginning of Appendix A contains a row identifying each figure in Appendix A. The last three columns of the table identify the following:

- The number of samples per year called for in the current monitoring plan

- The number of seasons assumed in the mixed model fitted to the data and used to simulate monitoring data
- The proportion of “No Bottle Samples” during the period January 1, 2000 through September 30, 2004 which was used as a probability for generating missing data when the Monte Carlo simulation was performed

Each figure in Appendix A displays the actual TPO4 time series for an individual station as black dots connected by black lines. The plotted values are the natural logarithm of TPO4 concentration. The fixed portion of the fitted mixed model is illustrated as a red curve. As illustrated in Figures A-1 through A-7, monitoring data collected prior to 2000 were excluded from the power analyses.

A summary of the power analysis results are reported in Table 2. Table 2 contains a row for each power analysis performed. In this case that is three power analyses per station. A power analysis was performed for the current sampling frequency of weekly sampling (52 samples per year). In addition, alternative monitoring designs calling for bi-monthly sampling (24 samples per year) and monthly sampling (12 samples per year) were also investigated.

For each station, the standard deviation of the monitoring data about the fitted fixed effects model and the correlation coefficient for two measurements taken exactly one month apart are reported. These two quantities are key drivers of the power analysis results. In addition, the number of samples per year simulated and the detectable annual percentage change for that monitoring scenario are reported in the last two columns of Table 2.

The detectable annual percentage change (detectable APC) is the minimum true percentage change per year that would be consistently detected by the test for trend based on the median slope estimator that accompanies the Seasonal Kendall’s Tau procedure. Consistently detected means that the null hypothesis of no trend would be rejected 80% of the time.

Table 2. Summary of Power Analysis Results

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|-------------------|------------------|---------------------------|------------------------------------|-------------------------|--------------------------------------------|
| LKR_S154 | TPO4 | 0.74 | 0.55 | 12 | 34% |
| LKR_S154 | TPO4 | 0.74 | 0.55 | 24 | 30% |
| LKR_S154 | TPO4 | 0.74 | 0.55 | 52 | 28% |
| LKR_S191 | TPO4 | 0.30 | 0.37 | 12 | 11% |
| LKR_S191 | TPO4 | 0.30 | 0.37 | 24 | 9% |
| LKR_S191 | TPO4 | 0.30 | 0.37 | 52 | 8% |
| LKR_S65 | TPO4 | 0.35 | 0.36 | 12 | 14% |
| LKR_S65 | TPO4 | 0.35 | 0.36 | 24 | 11% |
| LKR_S65 | TPO4 | 0.35 | 0.36 | 52 | 10% |
| LKR_S65A | TPO4 | 0.36 | 0.43 | 12 | 14% |
| LKR_S65A | TPO4 | 0.36 | 0.43 | 24 | 12% |
| LKR_S65A | TPO4 | 0.36 | 0.43 | 52 | 11% |
| LKR_S65C* | TPO4* | 0.33 | -0.22 | 12 | 11% |

| | | | | | |
|-----------|-------|------|-------|----|-----|
| LKR_S65C* | TPO4* | 0.33 | -0.22 | 24 | 7% |
| LKR_S65C* | TPO4* | 0.33 | -0.22 | 52 | 4% |
| LKR_S65D | TPO4 | 0.34 | 0.44 | 12 | 13% |
| LKR_S65D | TPO4 | 0.34 | 0.44 | 24 | 11% |
| LKR_S65D | TPO4 | 0.34 | 0.44 | 52 | 10% |
| LKR_S65E | TPO4 | 0.39 | 0.34 | 12 | 14% |
| LKR_S65E | TPO4 | 0.39 | 0.34 | 24 | 11% |
| LKR_S65E | TPO4 | 0.39 | 0.34 | 52 | 10% |

* Model assumptions may be violated for these stations

As noted in the footnote to Table 2 and Table A-1, because the estimated autocorrelation coefficient for the S65C station is negative, it is suspected that the assumptions underlying the mixed model used in the power analysis procedure are violated for this station. For this reason, the detectable APC results for this station will be largely ignored when drawing conclusions from the power analysis results.

The detectable APC results reported in Table 2 are illustrated graphically in Figure 2. The following conclusions may be drawn from Figure 2 and Table 2.

- The TPO4 time series data for all stations exhibit significant serial autocorrelation
- Detectable APC values for the S154 station are approximately 3 times larger than those for the other six stations; this result is apparently due to the much larger variability exhibited by the TPO4 data at S154 and the larger autocorrelation coefficient associated with this data
- Detectable APC values for stations other than S154 and the current monitoring frequency of 52 samples per year are in the range of 8%-10%
- The effect of reduced sampling frequencies on detectable APC values is much smaller than would be expected for independent time series data; if the monitoring data exhibited no serial autocorrelation, one would expect a reduction of the sampling frequency to 12 samples per year to cause a doubling of the detectable APC; in this case, the detectable APC values increase by a multiplicative factor in the range 1.2-1.4; the smaller effect associated with sample frequency reduction is due the significant autocorrelation exhibited in the TPO4 time series data

Recommendations for Current Monitoring Plans

A 70% reduction in TPO4 loads to Lake Okeechobee, if accomplished smoothly over the next decade, would require an 11.3% reduction in phosphorus load each year. In annual percentage change terminology that translates to a APC of 12.7%. For the purposes of evaluating the current and alternative monitoring designs for which power analysis results were generated, it seems reasonable to expect a design to have a detectable APC of 12.7% or smaller. If this requirement is satisfied by a monitoring design, then a smooth 11.3% annual reduction in TPO4 concentrations over a 5-year monitoring period would have an 80% chance of being declared a statistically significant trend.

Requiring a detectable APC of 12.7% is not a very restrictive requirement. Stated another way, the absolute error in estimating the annual percentage change in TPO4 concentrations would be on the order of 7.5%. If there was no change in the average TPO4 concentration over a 5-year

monitoring period (observed annual percentage change of 0%), then a 95% confidence interval for the true annual percentage change in TPO4 concentrations would be (-8.1%, +8.8%). Projecting the uncertainty in the annual percentage change over a 10-year time period, the 95% confidence interval for the percentage change over a 10-year time period would be (-57%, +132%). Therefore, a detectable APC of 12.7% still leaves the district in a position of some considerable uncertainty regarding 10-year trends in TPO4 concentrations.

The following recommendations are made regarding the monitoring plans for LKR monitoring stations:

1. The District should consider reduction of the sampling frequency at the S65, S65A, S65C, and S65E stations to 24 samples per year; such a reduction would have only a very small effect on the detectable APC at these stations
2. Due to high variability and high autocorrelation in the TPO4 concentrations at the S154 station, even the current sampling frequency of 52 samples per year is insufficient to provide a detectable APC anywhere near 12.7%; investigated alternative scenarios show that sampling frequency has little effect on detectable APC, implying that increasing the sampling frequency is not the answer; it is recommended that the District investigate alternative more sophisticated methods for analyzing the S154 TPO4 concentration data in an attempt to better explain the systematic variations over time; no changes to the S154 monitoring plan are recommended at this time
3. Due to violations of the modeling assumptions employed in the power analysis procedures, it was not possible to draw conclusions regarding the optimal monitoring plan for the S65C monitoring station; the variability exhibited is in line with stations S191, S65A, S65C, and S65E, suggesting that Recommendation 1 may also apply to S65C; to verify this, it is recommended that the District investigate alternative more sophisticated methods for analyzing the S65C TPO4 concentration data in an attempt to better explain the systematic variations over time

References

Reckhow KH, Kepford K, and Hicks WW (1993). Methods for the Analysis of Lake Water Quality Trends. EPA 841-R-93-003.

Rust SW (2005). Power Analysis Procedure for Trend Detection with Accompanying SAS Software. Battelle Report to South Florida Water Management District, November 2005.

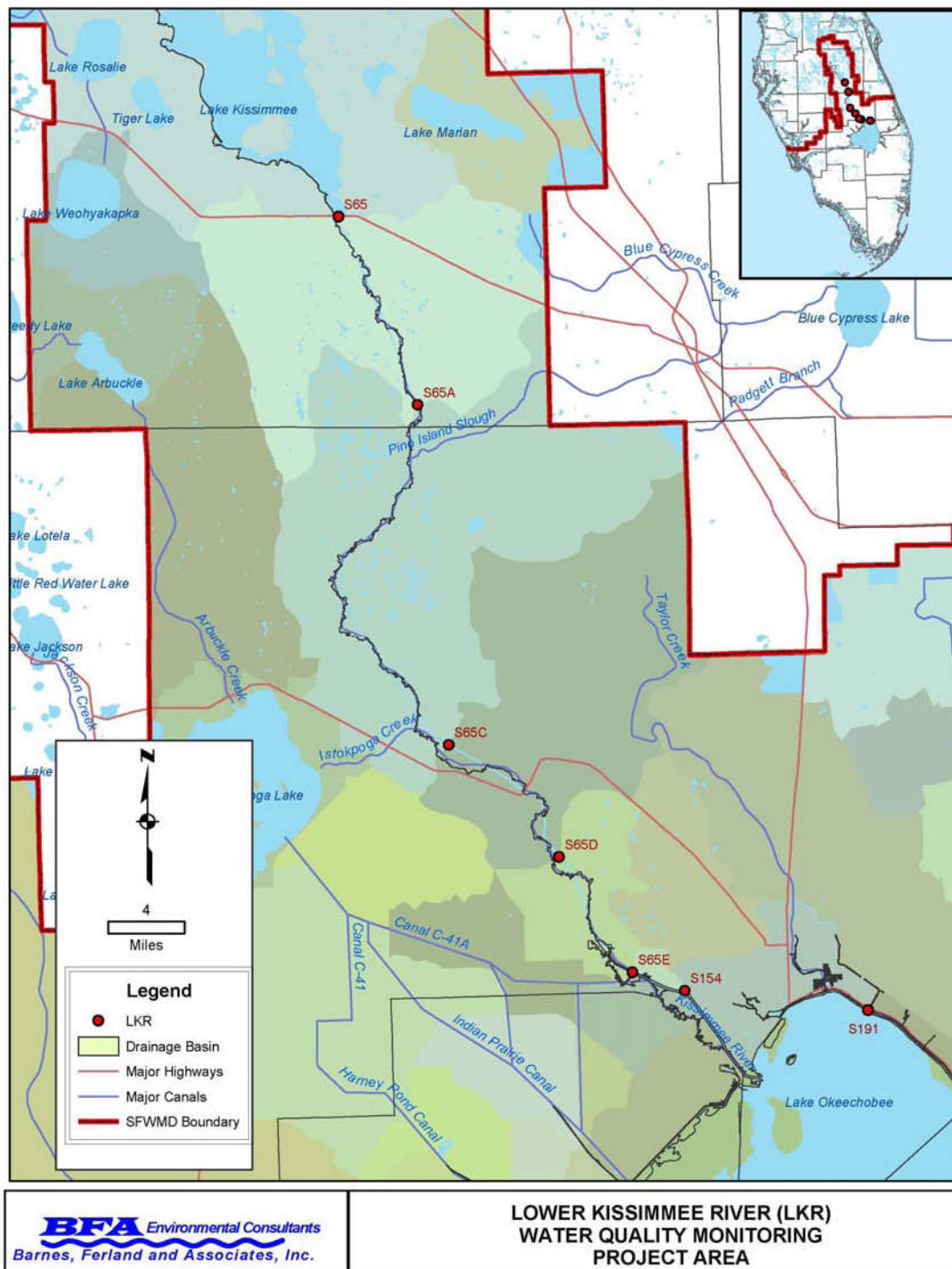


Figure 1. LKR Station Locations

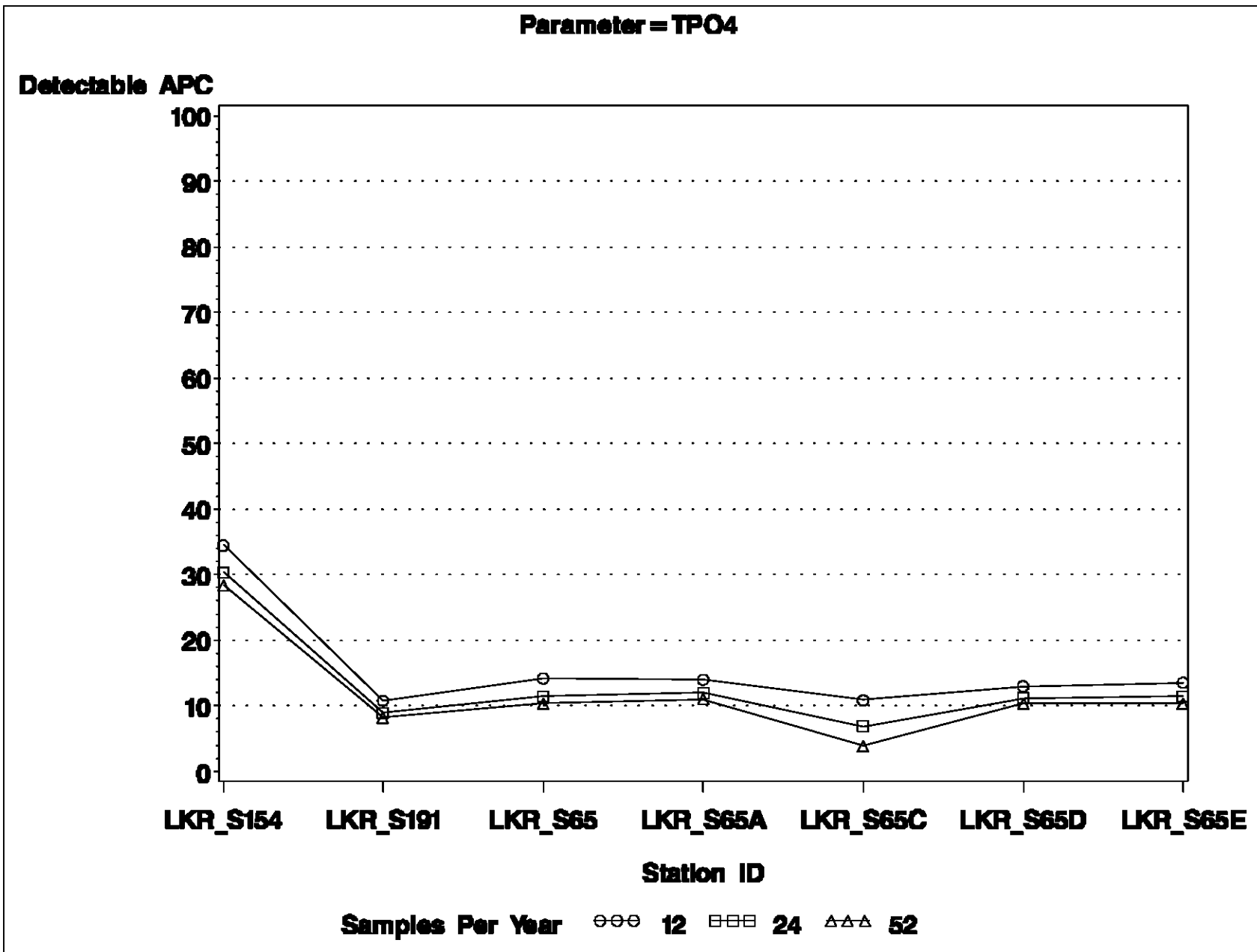


Figure 2

APPENDIX A

TIME SERIES PLOTS OF WATER QUALITY PARAMETERS OVERLAID WITH FITTED FIXED EFFECTS MODEL

Table A-1. Index of Figures Included in Appendix A

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 1 | LKR_S154 | TPO4 | 52 | 26 | 0.17 |
| 2 | LKR_S191 | TPO4 | 52 | 26 | 0.09 |
| 3 | LKR_S65 | TPO4 | 52 | 26 | 0.17 |
| 4 | LKR_S65A | TPO4 | 52 | 26 | 0.12 |
| 5* | LKR_S65C | TPO4 | 52 | 26 | 0.09 |
| 6 | LKR_S65D | TPO4 | 52 | 26 | 0.11 |
| 7 | LKR_S65E | TPO4 | 52 | 26 | 0.04 |

* Model assumptions may be violated for these stations

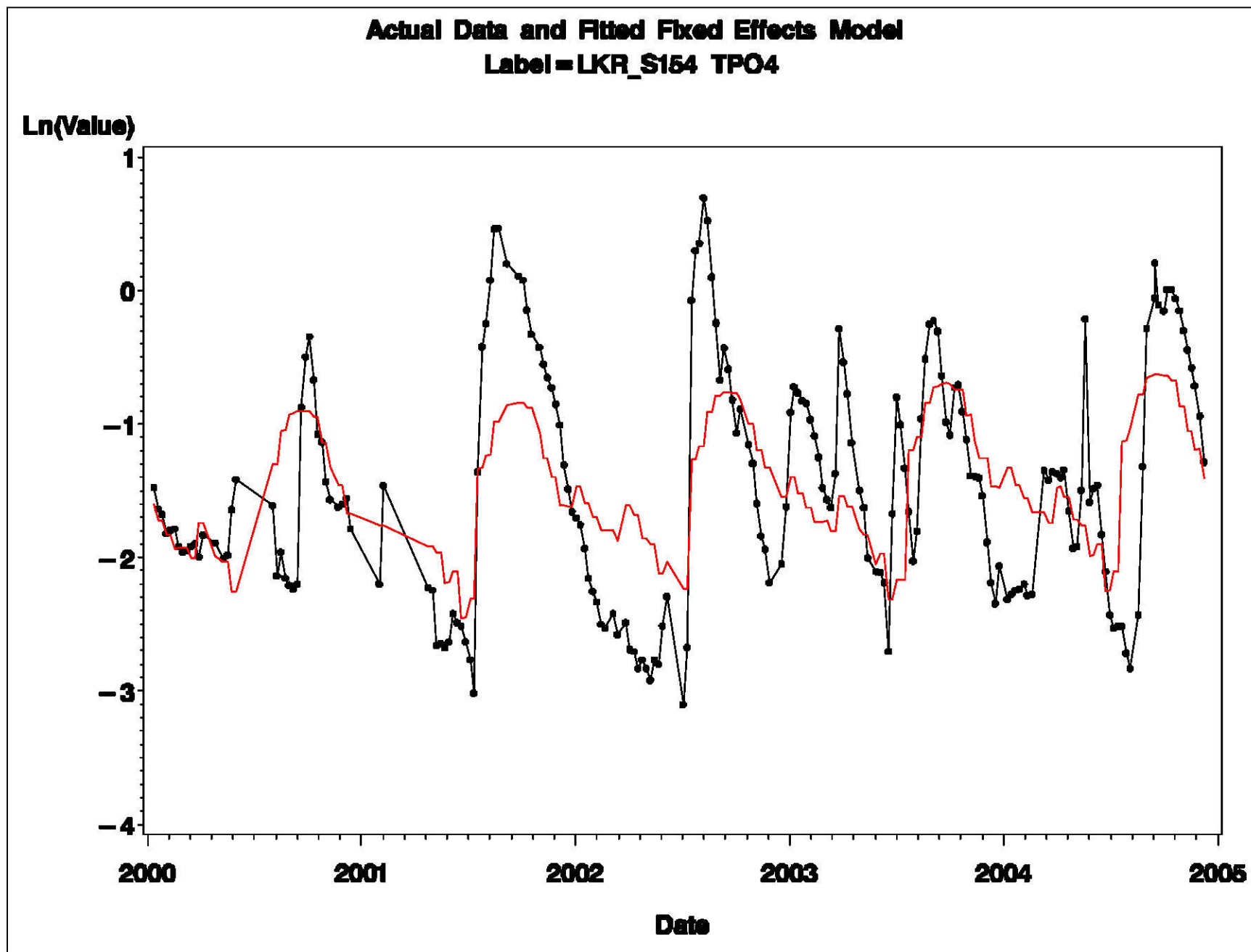


Figure A-1

Actual Data and Fitted Fixed Effects Model
Label = LKR_S191 TPO4

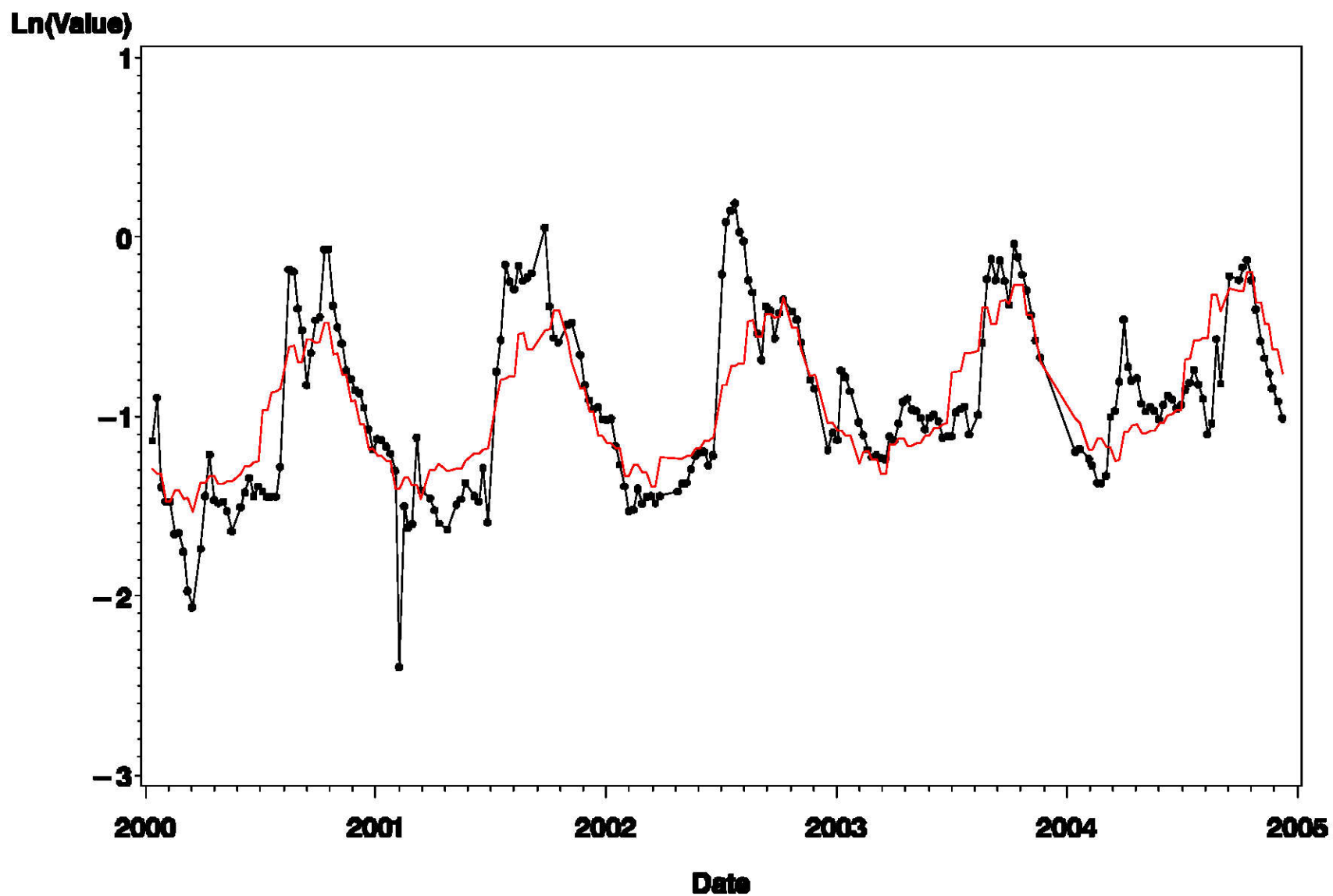


Figure A-2

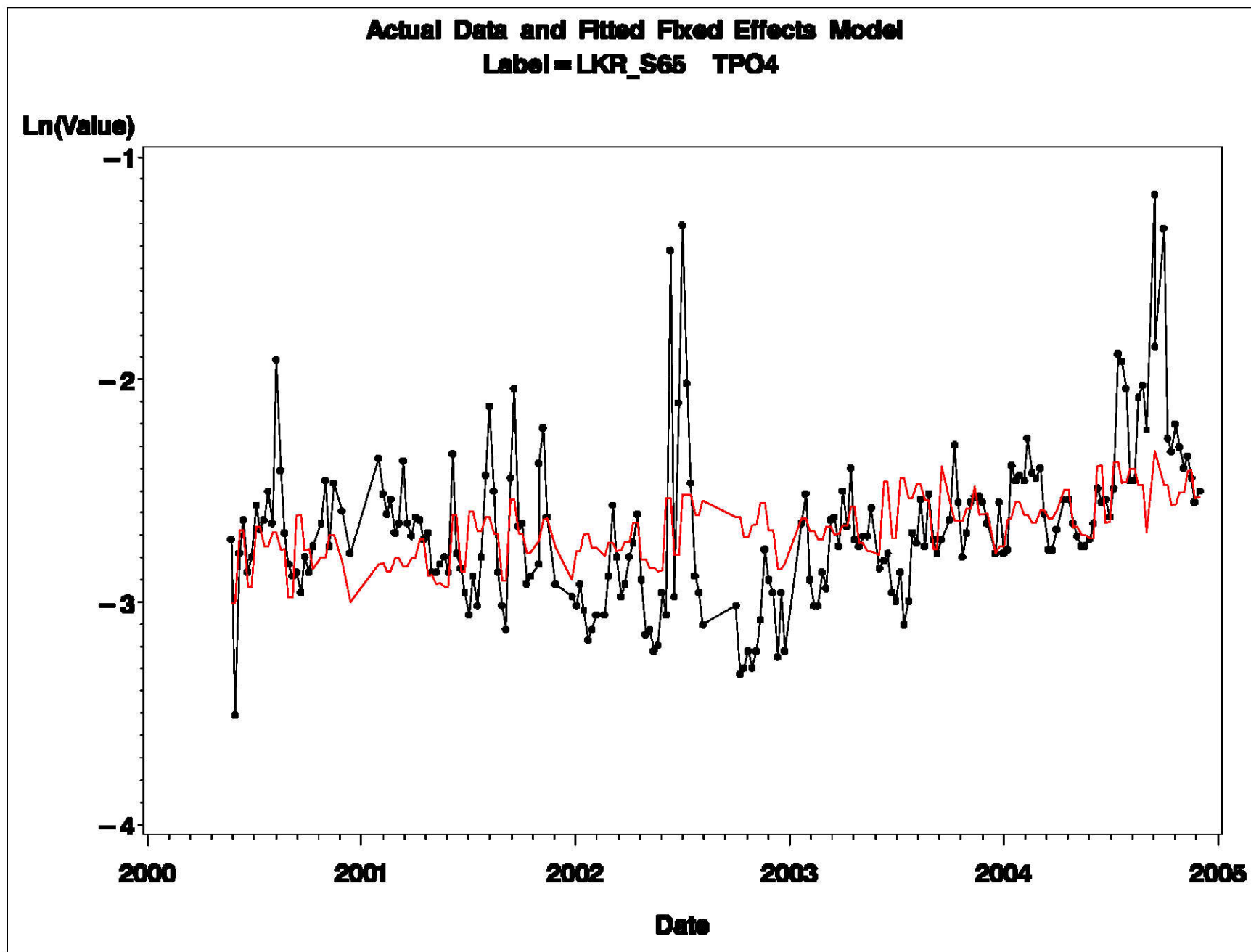


Figure A-3

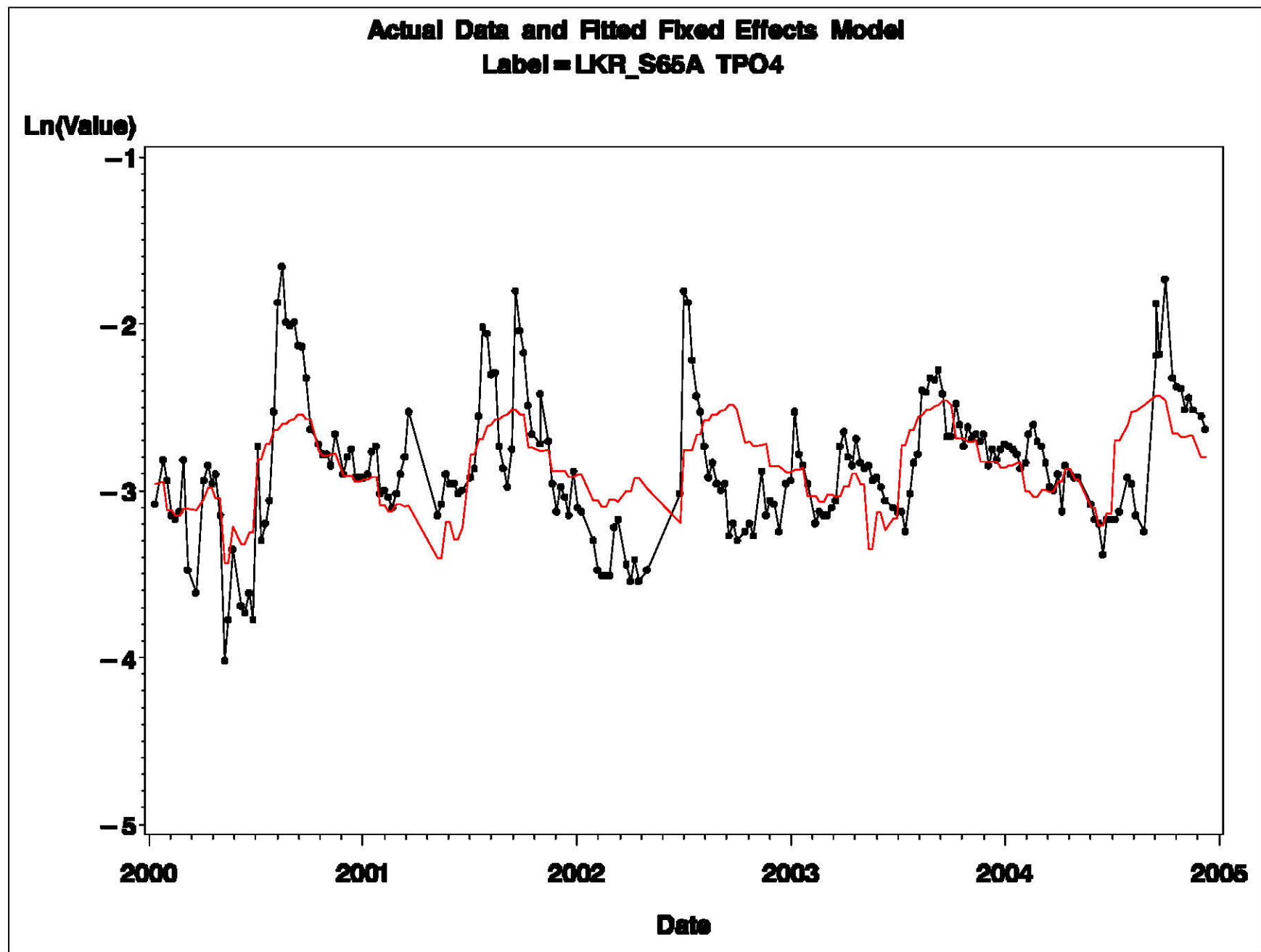


Figure A-4

Actual Data and Fitted Fixed Effects Model
Label=LKR_S65C TPO4

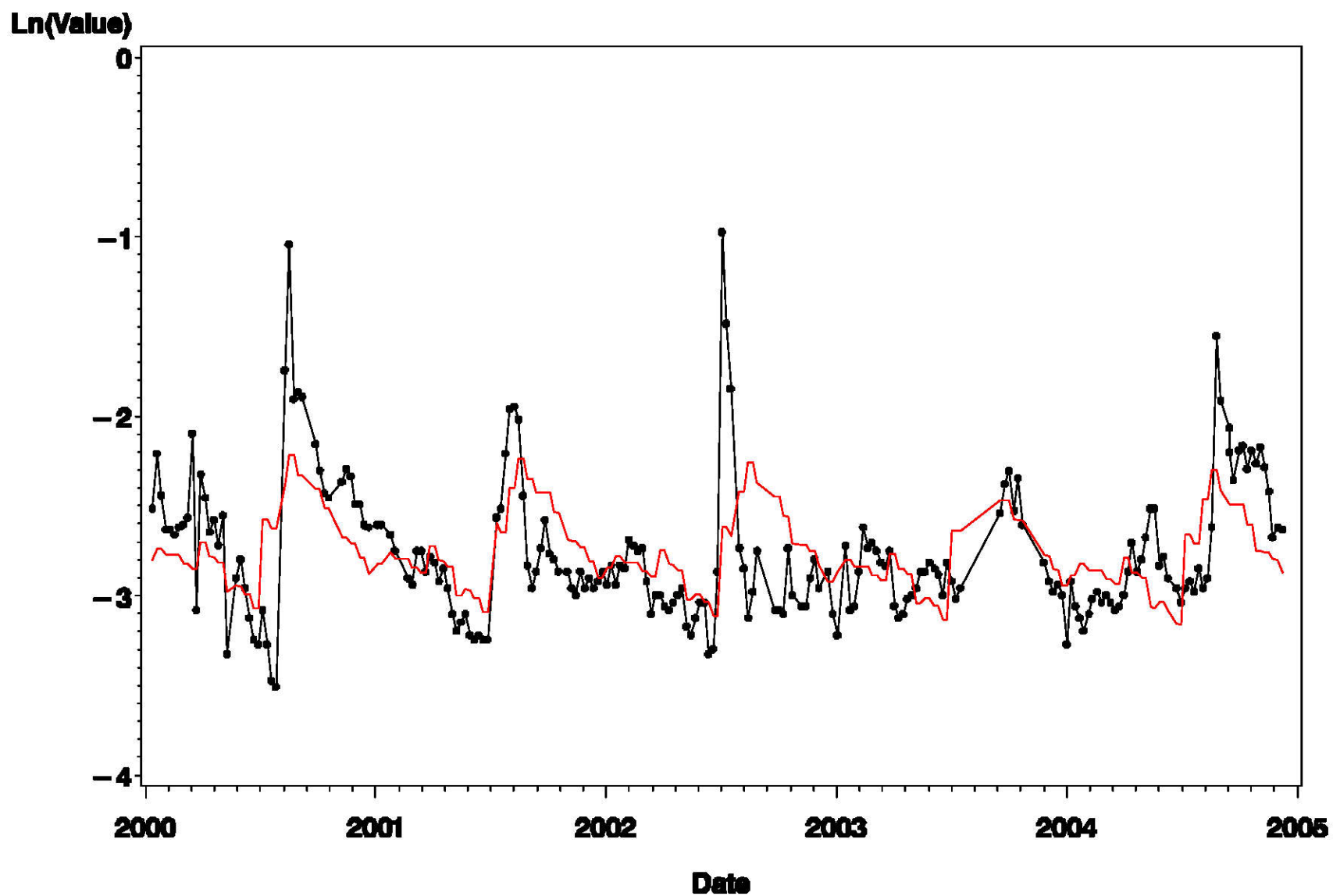


Figure A-5

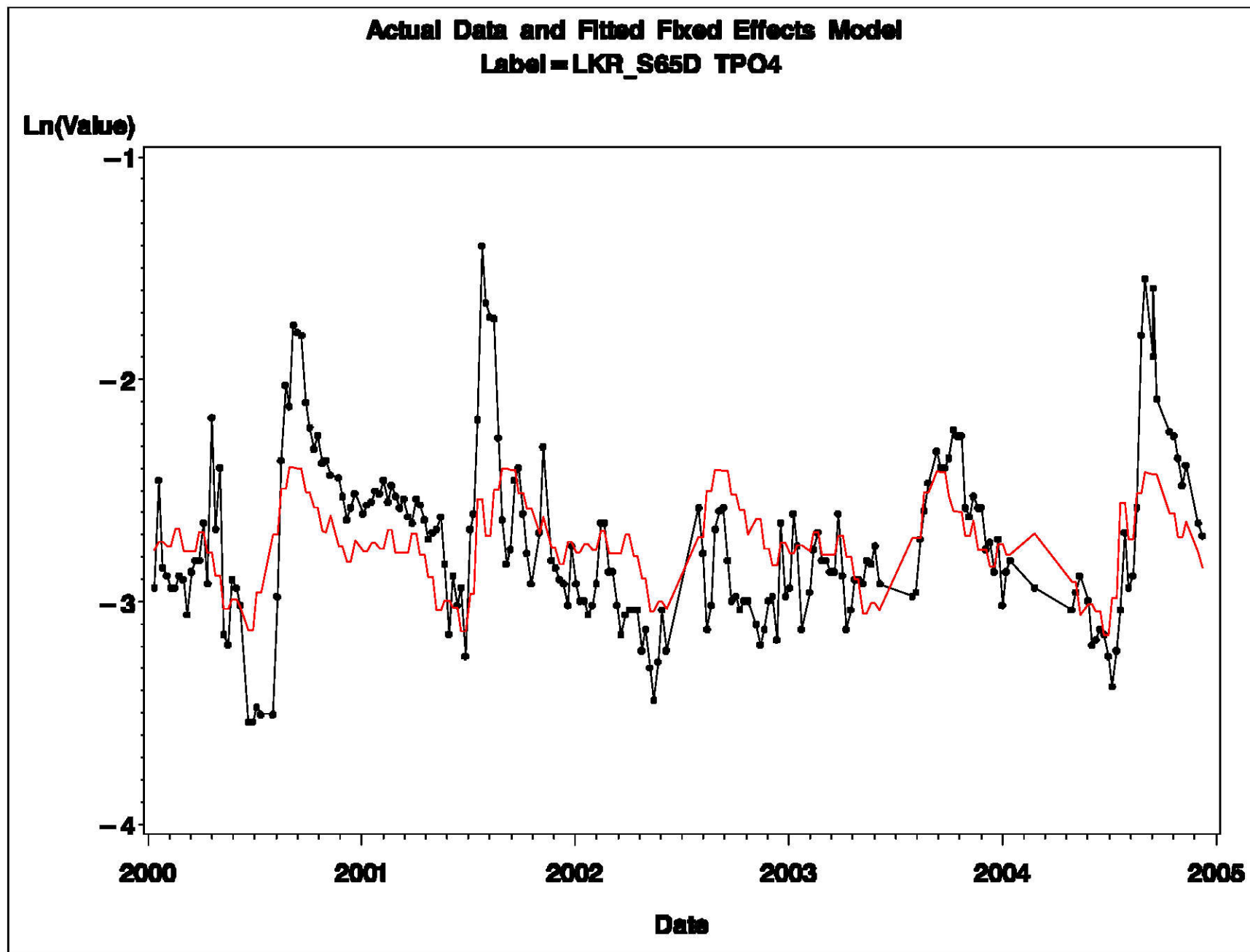


Figure A-6

Actual Data and Fitted Fixed Effects Model
Label=LKR_\$65E TPO4

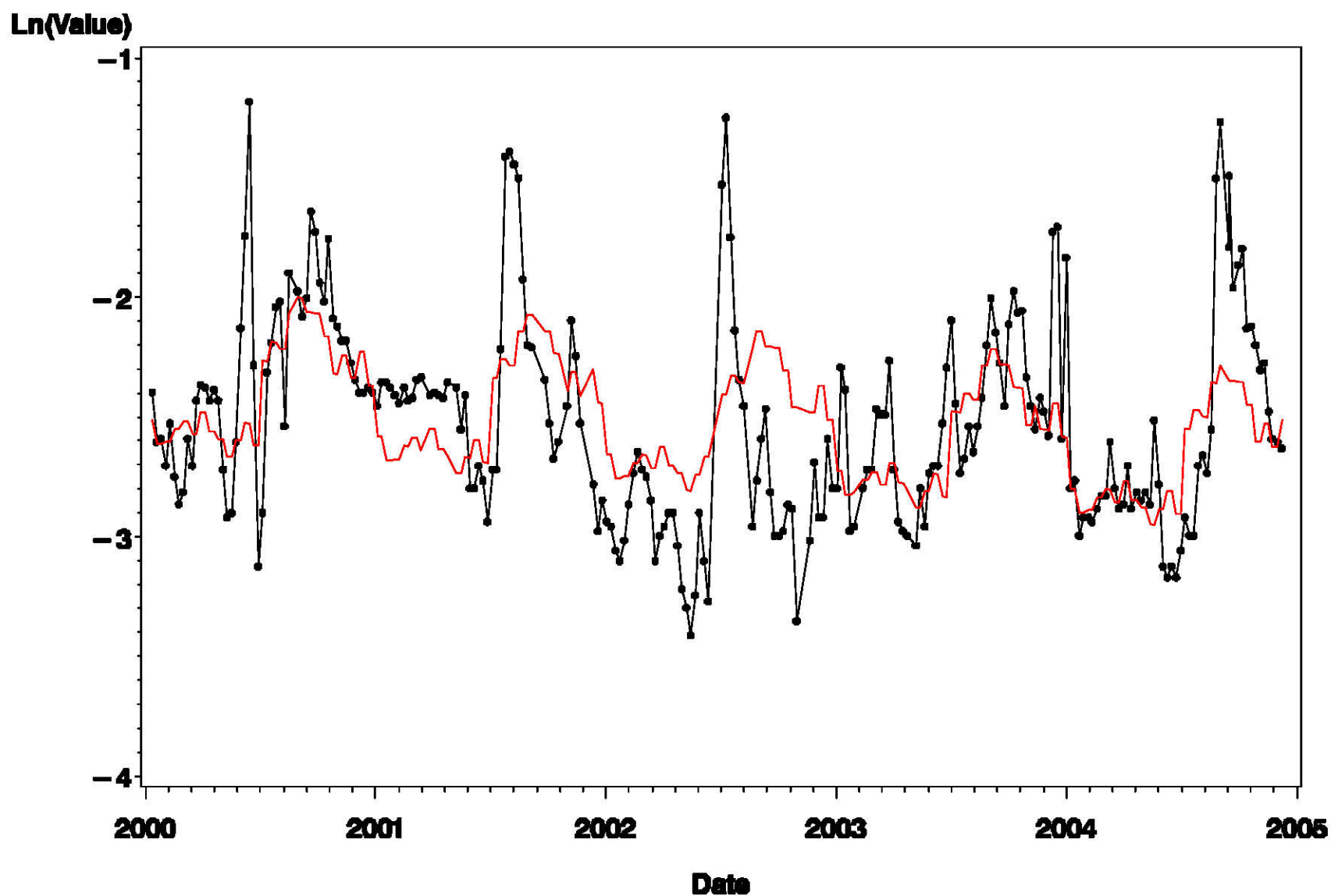


Figure A-7

Taylor Creek Nubbin Slough
Optimization Leader: Steve Rust, Battelle
Statistician: Steve Rust, Battelle

Project Code: TCNS

Type: Type II

Mandate or Permit:

- Lake Okeechobee Protection Plan Act
- Florida Watershed Restoration Act

Project Start Date: 1979

Division Manager: Okeechobee Division: Susan Gray

Program Manager: Steffany Gornak

Points of Contact: Gary Ritter, Steffany Gornak, Joyce Zhang, Patrick Davis

Field Point of Contact: Patrick Davis

Spatial Description

The Taylor Creek/Nubbin Slough project encompasses an area characterized by beef and intensive dairy cattle operations. Best Management Practices (BMPs) have been implemented in this watershed for the Works of the District Program as well as the Dairy Rule and the Rural Clean Waters Program. The basin is located in southeast and central Okeechobee County and portions of Martin County. Fourteen locations are sampled for this project. The LOWA Project also collects samples in this watershed; however, it is important to note that there is no duplication of effort with Project TCNS. Ten stations that are now sampled as part of Project LOWA should also be considered in the optimization of Project TCNS. These ten stations include (TCNS210, TCNS211, TCNS231, TCNS243, TCNS262, TCNS263, TCNS265, TCNS277, TCNS280, TCNS281). Due to the nature of LOWA sampling (i.e., focus on one specific basin and then move and focus on a different basin), these ten stations may be incorporated back into Project TCNS in the near future.

Project Purpose, Goals and Objectives

The primary purpose of Project TCNS is to provide baseline and assessment data for Lake Okeechobee watershed restoration and enhancement projects. Specific objectives of the project are to:

- A. Provide monitoring data to assess the efficacy of Best Management Practices (BMPs) for reducing phosphorous in surface discharge from dairies
- B. Monitor phosphorous contributions from each tributary
- C. Estimate phosphorous loads leaving Lake Okeechobee watershed basins
- D. Identifying high episodic phosphorous events and locating corresponding source areas

Sampling Frequency and Parameters Sampled

Samples are collected on a bi-weekly basis via grab samples at 14 stations: TCNS 201, TCNS 204, TCNS 207, TCNS 209, TCNS 212, TCNS 213, TCNS 214, TCNS 217, TCNS 220, TCNS

222, TCNS 228, TCNS 230, TCNS 233, and TCNS 249. Samples are analyzed for DO, PH, H2OT, SCOND, CL, NH4, TKN, NO2, NOX, TPO4, and OPO4.

Station locations are illustrated on the map in Figure 1. Sampling frequencies for TCNS station-parameter combinations are reported in Table 1. The TCNS stations are listed below by basin.

Nubbin Slough Basin

- TCNS 220
- TCNS 222
- TCNS 249

S133 Basin

- TCNS 217
- TCNS 228

S135 Basin

- TCNS 230
- TCNS 233

Taylor Creek Basin

- TCNS 201
- TCNS 204
- TCNS 207
- TCNS 209
- TCNS 212
- TCNS 213
- TCNS 214

Stations 201, 213 and 214 are on Taylor Creek while stations 204, 207, 209 and 212 are east of the creek.

Early on in the optimization project, District staff indicated that relevant data may be collected under the LOWA project at the following stations: TCNS 210, TCNS 211, TCNS 231, TCNS 243, TCNS 262, TCNS 263, TCNS 265, TCNS 277, TCNS 280, and TCNS 281. After consultation with District staff while finalizing the TCNS data set, it was determined that the LOWA data would not be employed in the TCNS optimization analyses performed.

District staff questioned the use of the in situ measurements and suggested that a quarterly deployment of a data sonde for a continuous 4 day period may provide more useful information than measurements taken at single point in time during grab sample collection. District staff also mentioned that the capability to monitor episodic events is critical in this region and is currently not addressed by this project or others in the Kissimmee River watershed.

Current and Future Data Uses

The TCNS data are used in several District reports including the South Florida Environmental Report, and reports pertaining to the Kissimmee River Restoration. The Lake Okeechobee watershed modeling activities (CREAMS and FHANTM models) also use this information and the information is included in the Lake Okeechobee Annual Basin Assessment Reports.

In the future, this data will be used for TMDL development in cooperation with DEP (for

nitrogen and phosphorus). Additionally, this information will be critical for the CERP watershed critical projects, Taylor Creek and Nubbin Slough STAs.

Optimization Analyses

Perhaps the most significant water quality monitoring objective that motivates TCNS monitoring is detection of an increasing or decreasing trend in TPO4 concentrations over time. The Lake Okeechobee Protection Plan (LOPP) calls for a 70% reduction in the TPO4 load to Lake Okeechobee by 2015 and a near-shore TPO4 concentration of less than 40 ppb ($\mu\text{g/L}$). The LOPP also specifies construction projects, management projects, and a myriad of best management practices that are designed to achieve these TPO4 goals. Over the next decade, the District will use its TCNS monitoring data and statistical trend analysis procedures to assess the effectiveness of LOPP implementation toward meeting the 2015 TPO4 goals.

A key question related to the TCNS monitoring project is whether or not the monitoring data collected will be sufficient to assess the effectiveness of projects and practices implemented to control and improve water quality and determine whether or not sufficient progress is being made toward water quality goals and objectives. One way to address this question is to perform statistical power analyses to determine the smallest water quality trends that will be detectable with high probability based on water quality data collected according to current monitoring plans. Using the resulting detectable trends, District staff will be able to determine whether the trends necessary to achieve long-term goals will be discernable from trends that fail to achieve the long-term goals. The same statistical power analysis procedures can be used to identify detectable water quality trends for alternatives to the current monitoring design. With power analysis results for both the current and alternative monitoring designs in hand, District staff will be able to optimize the TCNS monitoring design for achievement of long-term goals and objectives.

Optimization Analysis Procedures

Four primary parameters were selected for which to perform TCNS optimization analyses. They are DO, TKN, TPO4 and CL with DBHYDRO codes 8, 21, 25, and 32, respectively. Power analyses for each station-parameter combination were performed by carrying out the following power analysis steps:

- Fit a statistical model to the water quality parameter data in order to have a basis for generating simulated data to support a Monte Carlo based power analysis procedure
- Generate multiple replicate simulated water quality time series data sets; for all power analyses reported here, each time series generated was for a 5-year monitoring period
- Perform a Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) for each simulated time series data set; in particular, obtain a point estimate of the slope vs. time for the log-transformed water quality parameter values
- Estimate the *annual proportion change* (APC) in water quality parameter values that is detectable with 80% power using a simple two-sided test based on the Seasonal Kendall's Tau slope estimate performed at a 5% significance level

Parameter values were natural log-transformed for statistical modeling because the log-transformed data was more nearly normally distributed than were the untransformed data. The fitted statistical model contains the following components:

- Fixed seasonal effects that repeat themselves in an annual cycle
- A long-term linear trend in the log-transformed parameter concentrations; this corresponds to a fixed percentage increase or decrease in the water quality parameter each year
- A random error term representing temporal variability in true water quality parameter values; these error terms are allowed to be correlated from one time point to the next in order to capture any serial autocorrelation that is present in the monitoring data
- A random error term representing sampling and chemical analysis variability; these error terms are assumed to be stochastically independent from one time point to the next

The fitted statistical model is used to perform a Monte Carlo simulation analysis in which multiple TPO4 time series data sets are simulated and used to determine the anticipated statistical properties of trend detection procedures that will be used by the District. All statistical trend analyses performed on the simulated data were based on the Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) preferred by the District.

In the course of performing the power analyses for the District, it was determined that the basic Seasonal Kendall's Tau trend detection procedures do not necessarily control the true significance level of the hypothesis test for trend when there is serial autocorrelation exhibited in the data. This was found to be true even for procedures that attempt to correct for serial autocorrelation. For this reason, all power analysis results reported here are for a simple hypothesis test procedure based on the median slope estimator that accompanies the Seasonal Kendall's Tau test procedure. The median slope estimator is assumed to follow a normal distribution and power results are obtained by performing a simple z-test with this estimator.

Power analyses were attempted for each of 56 station-parameter combinations. However, there was insufficient CL data for stations 204, 212, 220, and 249. Therefore, power analyses were completed for only 52 station-parameter combinations. For each combination, an attempt was made to simulate the following three monitoring designs:

- The current monitoring frequency of semi-monthly samples (24 samples per year)
- An alternative reduced sampling design of monthly samples (12 samples per year)
- A second alternative increased sampling design of weekly samples (52 samples per year)

In total, 156 station-parameter-design combinations were explored. For each station-parameter-design combination analyzed, an estimate was obtained of the minimum annual percentage change (APC) in parameter value that is detectable with 80% power using the median slope estimator z-test procedure performed at a two-sided significance level of 0.05.

Analysis of the data from DBHYDRO indicates that it was sometimes not possible to obtain one of the weekly autosamples called for by the current monitoring design. By analyzing TPO4 records from DBHYDRO along with "No Bottle Sample" records, it was possible to estimate the proportion of attempted sampling occasions for which no sample was obtained. This procedure was carried out for sampling dates during the period from January 1, 2000 through September 30, 2004 in order to estimate the proportion of the time that no sample was obtained. In the Monte

Carlo procedure used to generate simulated monitoring data, sampling results were set equal to missing values with probability equal to the proportion of “No Bottle Samples”.

Rust (2005) describes the power analysis procedure and underlying statistical model employed here in detail. Rust (2005) also documents the SAS program used to carry out the power analyses for which results are reported here.

Optimization Analysis Results

Appendix A contains a figure corresponding to each of the time series data sets for which power analyses were performed. For the TCNS project, that is 52 station-parameter combinations. Table A-1 contains a row identifying each of the 52 figures in Appendix A. The last three columns of Table A-1 identify the following:

- The number of samples per year called for in the current monitoring plan
- The number of seasons assumed in the mixed model fitted to the data and used to simulate monitoring data
- The proportion of “No Bottle Samples” during the period January 1, 2000 through September 30, 2004 which was used as a probability for generating missing data when the Monte Carlo simulation was performed

Each figure in Appendix A displays the actual water quality parameter time series for an individual station as black dots connected by black lines. The plotted values are the natural logarithm of water quality parameter values. The fixed portion of the fitted mixed model is illustrated as a red curve. As illustrated in the figures in Appendix A, data sets go back as far as early-to-mid 1992 except for the CL time series at station 201 which begins in late 1994.

A summary of the power analysis results are reported in Table B-1. Table B-1 contains a row for each of the 156 power analyses performed, three power analyses per station-parameter combination. A power analysis was performed for the current sampling frequency. In addition, alternative monitoring designs calling for sampling at half the current rate and double the current rate were also investigated.

For each station, the standard deviation of the monitoring data about the fitted fixed effects model and the correlation coefficient for two measurements taken exactly one month apart are reported. These two quantities are key drivers of the power analysis results. In addition, the number of samples per year simulated and the detectable annual percentage change for that monitoring scenario are reported in the last two columns of Table B-1.

The detectable annual percentage change (detectable APC) is the minimum true percentage change per year that would be consistently detected by the test for trend based on the median slope estimator that accompanies the Seasonal Kendall’s Tau procedure. Consistently detected means that the null hypothesis of no trend would be rejected 80% of the time.

As noted in the footnote to Tables A-1 and B-1, because the estimated autocorrelation coefficient for certain station-parameter combinations is negative, it is suspected that the assumptions underlying the mixed model used in the power analysis procedure are violated for those combinations. For this reason, the detectable APC results for these station-parameter combinations will be largely ignored when drawing conclusions from the power analysis results.

The detectable APC results reported in Table B-1 are illustrated graphically in Figures 2-5, one figure for each of the four parameters examined. The following conclusions related to TPO4 concentrations may be drawn from Figure 5 and the corresponding rows of Table B-1.

- The TPO4 time series data for stations 213 and 233 exhibit no autocorrelation according to the fitted mixed model; stations 201, 220, 222, and 228 exhibit moderate autocorrelation; the remaining eight stations exhibit high levels of autocorrelation
- Detectable APC values for stations 212 and 249 are considerable larger than those for other TCNS stations; this result is apparently due to high variability and the very high incidence of “No Bottle Samples” at these stations
- Detectable APC values for stations other than 212 and 249 at the current monitoring frequency of 24 samples per year are in the range of 11%-34%
- For some stations, the effect of reduced sampling frequencies on detectable APC values is smaller than would be expected for independent time series data; if the monitoring data exhibited no serial autocorrelation, one would expect an increase in the sampling frequency to 52 samples per year to cause the detectable APC to decrease by a multiplicative factor of 1.4; in this case, the detectable APC values decrease by a multiplicative factor less than 1.2 for stations 207, 209, 214, 217, 220 and 230; the smaller effect associated with sample frequency reduction is due the significant autocorrelation exhibited in the TPO4 time series data at these stations

The following conclusions related to CL, DO, and TKN water quality values may be drawn from Figures 2-4 and the corresponding rows of Table B-1.

- CL: Station 214 has a very large detectable APC values; for other stations, current sampling frequencies result in detectable APC values in the range 5%-24%; changing the sampling frequency has only a small effect on detectable APC values at stations with high autocorrelation but has a large effect at stations with low autocorrelation
- DO: Current sampling frequencies result in detectable APC values in the range 9%-34%; changing the sampling frequency has only a small effect on detectable APC values at stations with high autocorrelation but has a large effect at stations with low autocorrelation
- TKN: Stations 212, 217 and 249 have very large detectable APC values; for other stations, , current sampling frequencies result in detectable APC values in the range 8%-18%; changing the sampling frequency has only a small effect on detectable APC values at stations with high autocorrelation but has a large effect at stations with low autocorrelation

Recommendations for Current Monitoring Plans

A 70% reduction in TPO4 loads to Lake Okeechobee, if accomplished smoothly over the next decade, would require an 11.3% reduction in phosphorus load each year. In annual percentage change terminology that translates to a APC of 12.7%. For the purposes of evaluating the current and alternative monitoring designs for which power analysis results were generated, it seems reasonable to expect a design to have a detectable APC of 12.7% or smaller. If this requirement is satisfied by a monitoring design, then a smooth 11.3% annual reduction in TPO4

concentrations over a 5-year monitoring period would have an 80% chance of being declared a statistically significant trend.

Requiring a detectable APC of 12.7% is not a very restrictive requirement. Stated another way, the absolute error in estimating the annual percentage change in TPO4 concentrations would be on the order of 7.5%. If there was no change in the average TPO4 concentration over a 5-year monitoring period (observed annual percentage change of 0%), then a 95% confidence interval for the true annual percentage change in TPO4 concentrations would be (-8.1%, +8.8%). Projecting the uncertainty in the annual percentage change over a 10-year time period, the 95% confidence interval for the percentage change over a 10-year time period would be (-57%, +132%). Therefore, a detectable APC of 12.7% still leaves the district in a position of some considerable uncertainty regarding 10-year trends in TPO4 concentrations.

The following recommendations are made regarding the monitoring plans for TCNS monitoring stations:

1. Regarding detectable APC values for TPO4
 - A. Four TCNS stations (213, 214, 222, 228) have detectable near the target value of 12.7% and no changes are recommended for these stations
 - B. Five TCNS stations (201, 204, 212, 233, 249) would benefit from an increased sampling frequency and it is recommended that the District consider increasing the sampling frequency at these stations to weekly
 - C. Five TCNS stations (207, 209, 217, 220, 230) fail to meet the detectable APC target value of 12.7% but also do not exhibit benefits from an increased sampling frequency due to high serial autocorrelation; because there does not seem to be a simple monitoring change that will result in achievement of the target detectable APC at these stations, it is recommended that the District
 - Investigate alternative more sophisticated methods for analyzing the TPO4 concentration data in an attempt to better explain the systematic variations over time and produce more precise estimates of trend, and/or
 - Investigate methods of data aggregation that will result in more precise estimates of long-term trends
2. In general, detectable APC values for TKN concentrations are as good or better than those for TPO4; therefore, it is concluded that any monitoring plan that produces precise enough estimates of TPO4 trends will at the same time produce adequate estimates of TKN trends, allowing precise estimates of trends in TPO4 to TKN ratios to be determined as well; therefore, separate optimization recommendations for TKN will not be required
3. Detectable APC values for CL and DO vary considerably from station to station, making it difficult to draw general conclusions regarding these parameters; it is recommended that these parameters be examined more thoroughly on a station-by-station basis in order to develop station-specific recommendations
4. It is recommended that the data sets with potential model violations and potential outliers be re-analyzed to produce robust power analysis results for these data sets; however, it is doubtful that such re-analyses would change the general recommendations just offered above.

References

Reckhow KH, Kepford K, and Hicks WW (1993). Methods for the Analysis of Lake Water Quality Trends. EPA 841-R-93-003.

Rust SW (2005). Power Analysis Procedure for Trend Detection with Accompanying SAS Software. Battelle Report to South Florida Water Management District, November 2005.

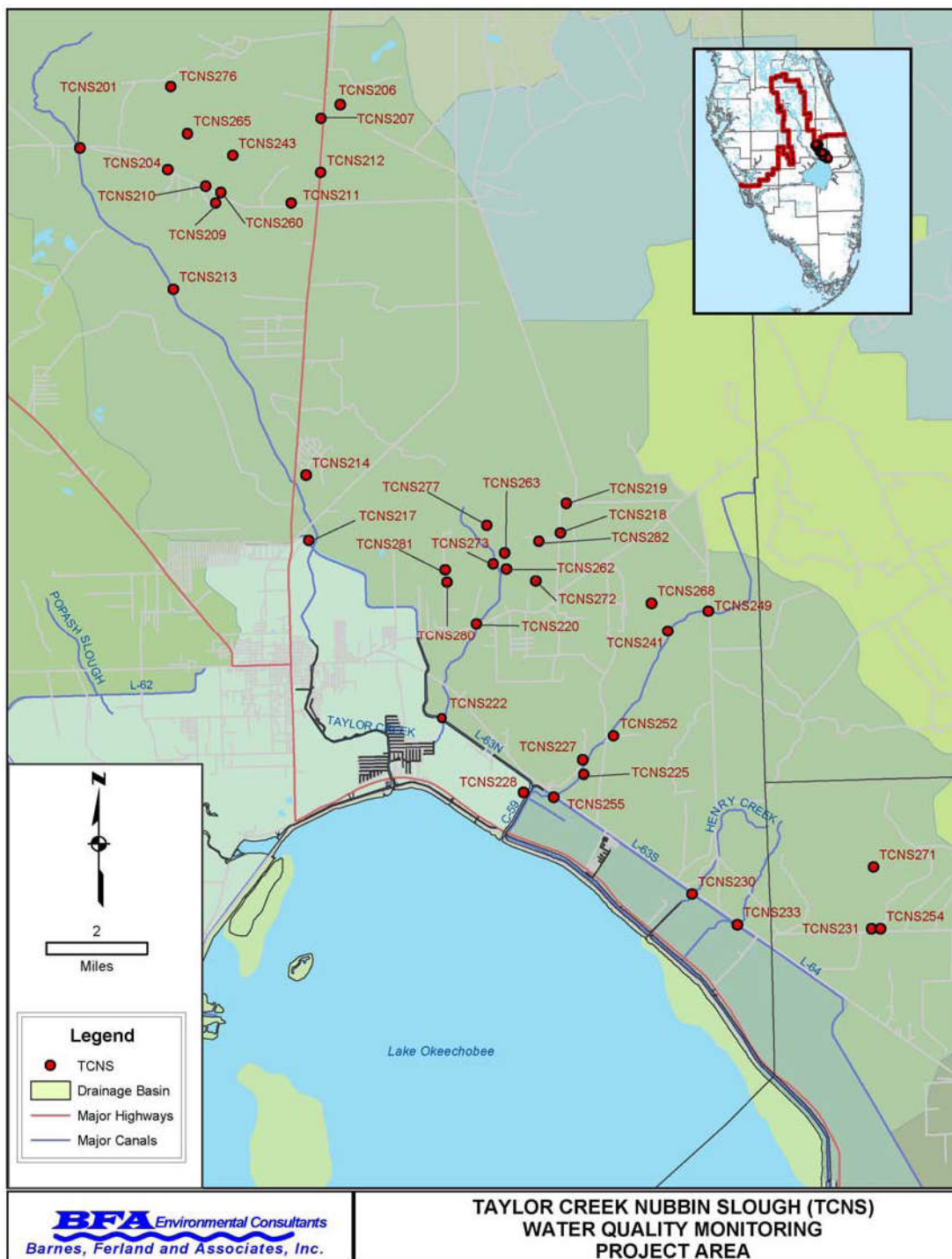


Figure 1. TCNS Station Locations

Table 1. Parameters Measured Either In Situ or by Grab Samples for Project TCNS

| Station | DO | PH | TEMP | SCOND | CL | NH4 | TKN | NO2 | NOX | TPO4 | OPO4 |
|----------|----|----|------|-------|----|-----|-----|-----|-----|------|------|
| TCNS 201 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 207 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 209 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 213 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 214 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 217 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 222 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 228 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 230 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 233 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 204 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 212 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 220 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| TCNS 249 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |

bw = bi-weekly

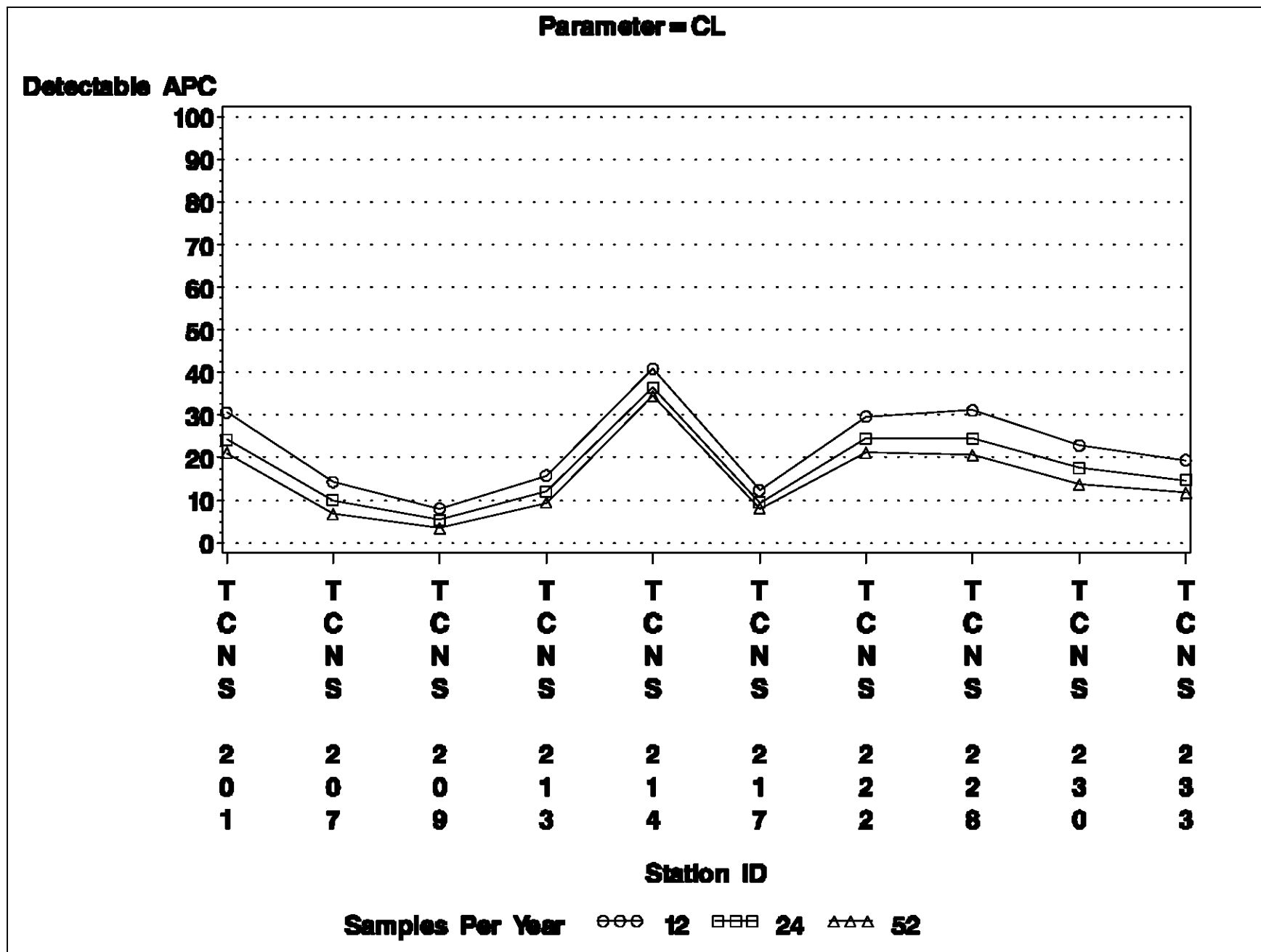


Figure 2

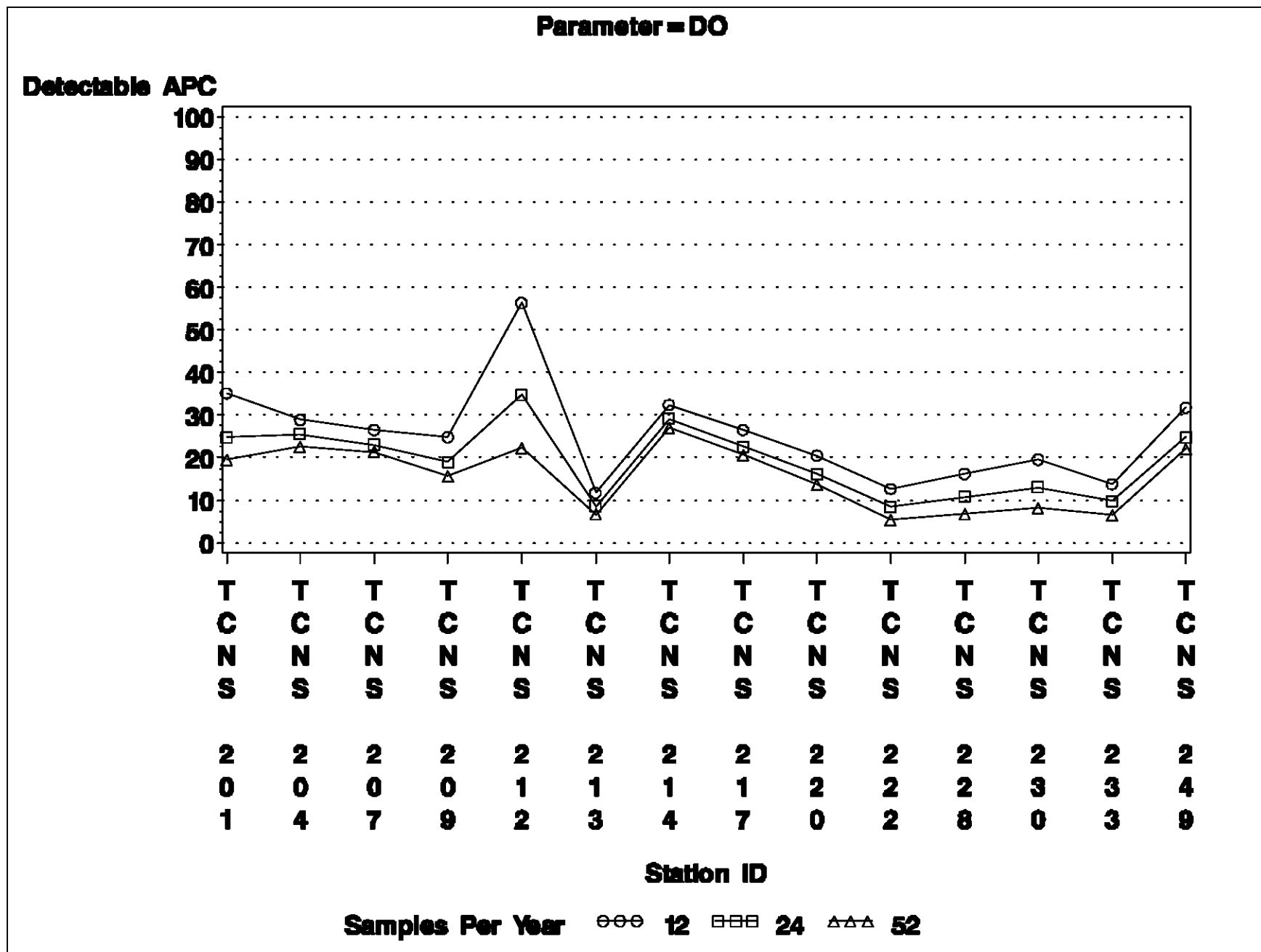


Figure 3

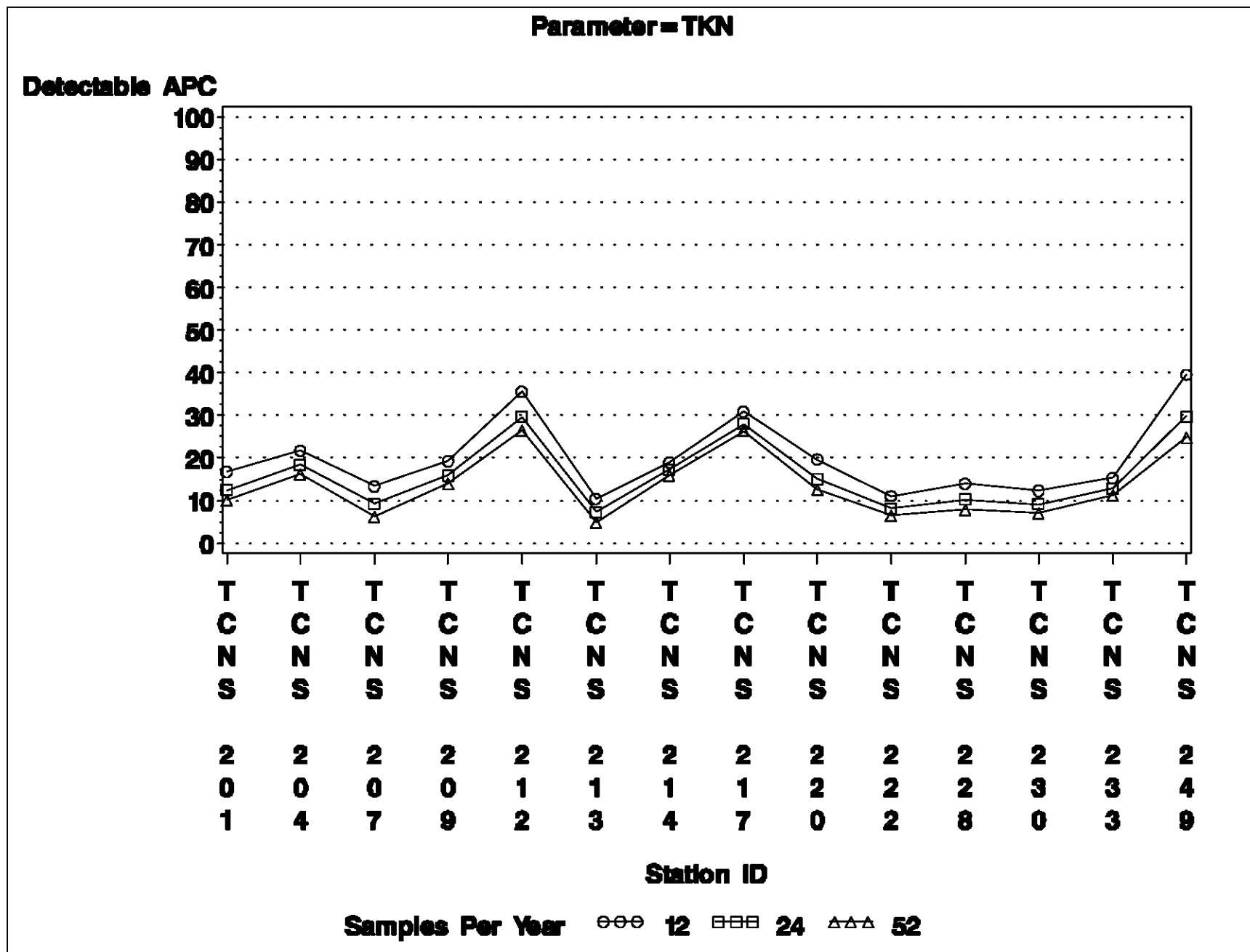


Figure 4

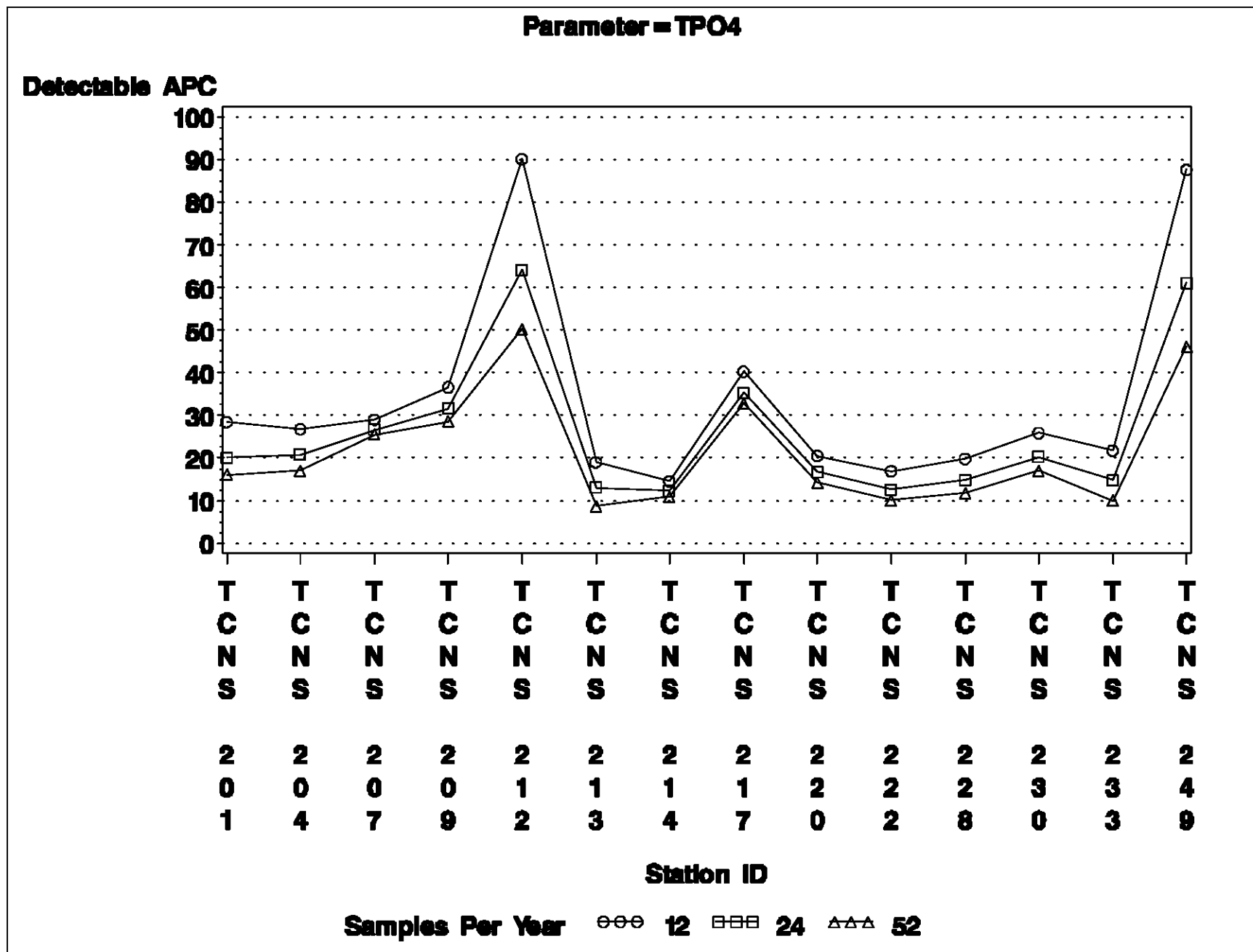


Figure 5

APPENDIX A

TIME SERIES PLOTS OF WATER QUALITY PARAMETERS OVERLAID WITH FITTED FIXED EFFECTS MODEL

Table A-1. Index of Figures Included in Appendix A

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 1 | TCNS 201 | DO | 24 | 24 | 0.41 |
| 2 | TCNS 204 | DO | 24 | 24 | 0.37 |
| 3 | TCNS 207 | DO | 24 | 24 | 0.07 |
| 4 | TCNS 209 | DO | 24 | 24 | 0.24 |
| 5 | TCNS 212 | DO | 12 | 6 | 0.66 |
| 6 | TCNS 213 | DO | 24 | 24 | 0.09 |
| 7 | TCNS 214 | DO | 24 | 24 | 0.06 |
| 8 | TCNS 217 | DO | 24 | 24 | 0.14 |
| 9 | TCNS 220 | DO | 12 | 12 | 0.34 |
| 10 | TCNS 222 | DO | 24 | 24 | 0.36 |
| 11* | TCNS 228 | DO | 24 | 24 | 0.33 |
| 12* | TCNS 230 | DO | 24 | 24 | 0.38 |
| 13 | TCNS 233 | DO | 24 | 24 | 0.23 |
| 14 | TCNS 249 | DO | 12 | 12 | 0.60 |
| 15 | TCNS 201 | TKN | 24 | 24 | 0.41 |
| 16 | TCNS 204 | TKN | 24 | 24 | 0.37 |
| 17 | TCNS 207 | TKN | 24 | 24 | 0.07 |
| 18 | TCNS 209 | TKN | 24 | 24 | 0.24 |
| 19 | TCNS 212 | TKN | 12 | 6 | 0.66 |
| 20 | TCNS 213 | TKN | 24 | 24 | 0.09 |
| 21 | TCNS 214 | TKN | 24 | 24 | 0.06 |
| 22 | TCNS 217 | TKN | 24 | 24 | 0.14 |
| 23 | TCNS 220 | TKN | 12 | 12 | 0.34 |
| 24 | TCNS 222 | TKN | 24 | 24 | 0.36 |
| 25 | TCNS 228 | TKN | 24 | 24 | 0.33 |
| 26 | TCNS 230 | TKN | 24 | 24 | 0.38 |
| 27 | TCNS 233 | TKN | 24 | 24 | 0.23 |
| 28 | TCNS 249 | TKN | 12 | 12 | 0.60 |
| 29** | TCNS 201 | TPO4 | 24 | 24 | 0.41 |
| 30 | TCNS 204 | TPO4 | 24 | 24 | 0.37 |
| 31 | TCNS 207 | TPO4 | 24 | 24 | 0.07 |
| 32 | TCNS 209 | TPO4 | 24 | 24 | 0.24 |

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 33 | TCNS 212 | TPO4 | 12 | 6 | 0.66 |
| 34 | TCNS 213 | TPO4 | 24 | 24 | 0.09 |
| 35 | TCNS 214 | TPO4 | 24 | 24 | 0.06 |
| 36 | TCNS 217 | TPO4 | 24 | 24 | 0.14 |
| 37 | TCNS 220 | TPO4 | 12 | 12 | 0.34 |
| 38 | TCNS 222 | TPO4 | 24 | 24 | 0.36 |
| 39 | TCNS 228 | TPO4 | 24 | 24 | 0.33 |
| 40 | TCNS 230 | TPO4 | 24 | 24 | 0.38 |
| 41 | TCNS 233 | TPO4 | 24 | 24 | 0.23 |
| 42 | TCNS 249 | TPO4 | 12 | 12 | 0.60 |
| 43 | TCNS 201 | CL | 24 | 24 | 0.41 |
| 44** | TCNS 207 | CL | 24 | 24 | 0.07 |
| 45* | TCNS 209 | CL | 24 | 24 | 0.24 |
| 46** | TCNS 213 | CL | 24 | 24 | 0.09 |
| 47 | TCNS 214 | CL | 24 | 24 | 0.06 |
| 48 | TCNS 217 | CL | 24 | 24 | 0.14 |
| 49 | TCNS 222 | CL | 24 | 24 | 0.36 |
| 50** | TCNS 228 | CL | 24 | 24 | 0.33 |
| 51 | TCNS 230 | CL | 24 | 24 | 0.38 |
| 52 | TCNS 233 | CL | 24 | 24 | 0.23 |

* Model assumptions may be violated

** Time series data may contain overly influential outliers

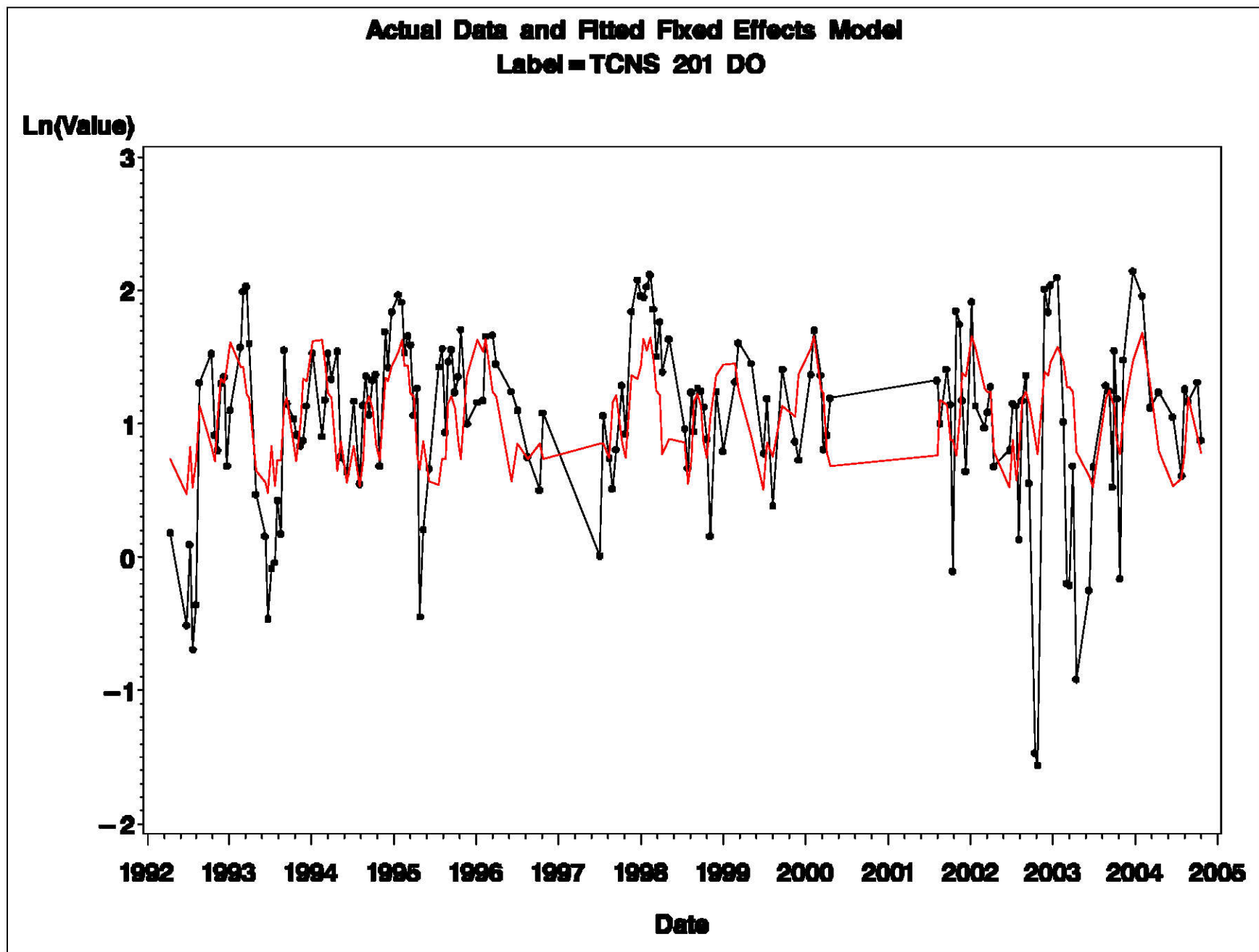


Figure A-1

Actual Data and Fitted Fixed Effects Model
Label=TCNS 204 DO

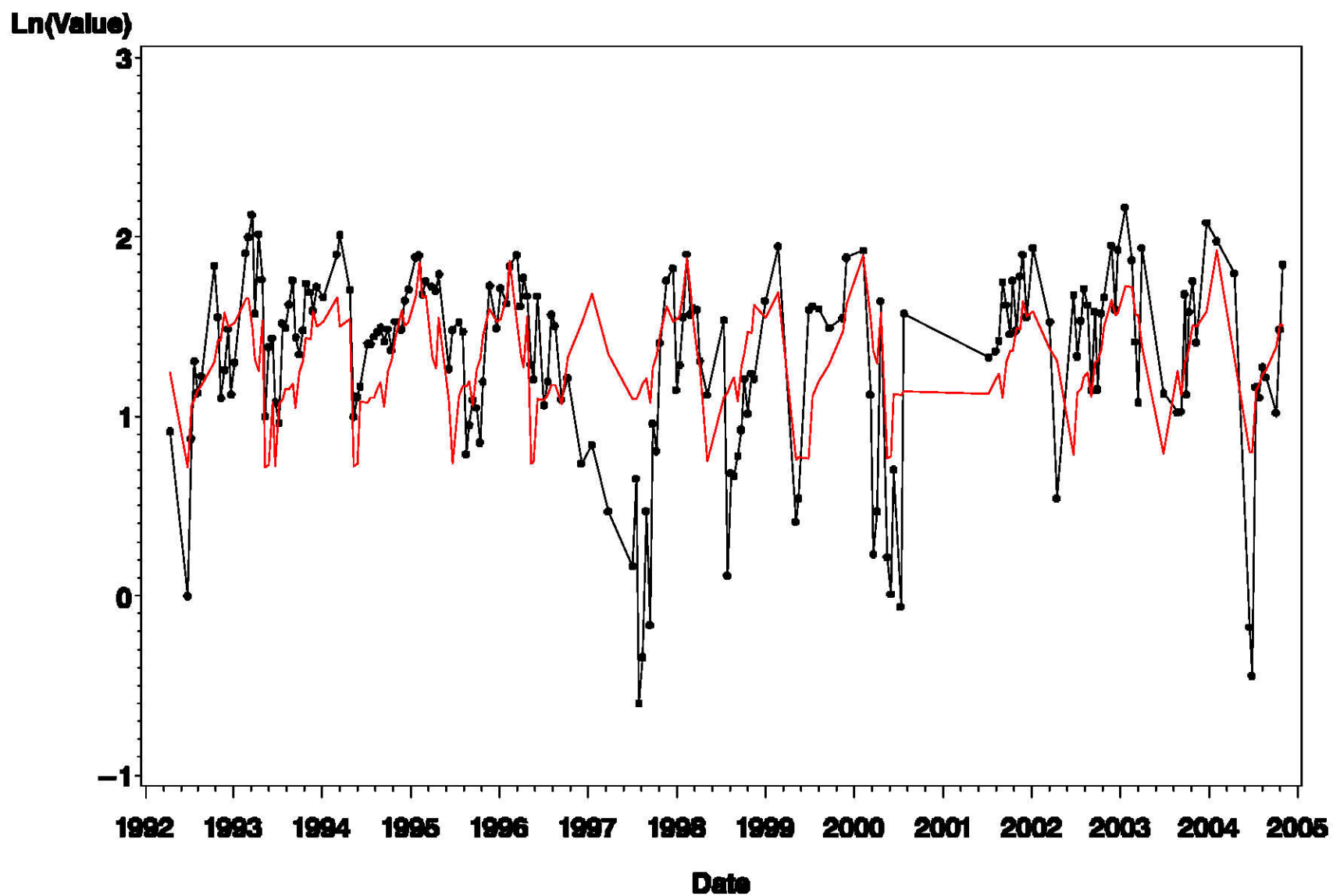


Figure A-2

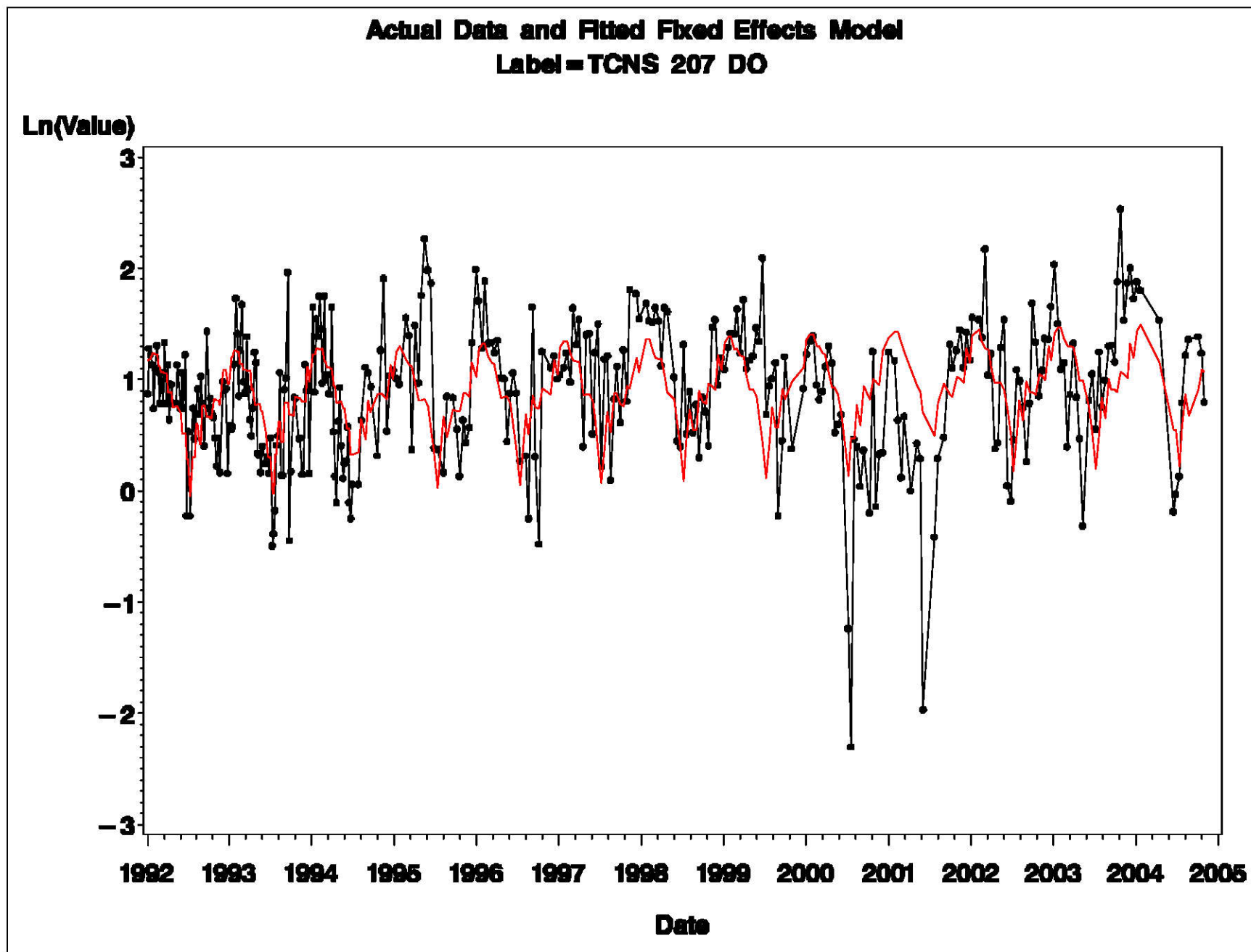


Figure A-3

Actual Data and Fitted Fixed Effects Model
Label=TCNS 209 DO

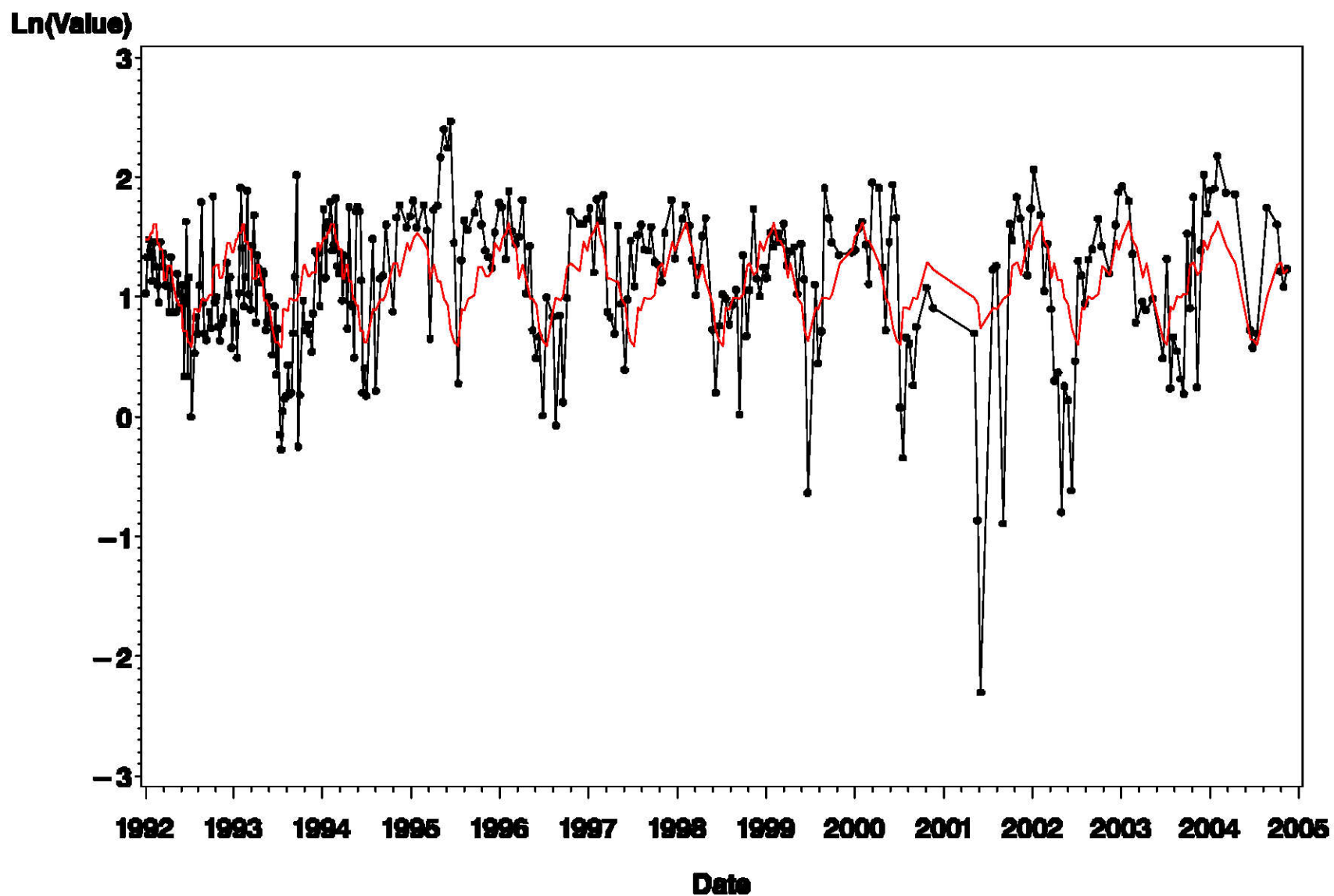


Figure A-4

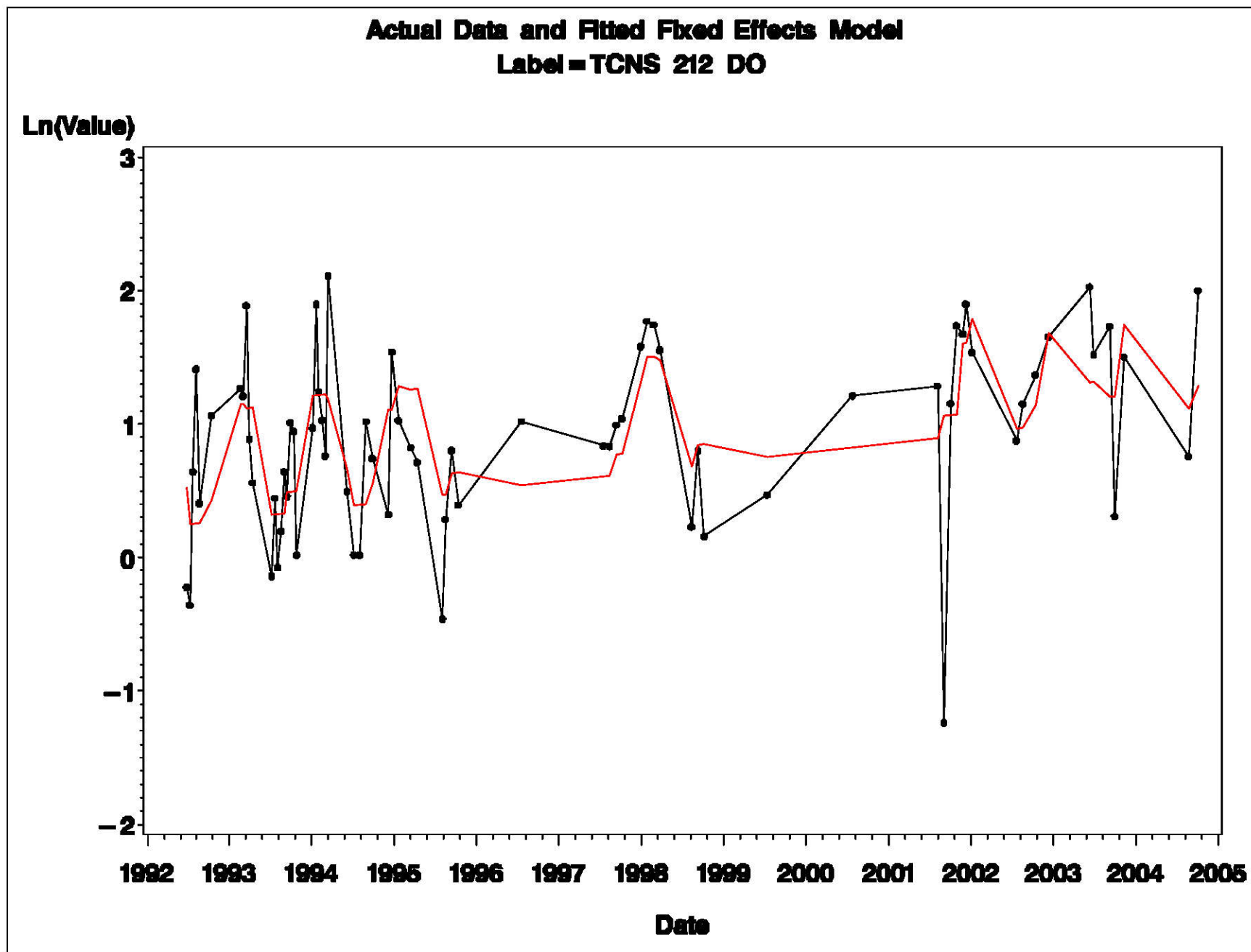


Figure A-5

Actual Data and Fitted Fixed Effects Model
Label = TCNS 213 DO

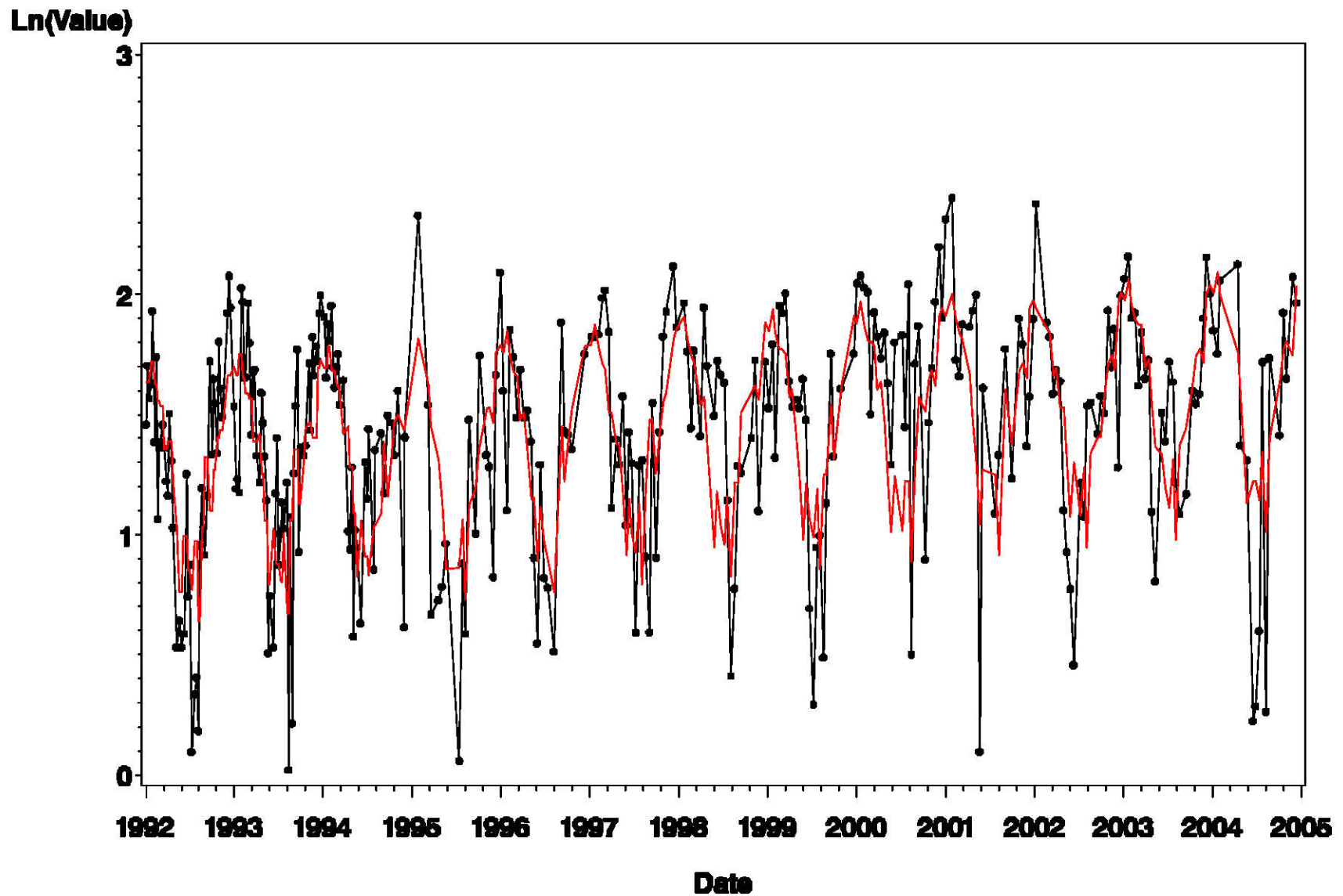


Figure A-6

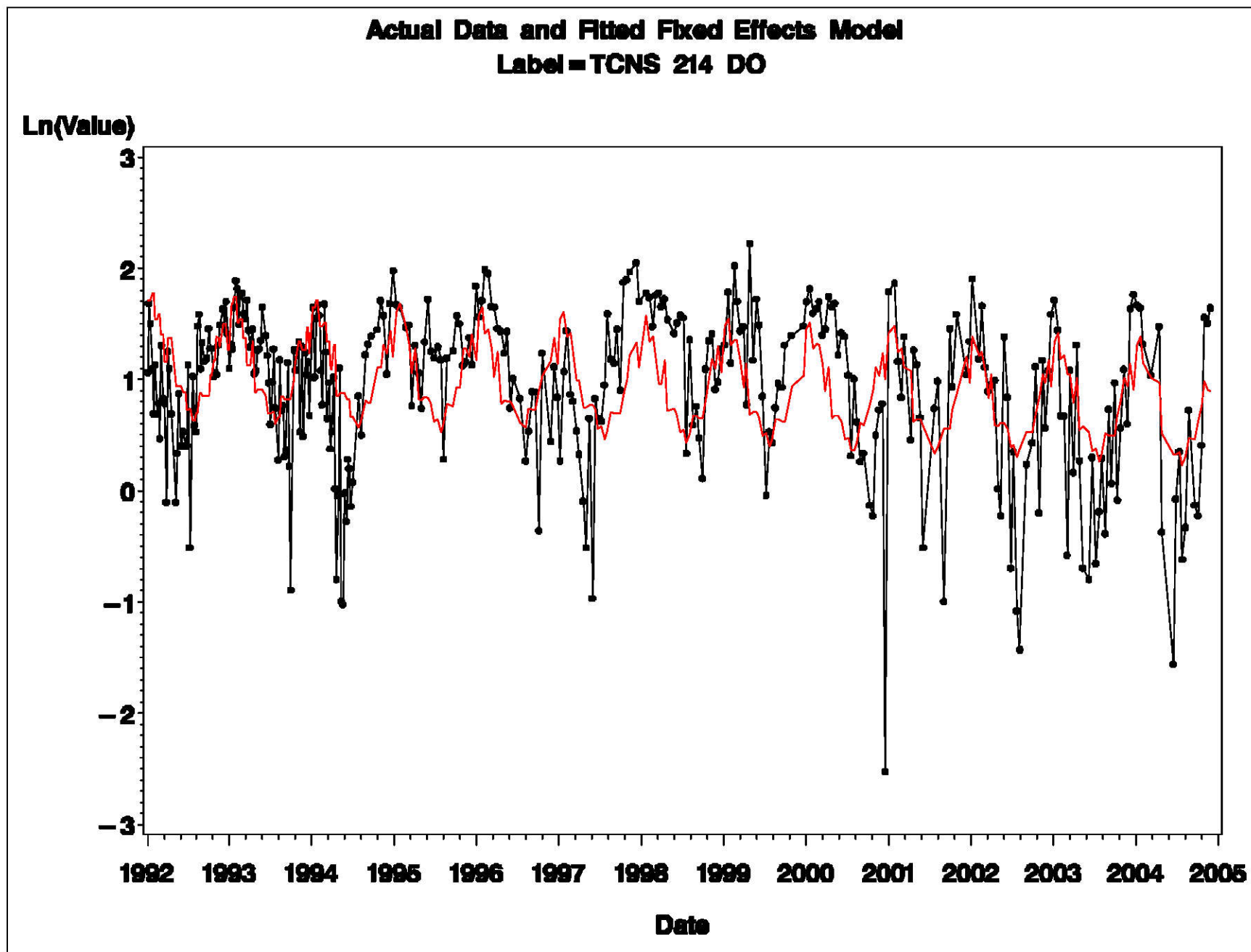


Figure A-7

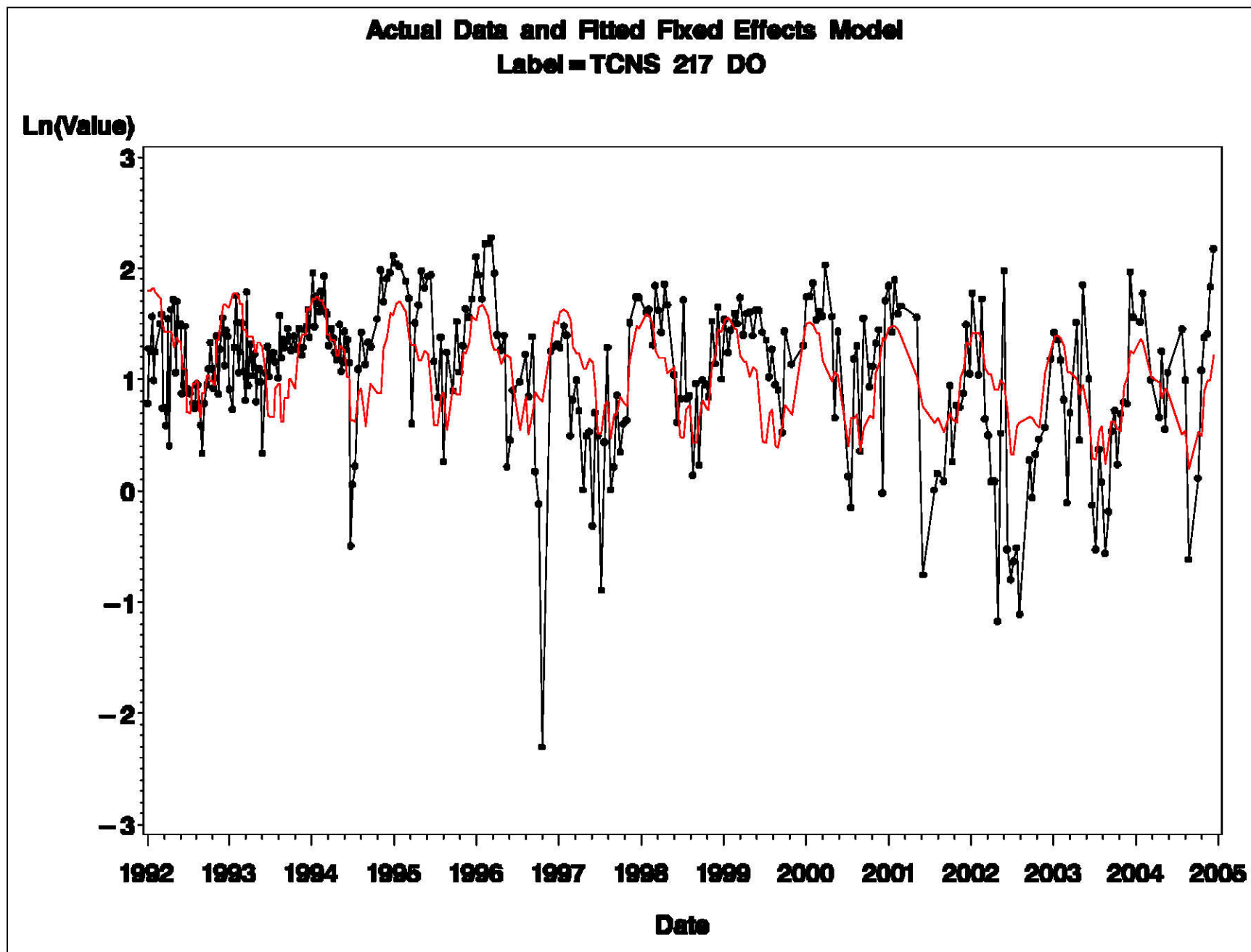


Figure A-8

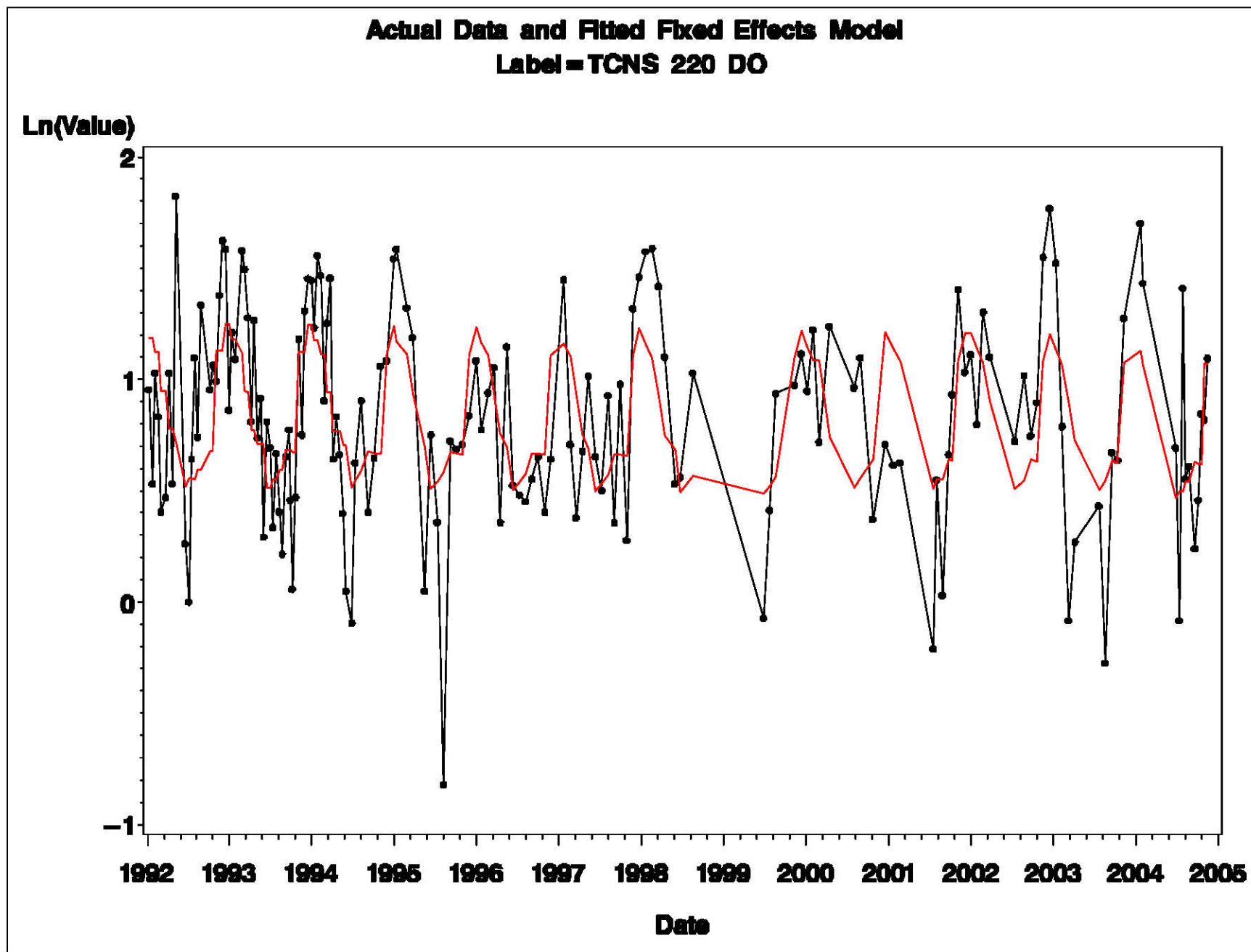


Figure A-9

Actual Data and Fitted Fixed Effects Model
Label = TCNS 222 DO

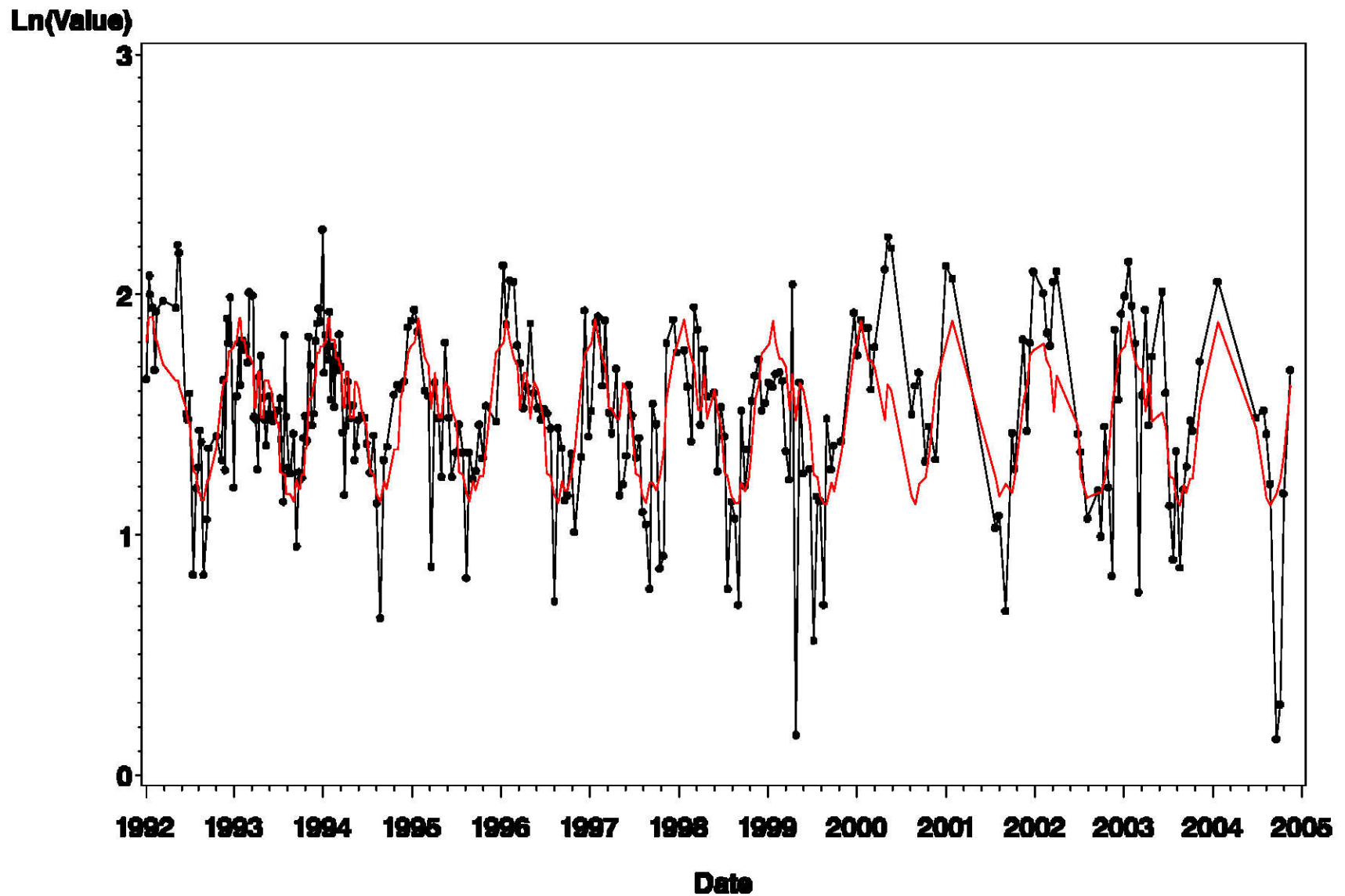


Figure A-10

Actual Data and Fitted Fixed Effects Model
Label=TCNS 228 DO

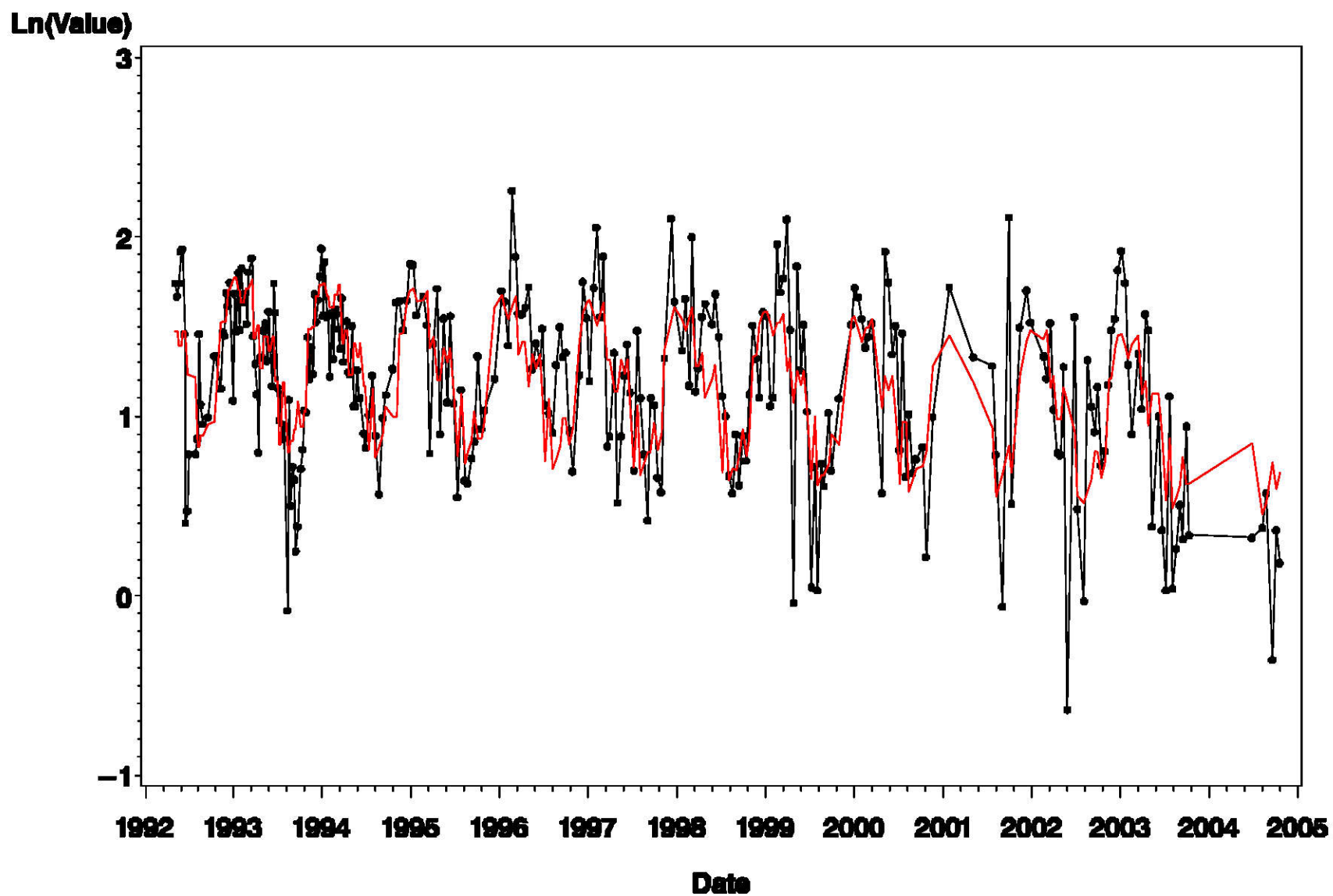


Figure A-11

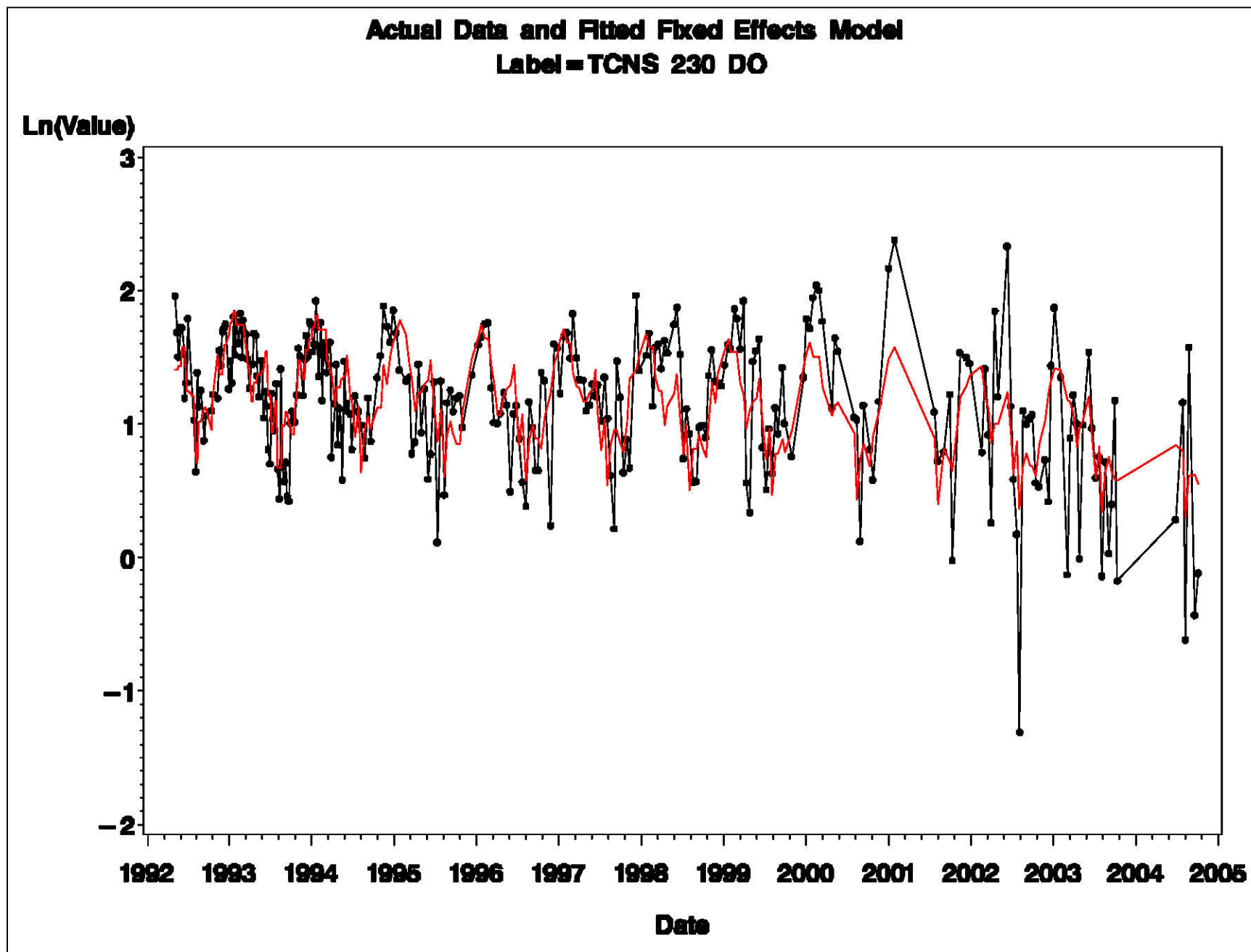


Figure A-12

Actual Data and Fitted Fixed Effects Model
Label = TCNS 233 DO

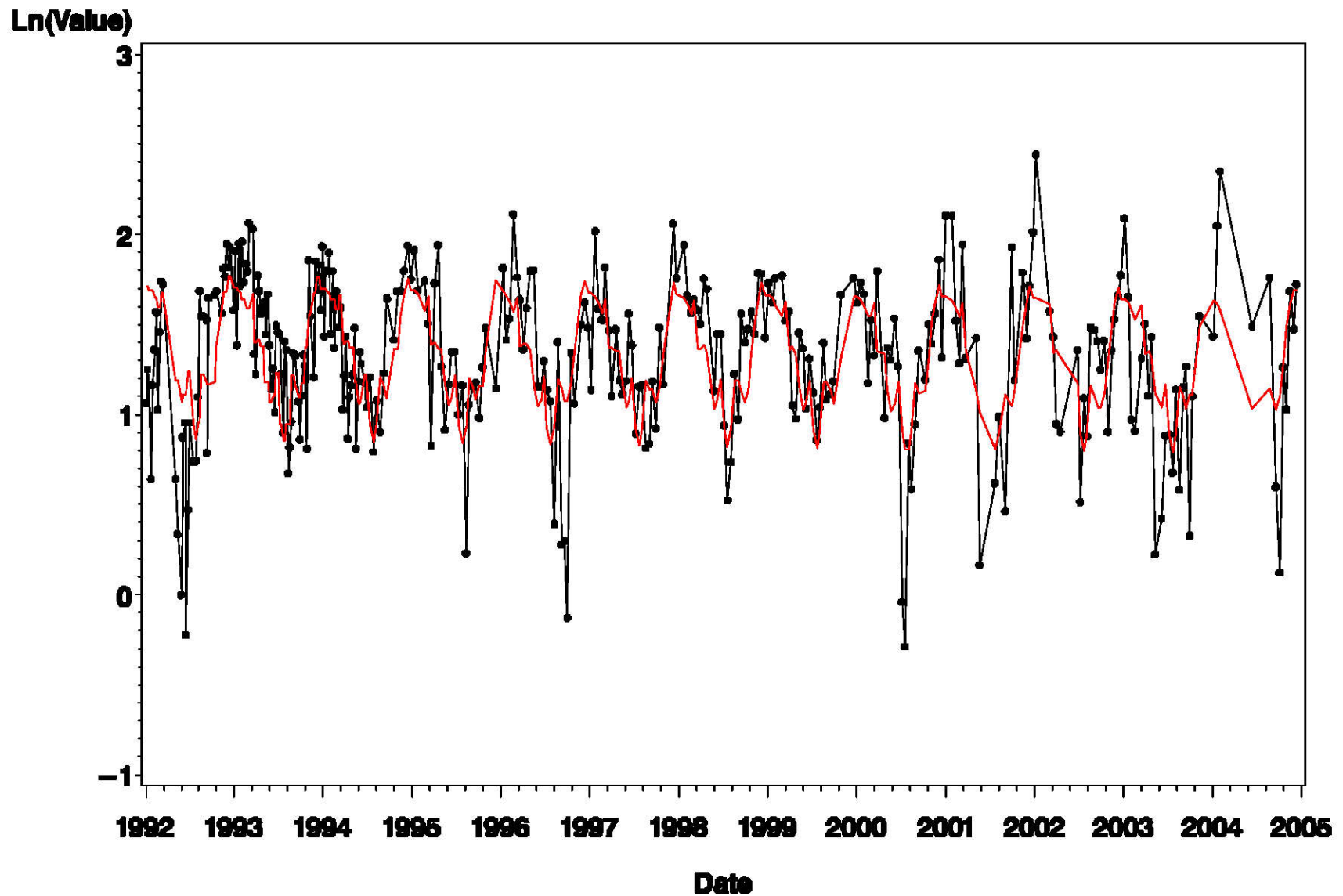


Figure A-13

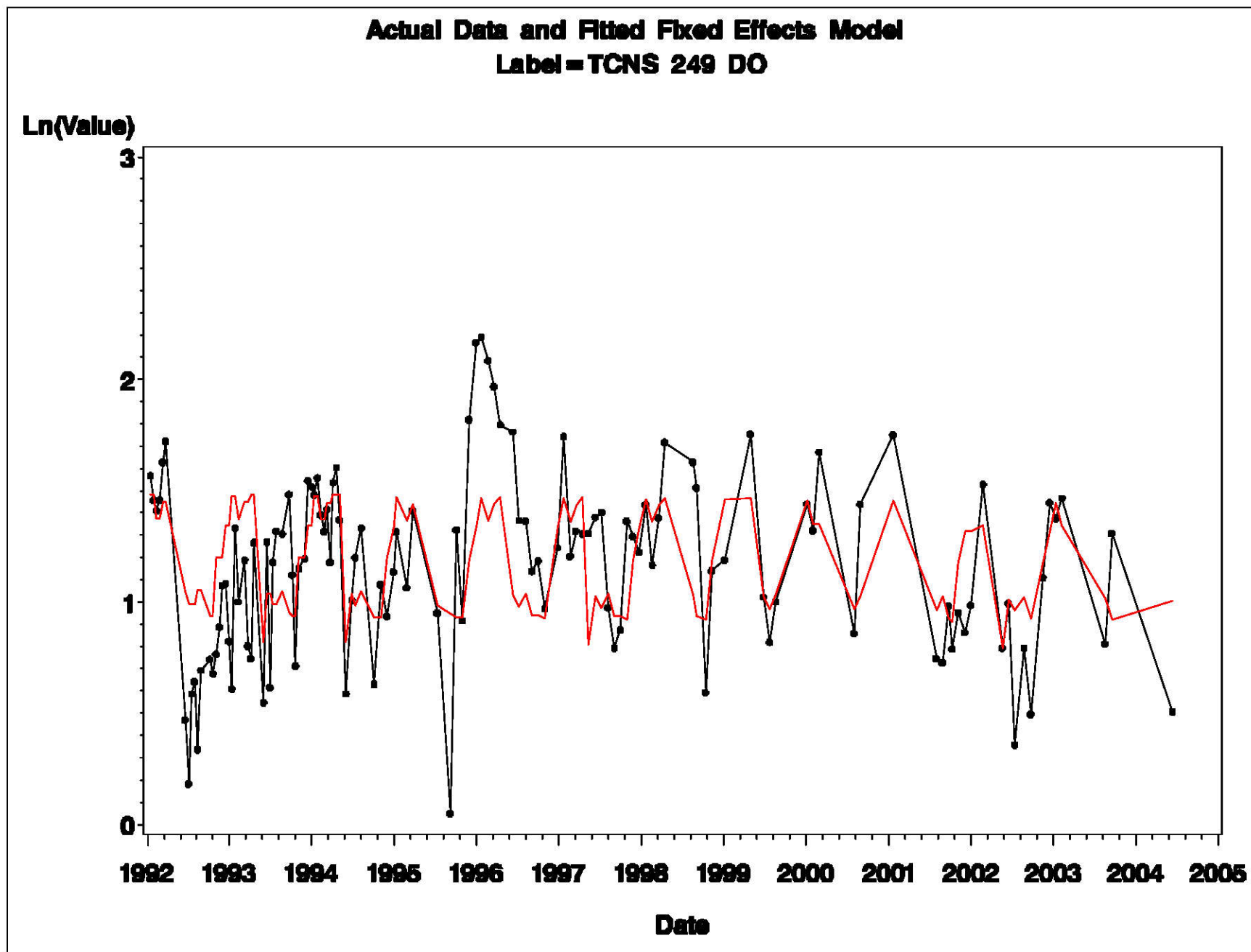


Figure A-14

Actual Data and Fitted Fixed Effects Model
Label=TCNS 201 TKN

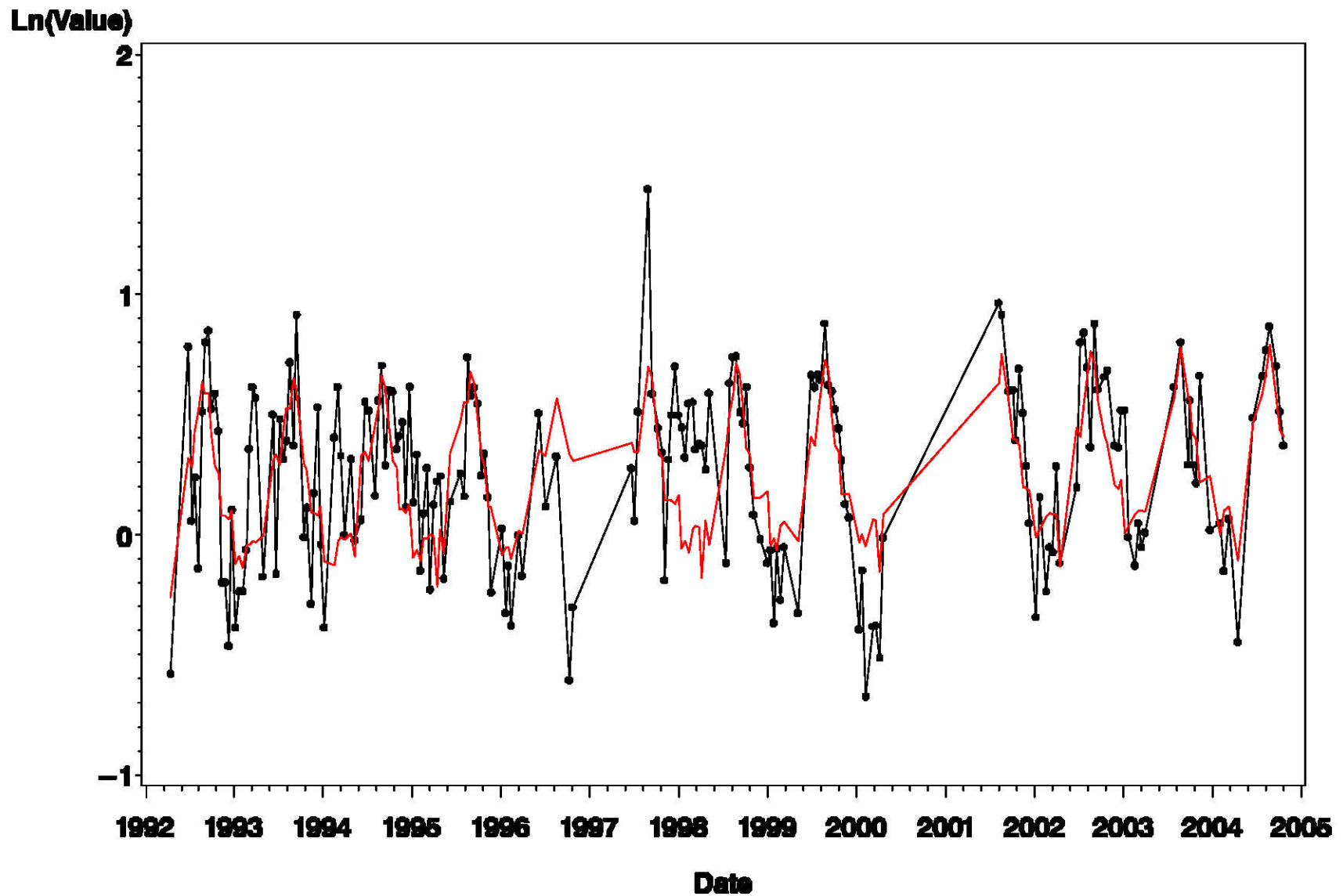


Figure A-15

Actual Data and Fitted Fixed Effects Model
Label=TCNS 204 TKN

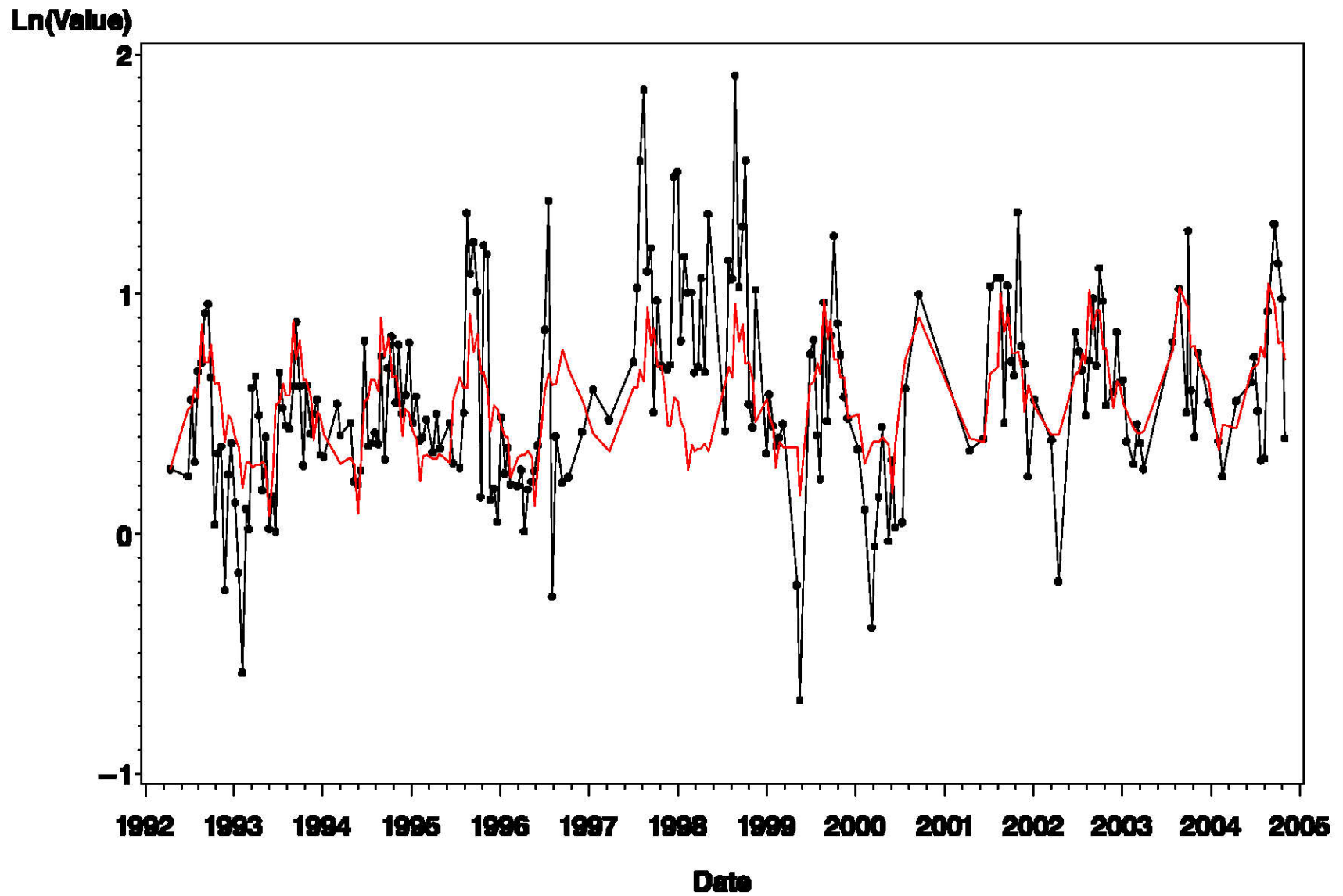


Figure A-16

Actual Data and Fitted Fixed Effects Model
Label=TCNS 207 TKN

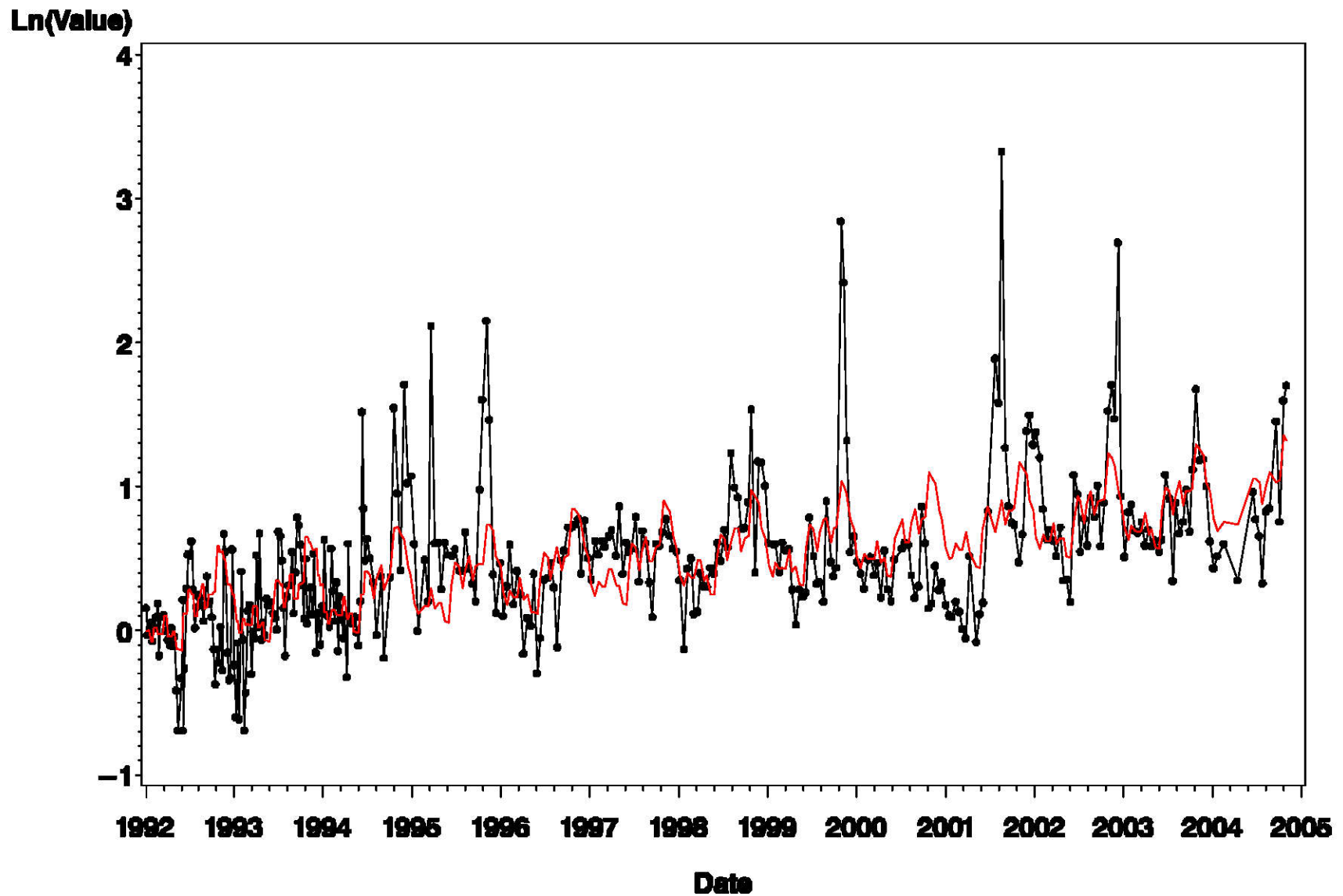


Figure A-17

Actual Data and Fitted Fixed Effects Model
Label=TCNS 209 TKN

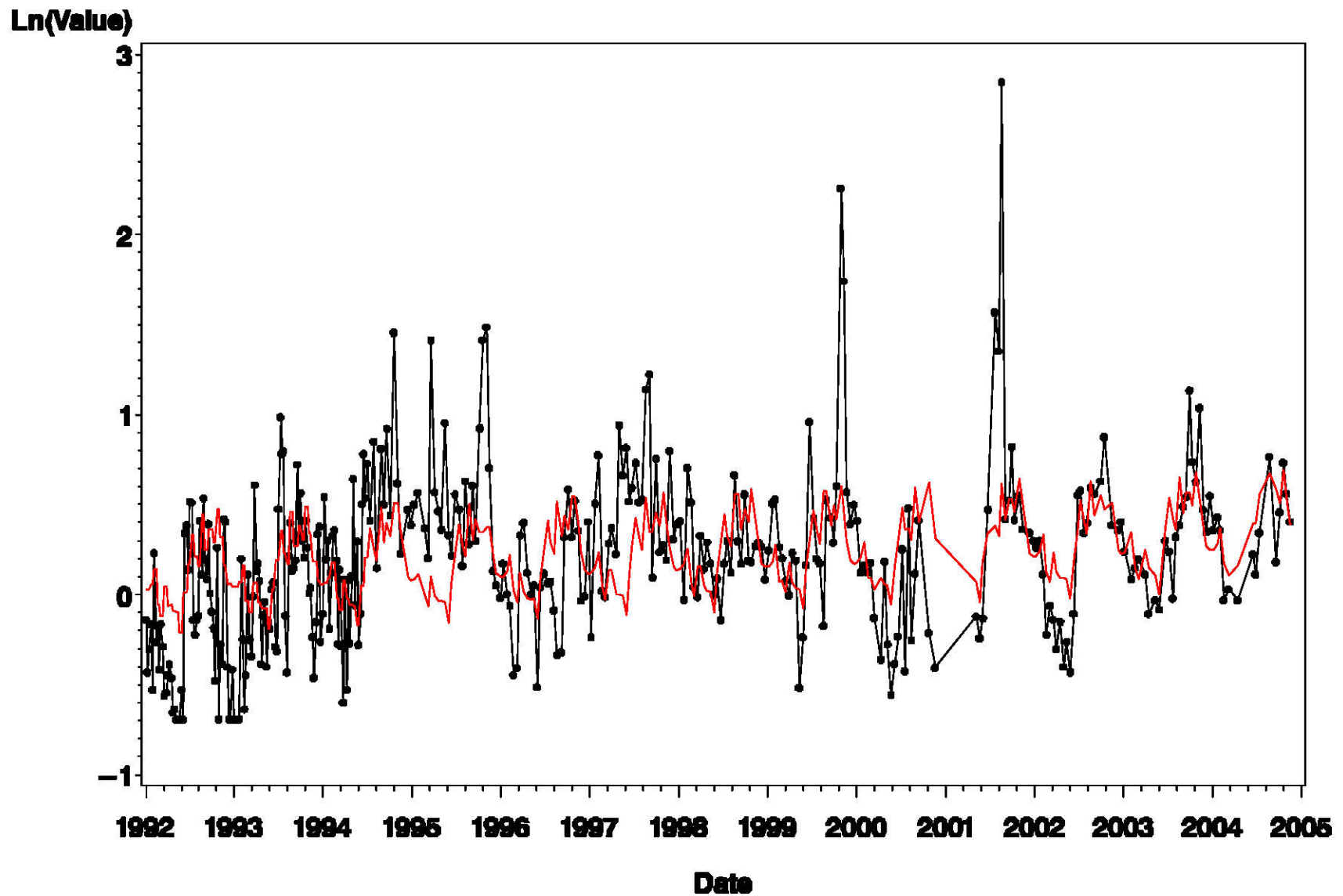


Figure A-18

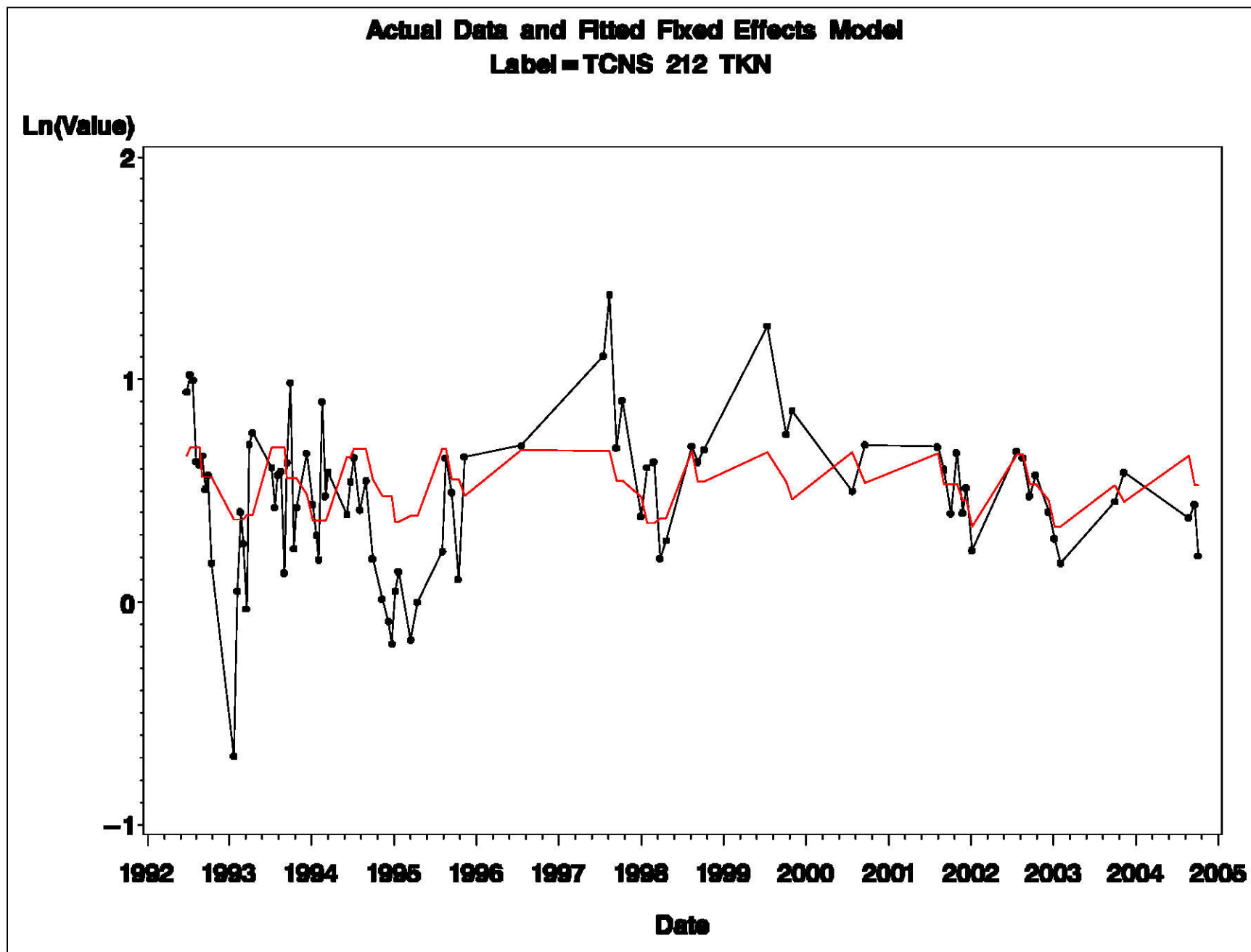


Figure A-19

Actual Data and Fitted Fixed Effects Model
Label=TCNS 213 TKN

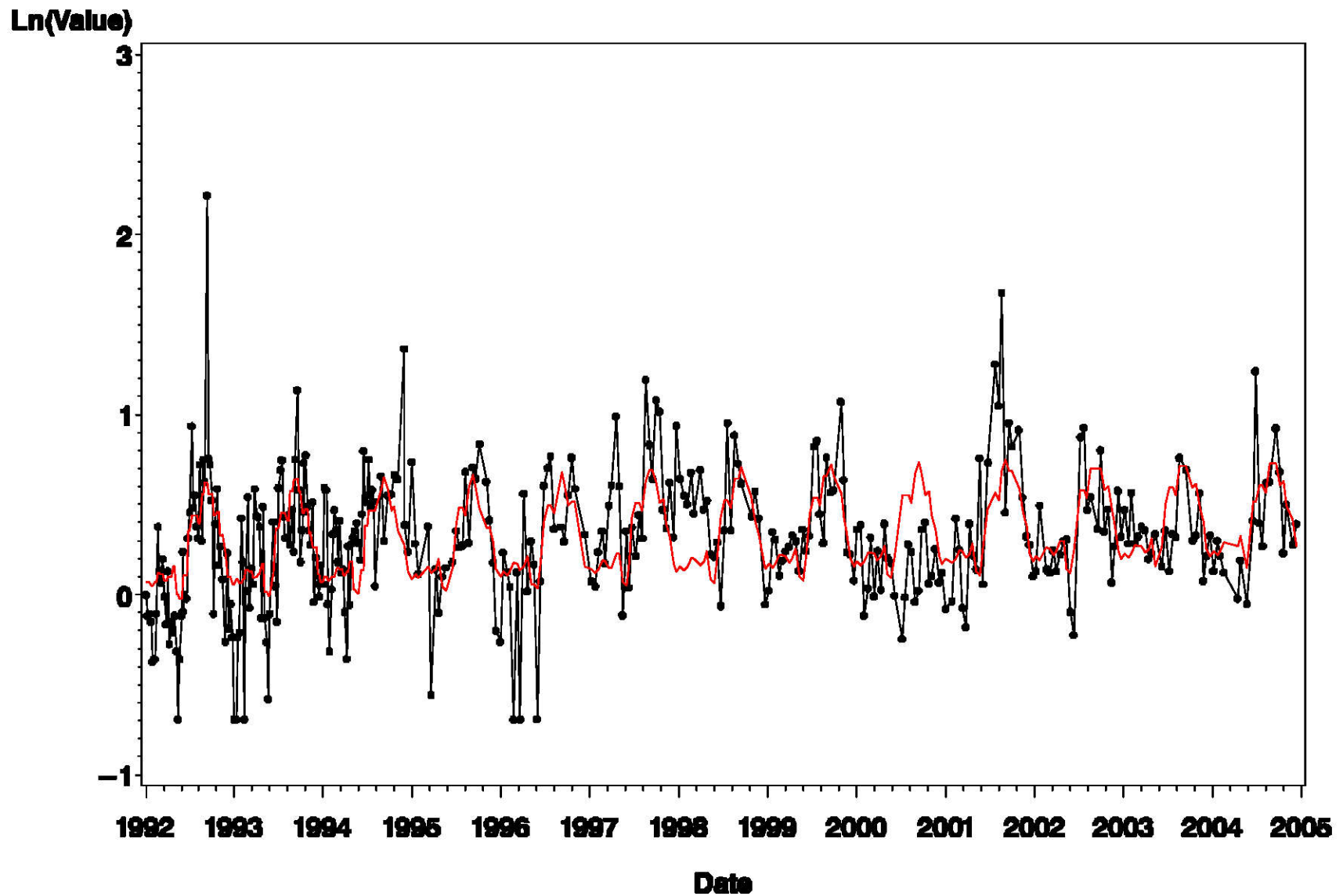


Figure A-20

Actual Data and Fitted Fixed Effects Model
Label=TCNS 214 TKN

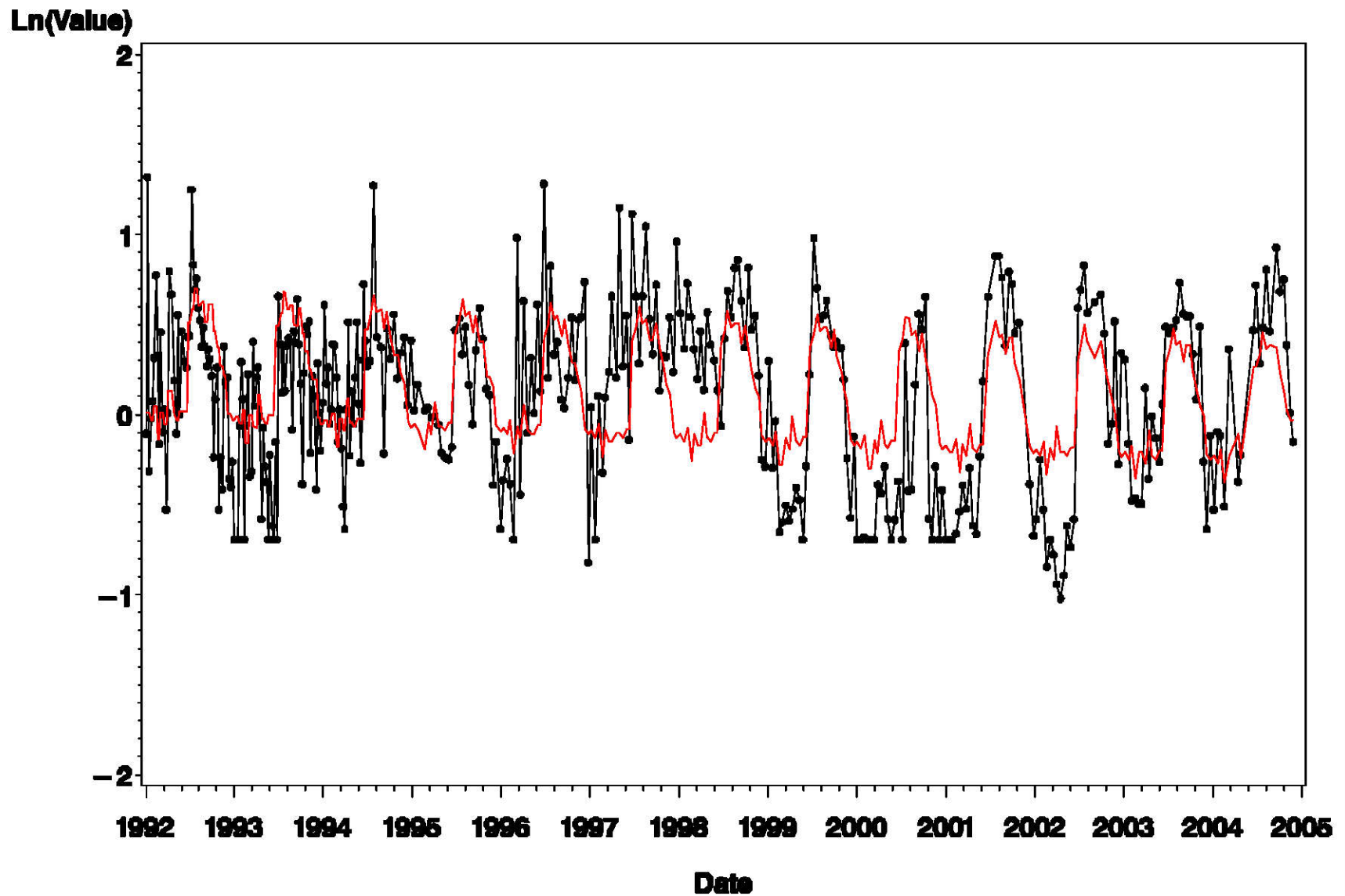


Figure A-21

Actual Data and Fitted Fixed Effects Model
Label=TCNS 217 TKN

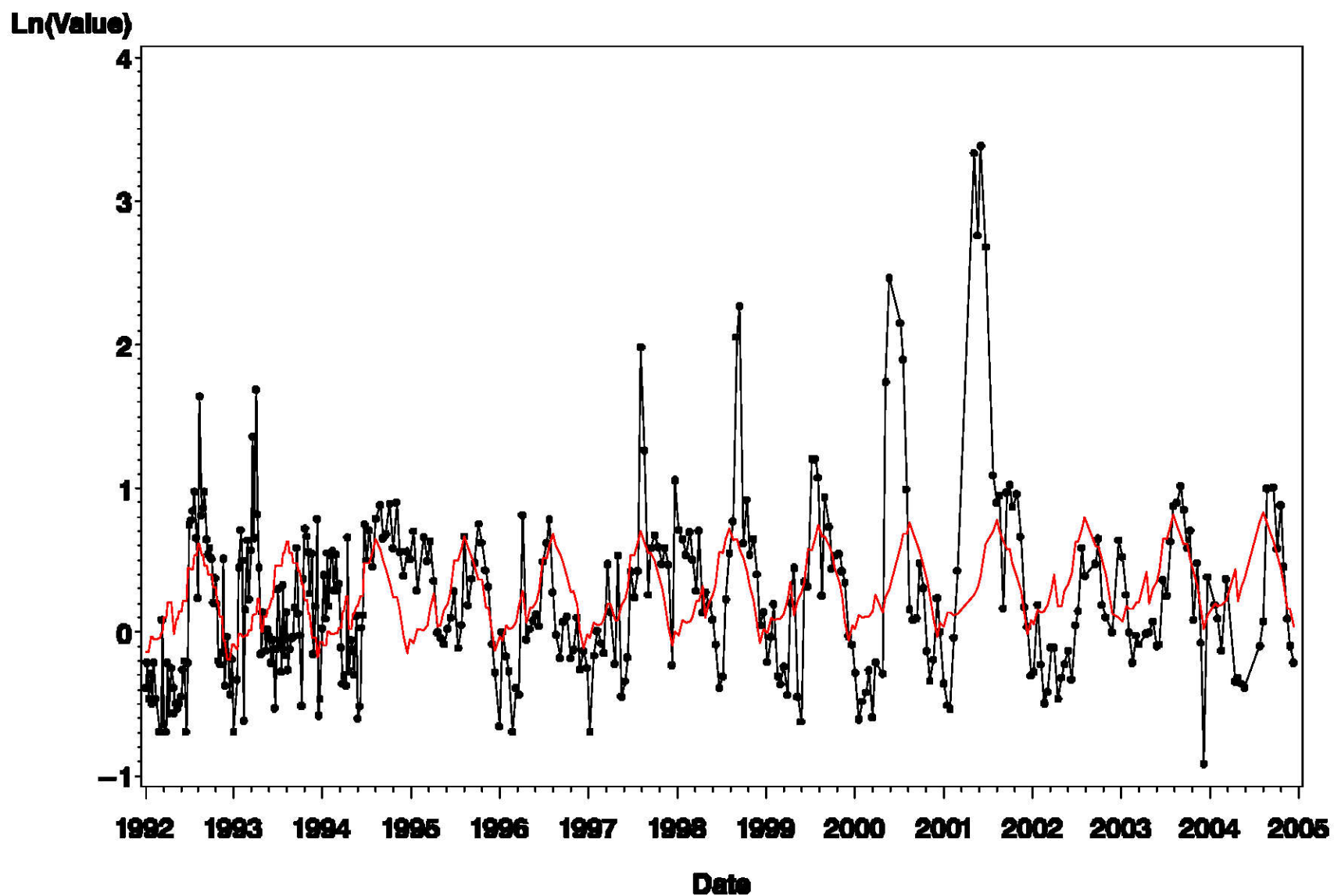


Figure A-22

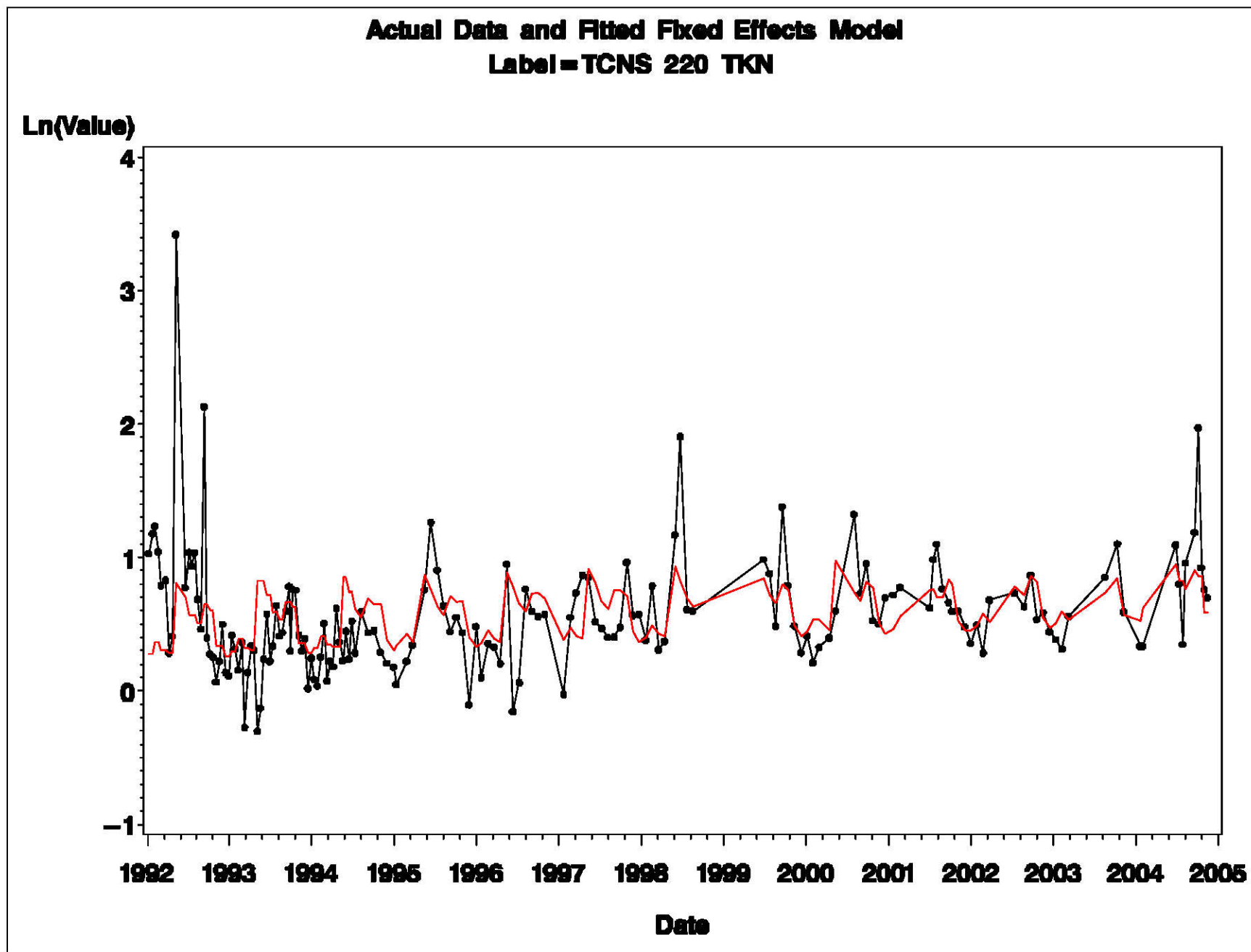


Figure A-23

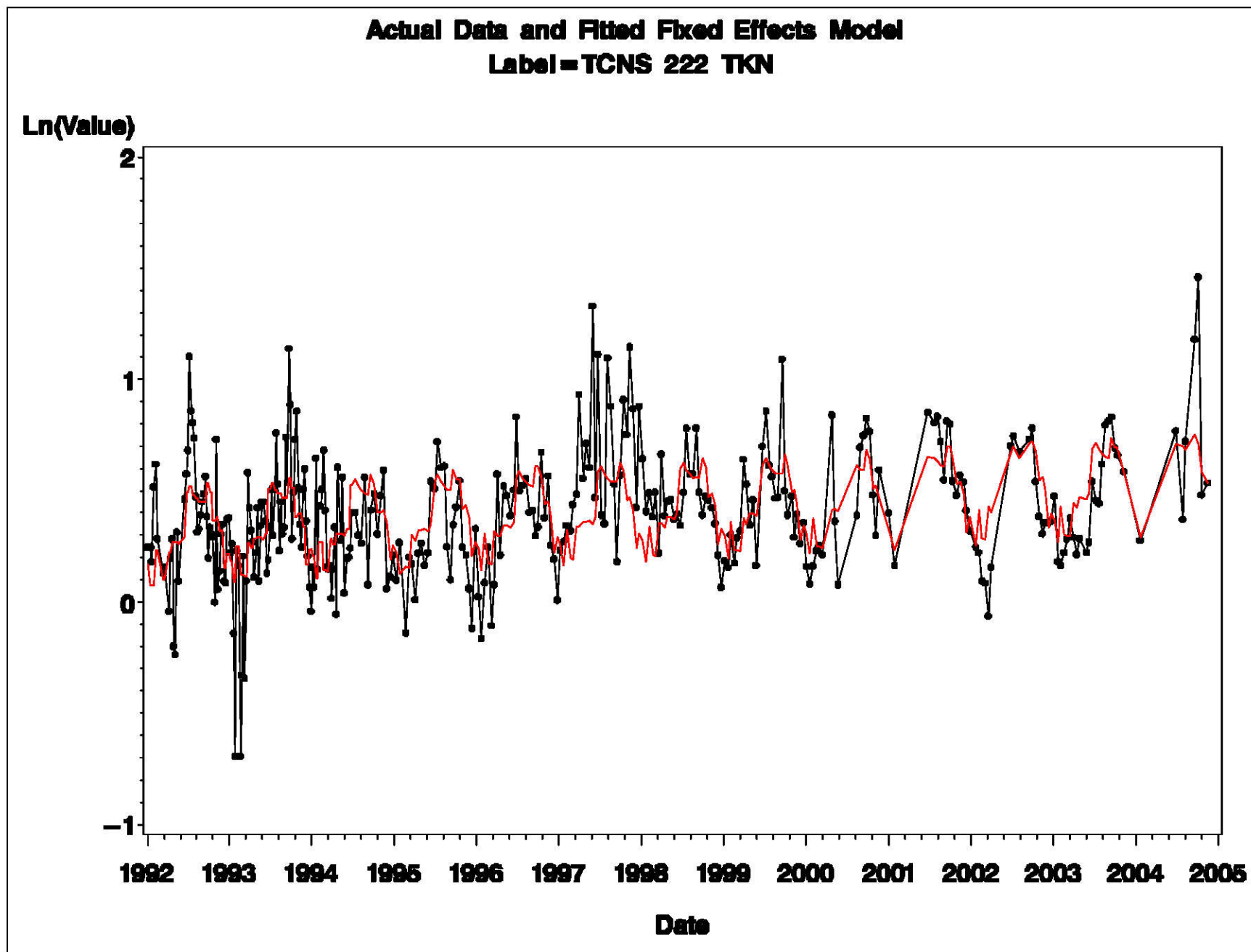


Figure A-24

Actual Data and Fitted Fixed Effects Model
Label=TCNS 228 TKN

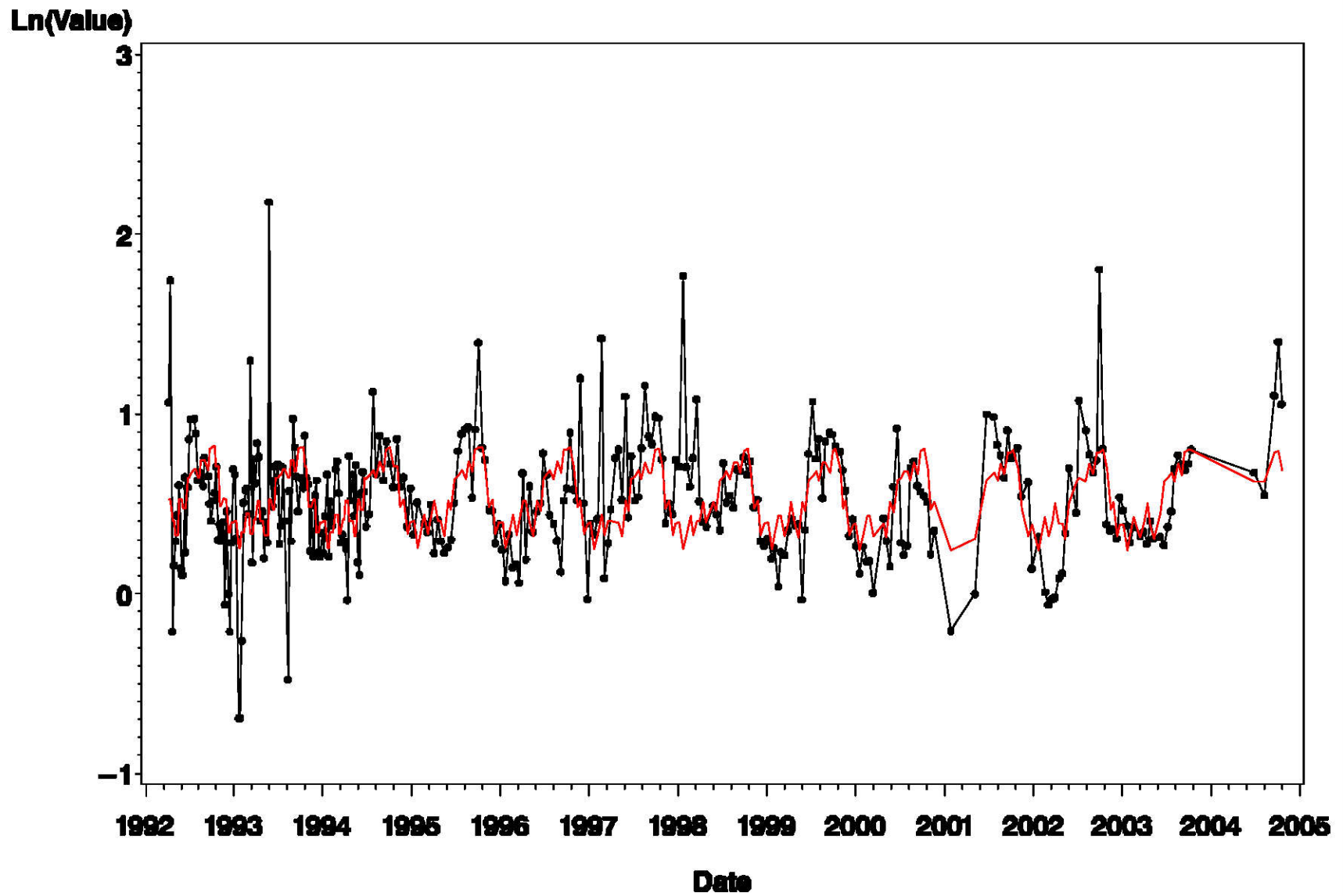


Figure A-25

Actual Data and Fitted Fixed Effects Model
Label=TCNS 230 TKN

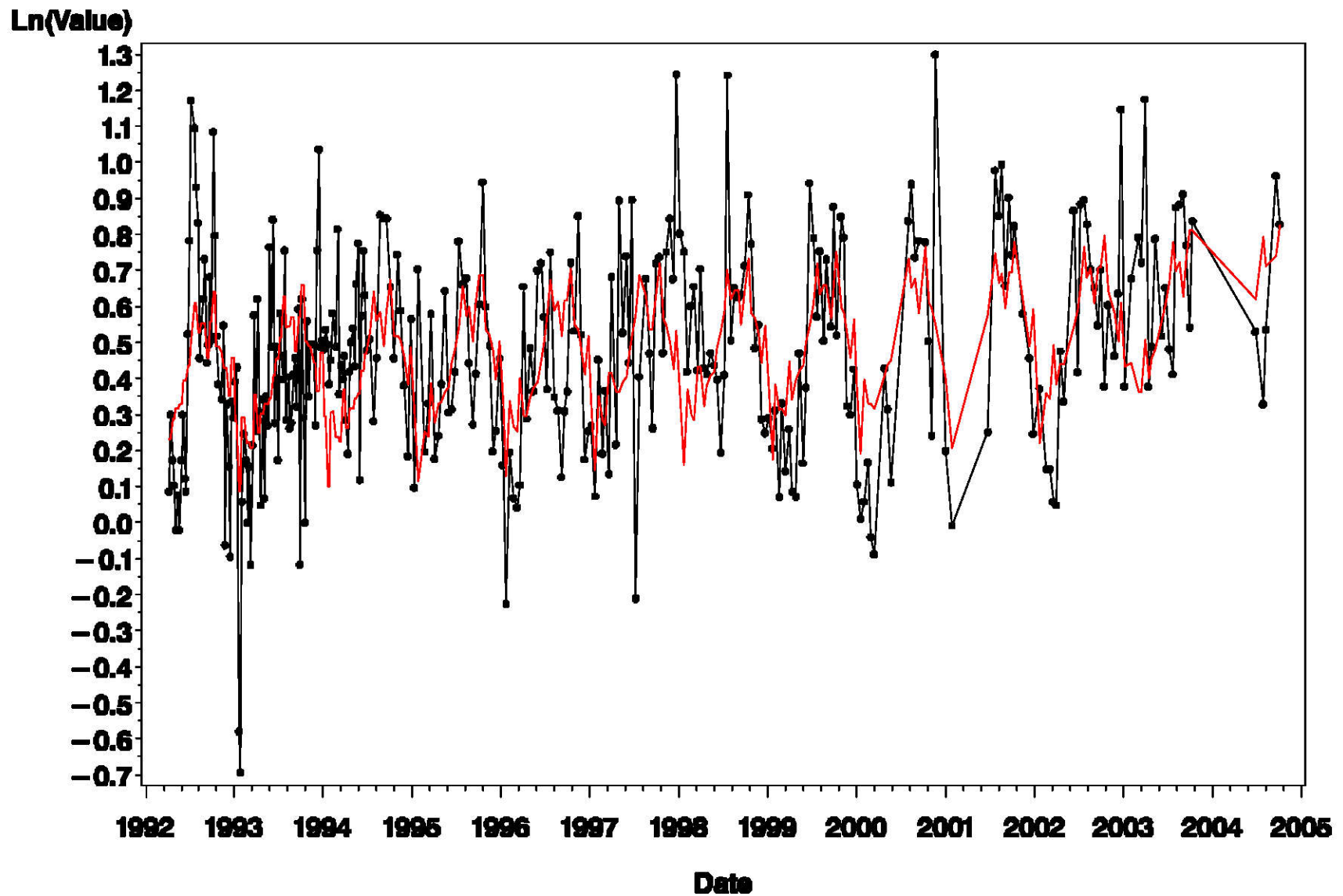


Figure A-26

Actual Data and Fitted Fixed Effects Model
Label=TCNS 233 TKN

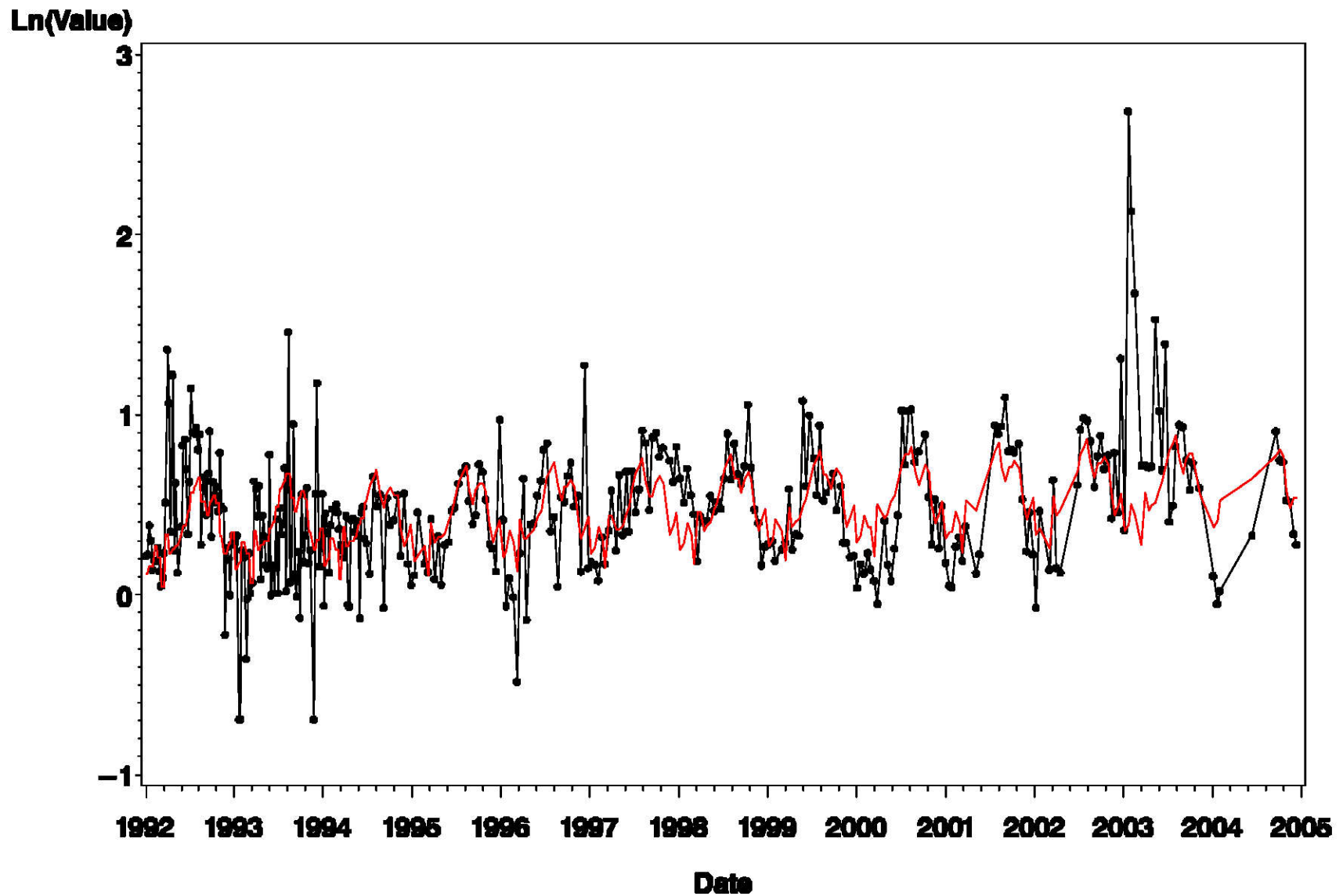


Figure A-27

Actual Data and Fitted Fixed Effects Model
Label=TCNS 249 TKN

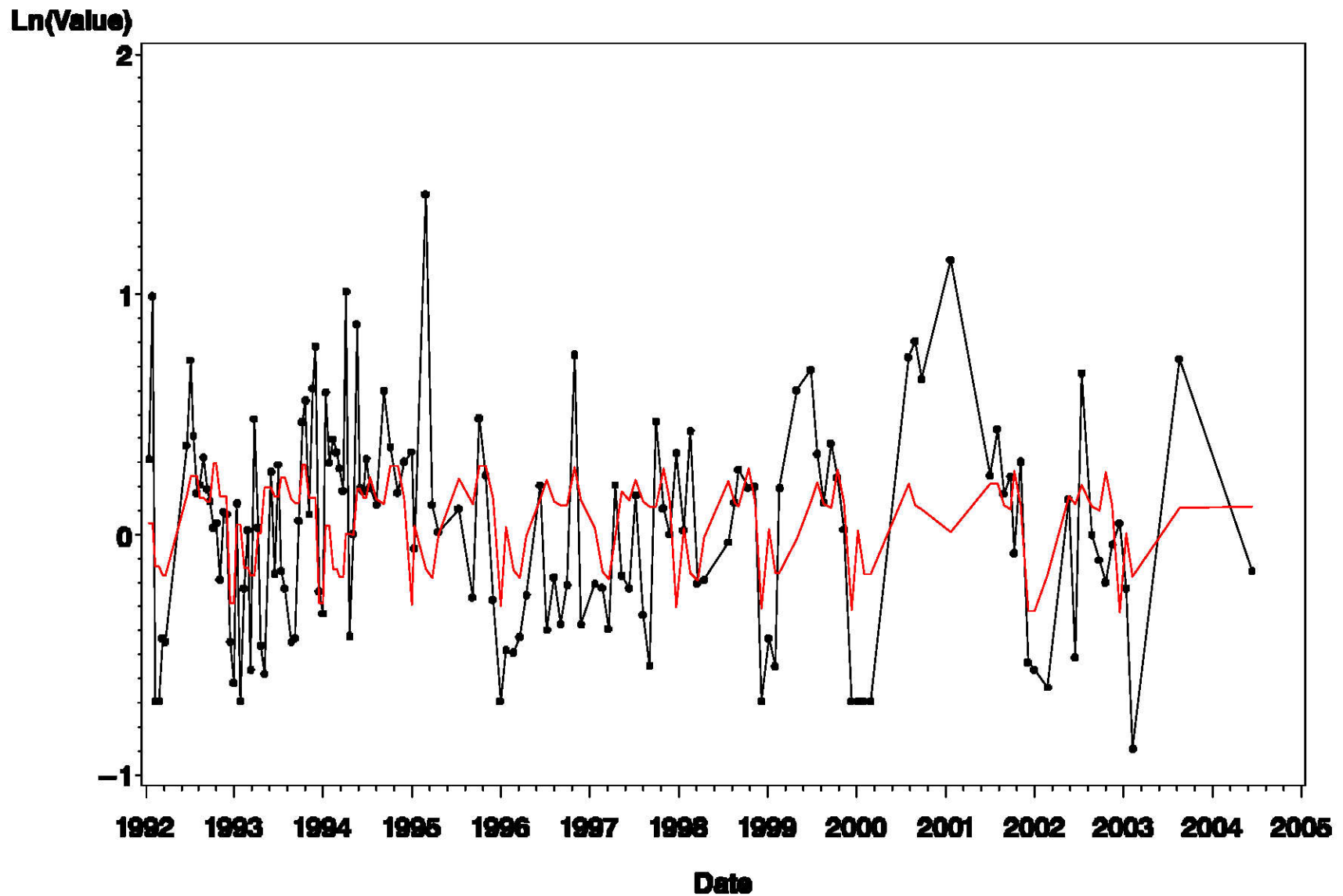


Figure A-28

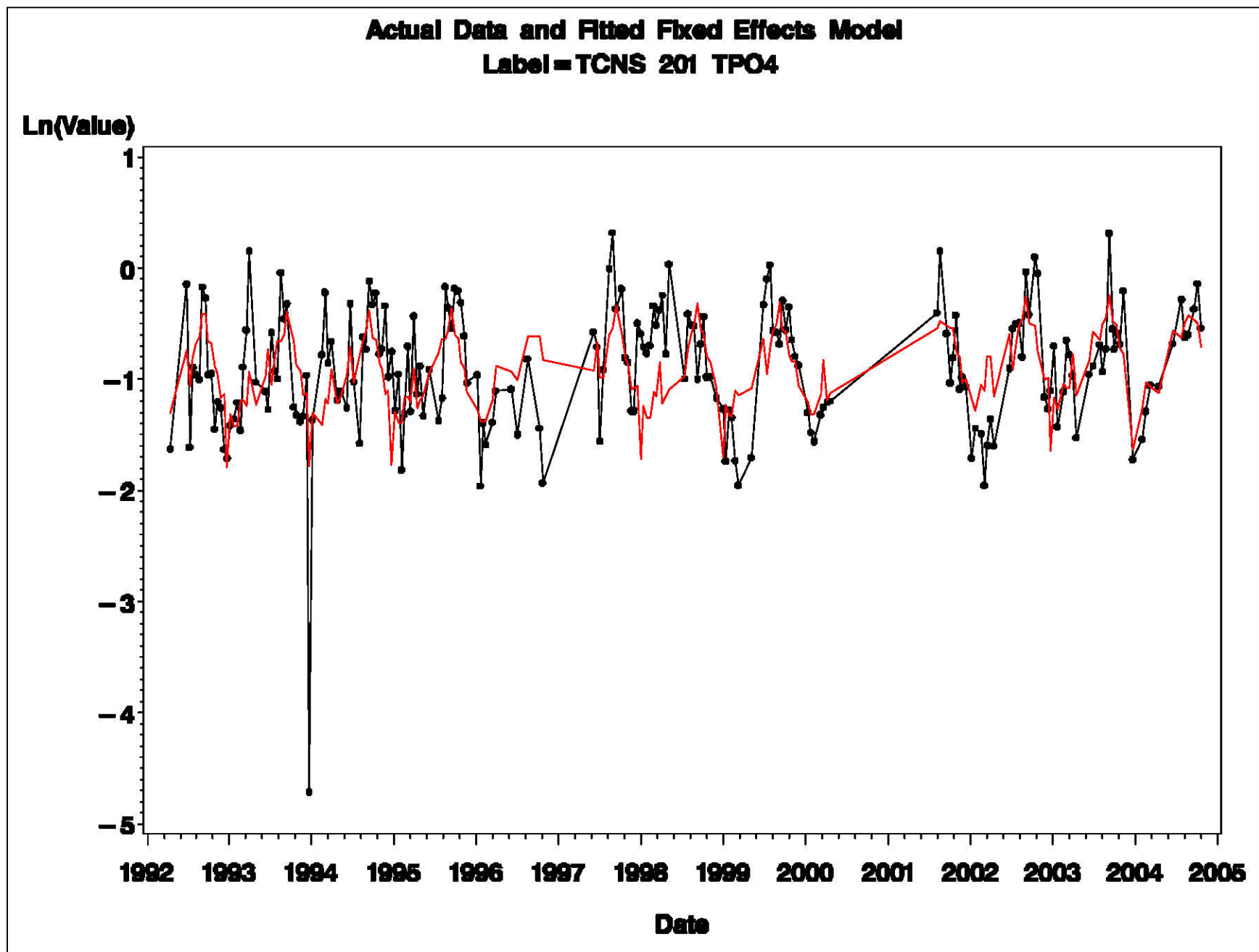


Figure A-29

Actual Data and Fitted Fixed Effects Model
Label=TCNS 204 TPO4

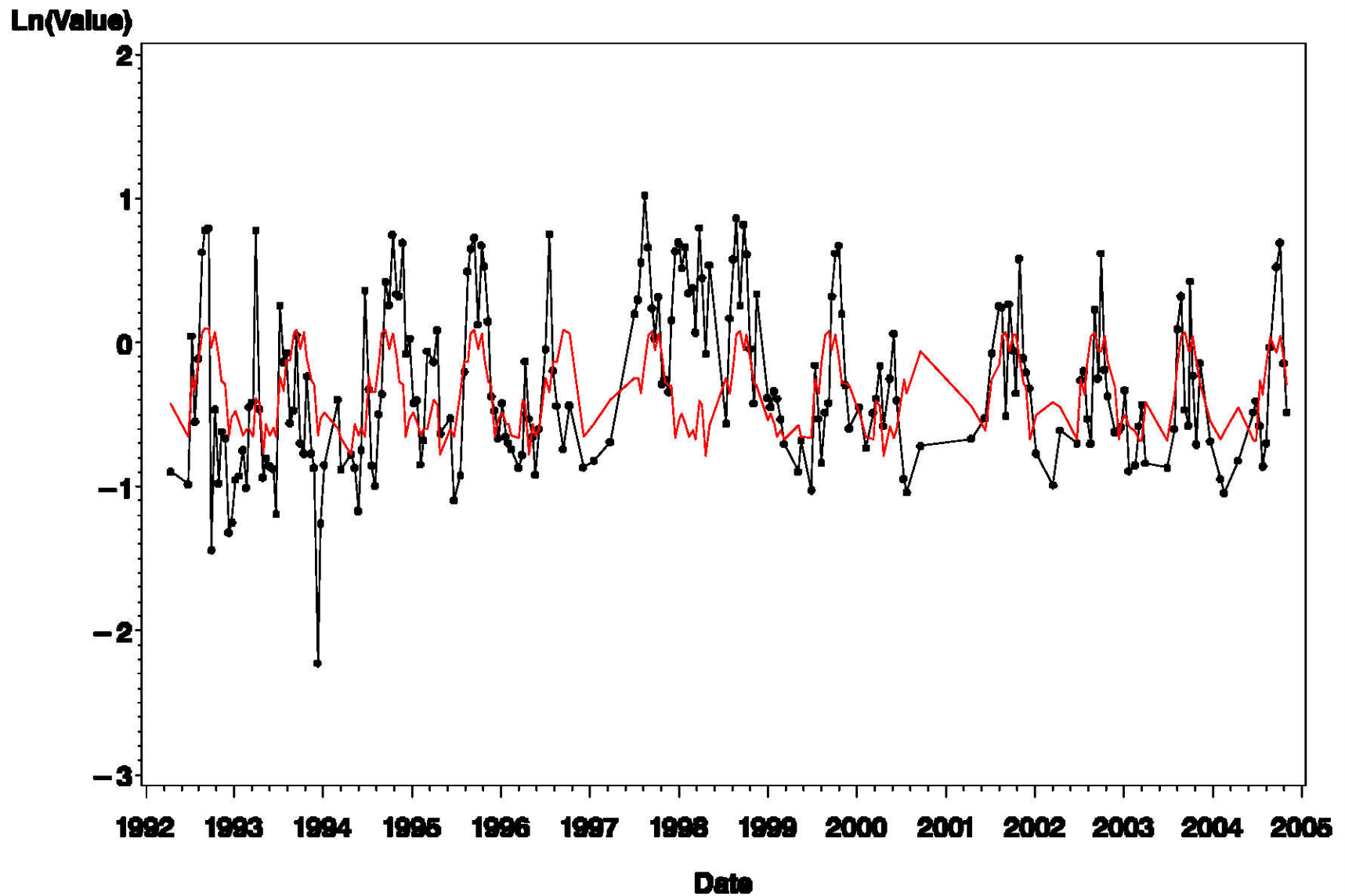


Figure A-30

Actual Data and Fitted Fixed Effects Model
Label=TCNS 207 TPO4

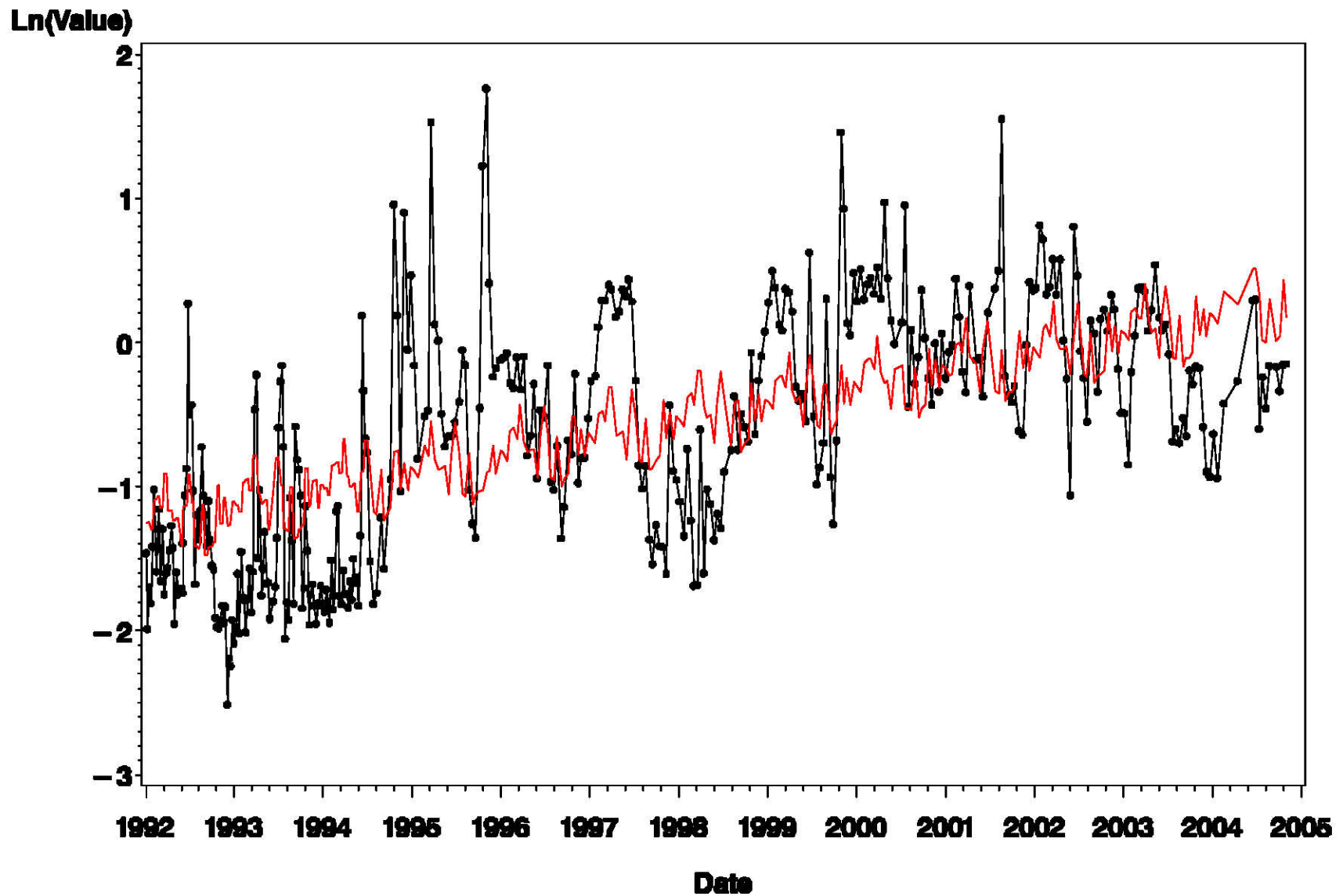


Figure A-31

Actual Data and Fitted Fixed Effects Model
Label=TCNS 209 TPO4

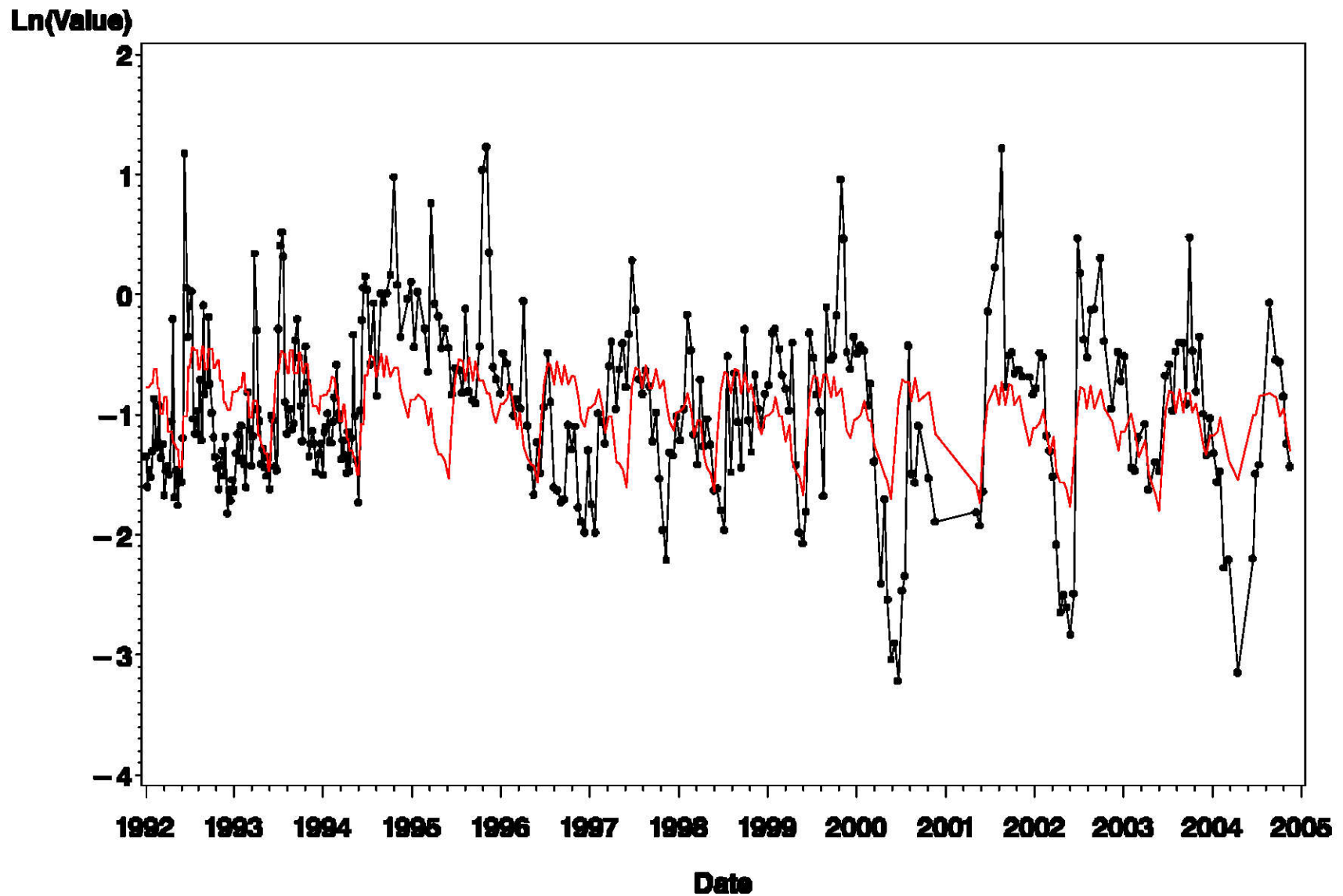


Figure A-32

Actual Data and Fitted Fixed Effects Model
Label = TCNS 212 TPO4

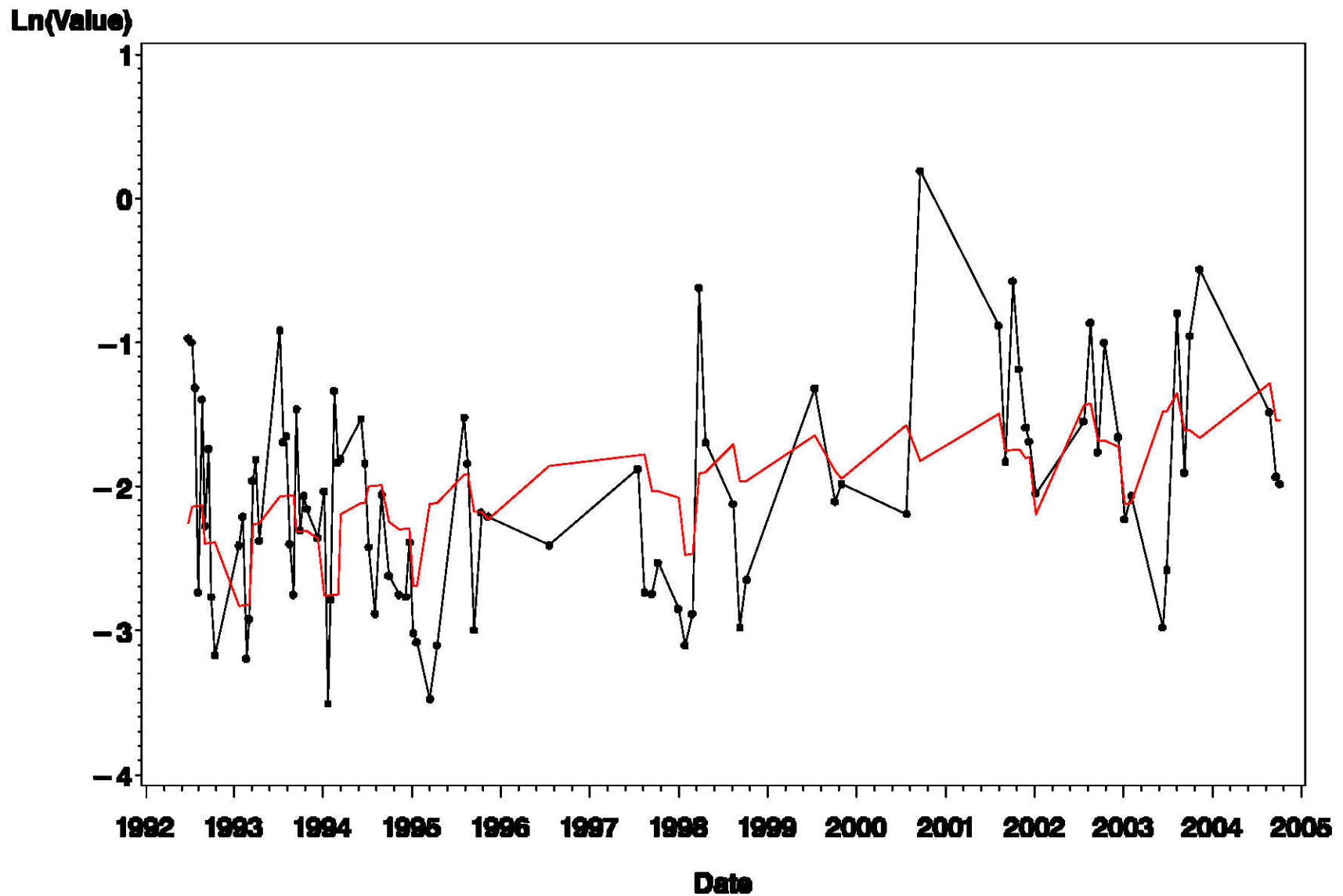


Figure A-33

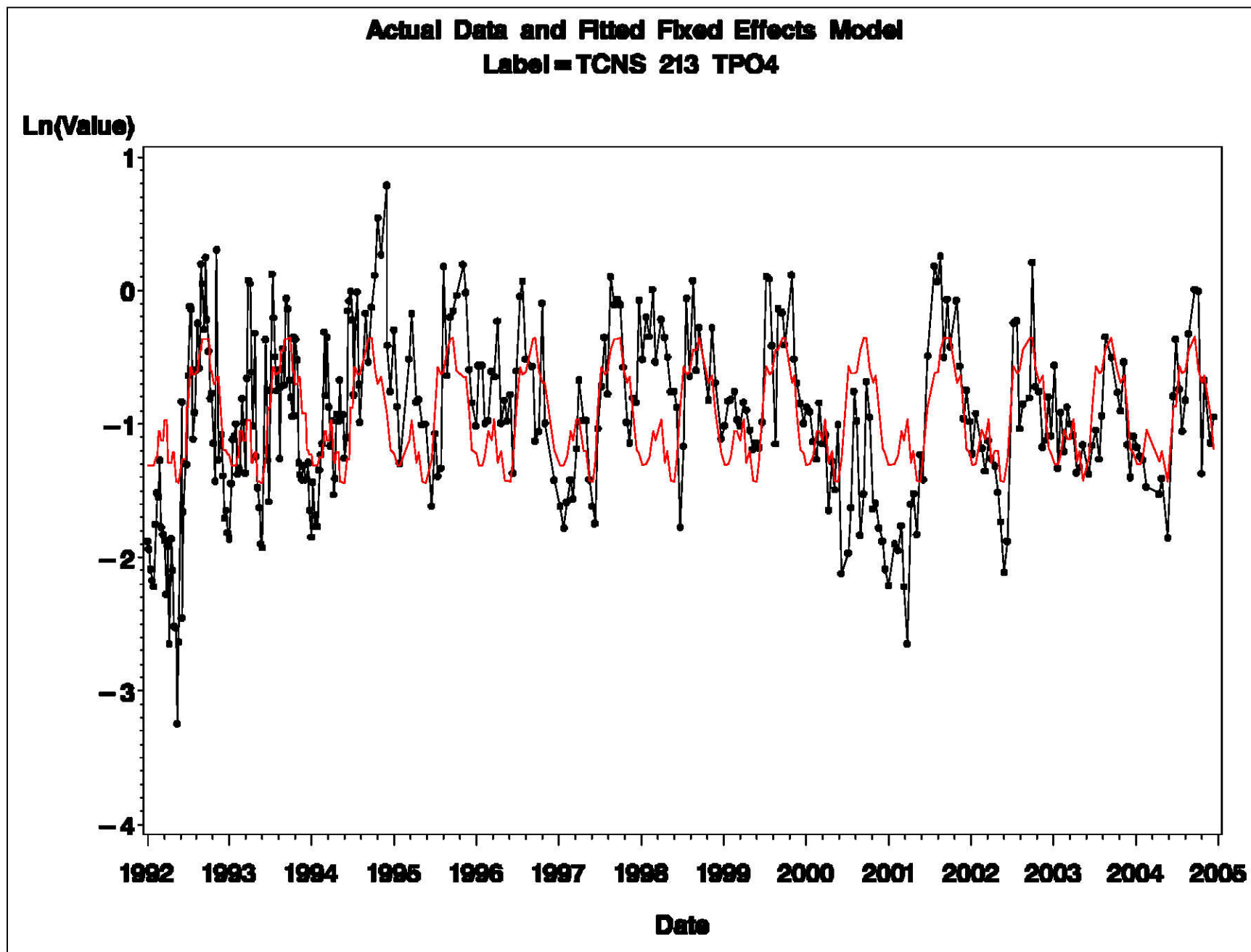


Figure A-34

Actual Data and Fitted Fixed Effects Model
Label=TCNS 214 TPO4

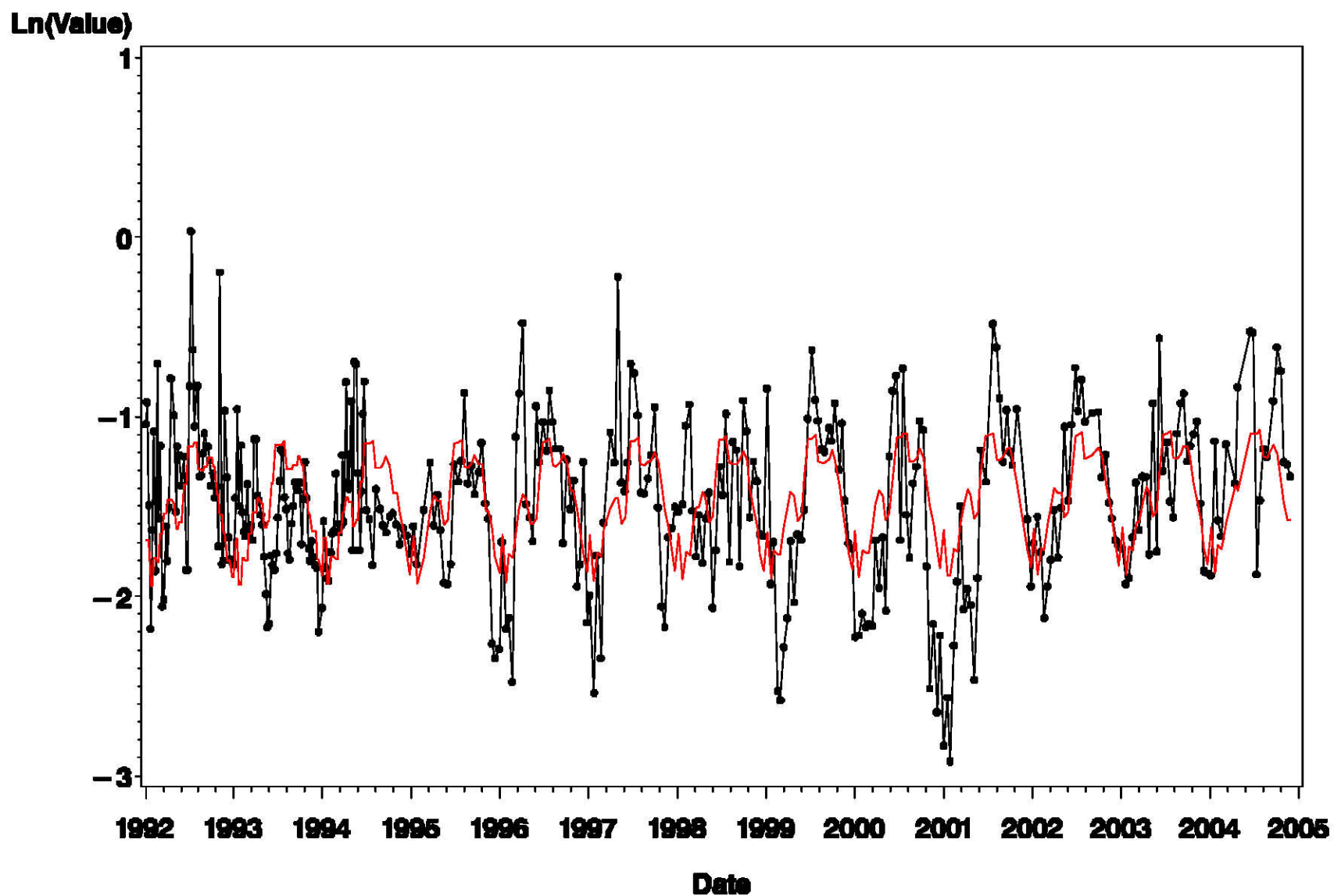


Figure A-35

Actual Data and Fitted Fixed Effects Model
Label=TCNS 217 TPO4

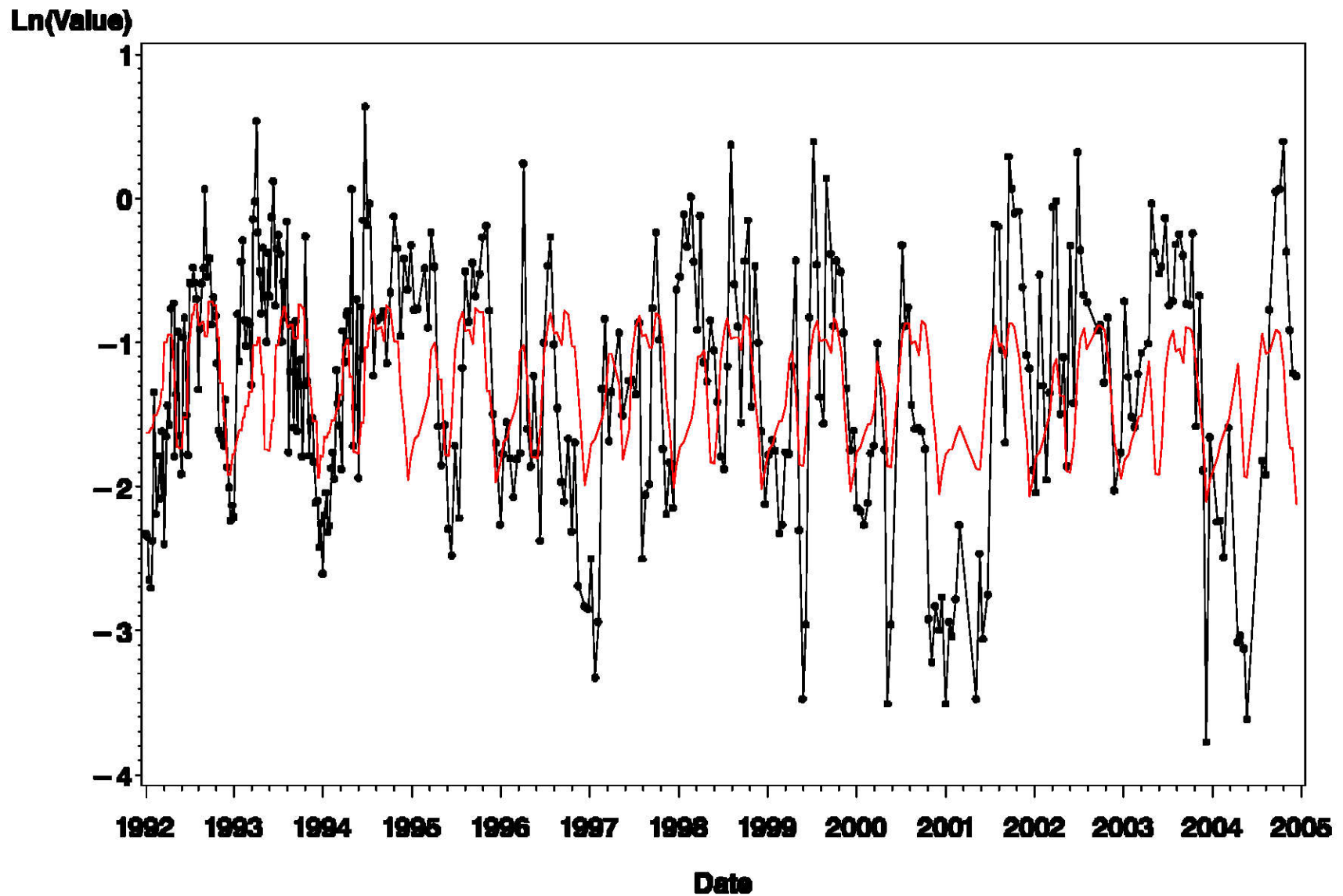


Figure A-36

Actual Data and Fitted Fixed Effects Model
Label=TCNS 220 TPO4

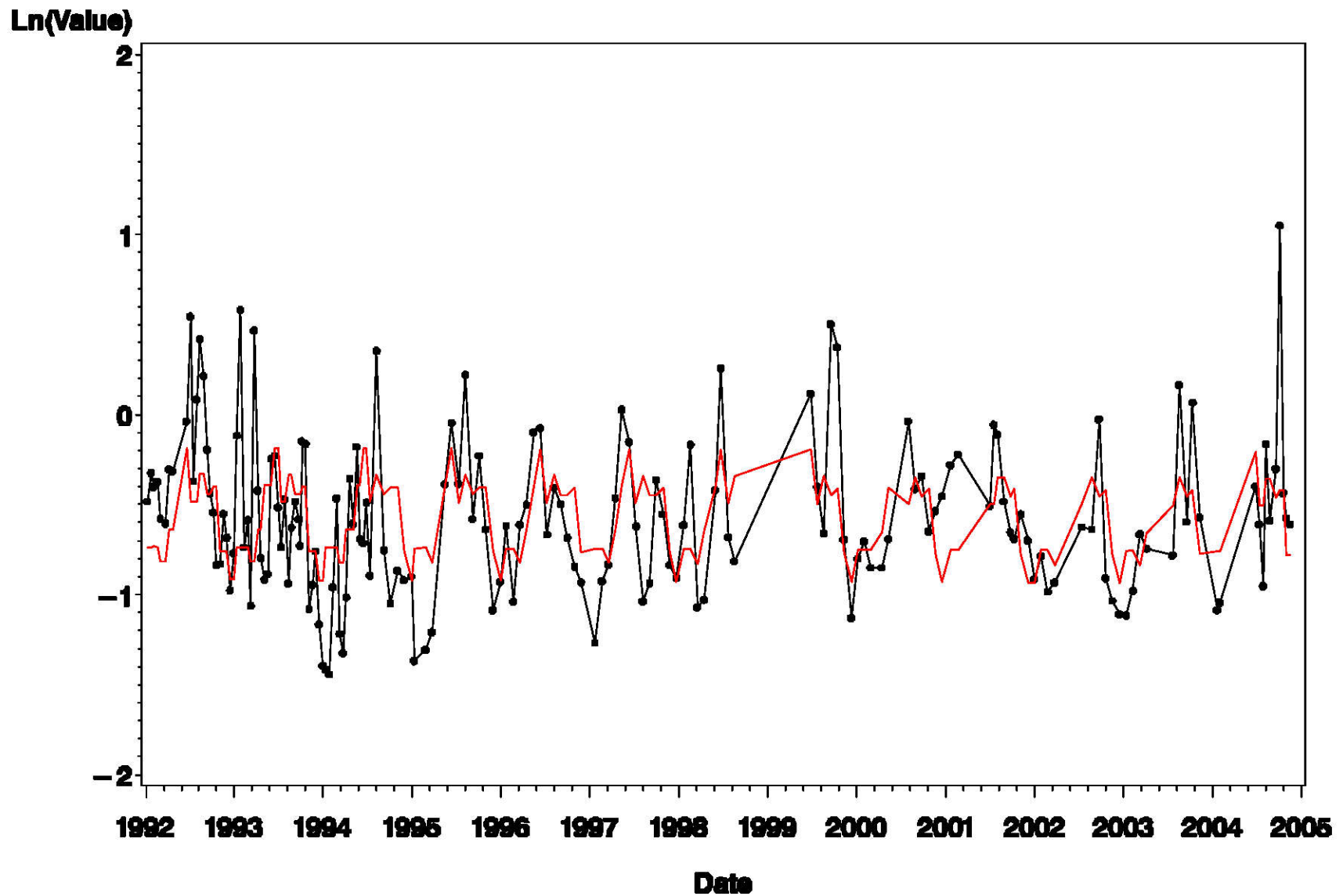


Figure A-37

Actual Data and Fitted Fixed Effects Model
Label=TCNS 222 TPO4

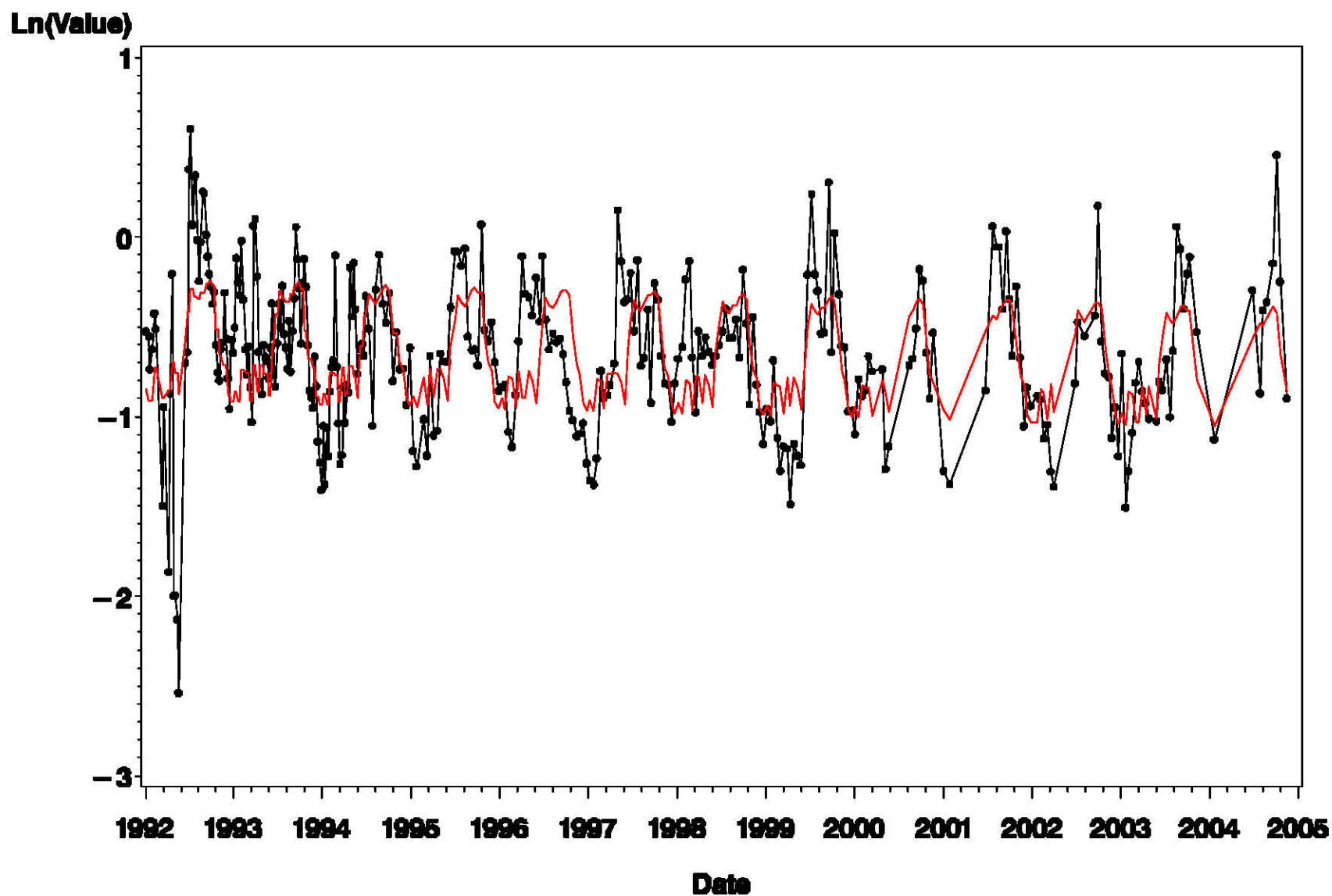


Figure A-38

Actual Data and Fitted Fixed Effects Model
Label=TCNS 228 TPO4

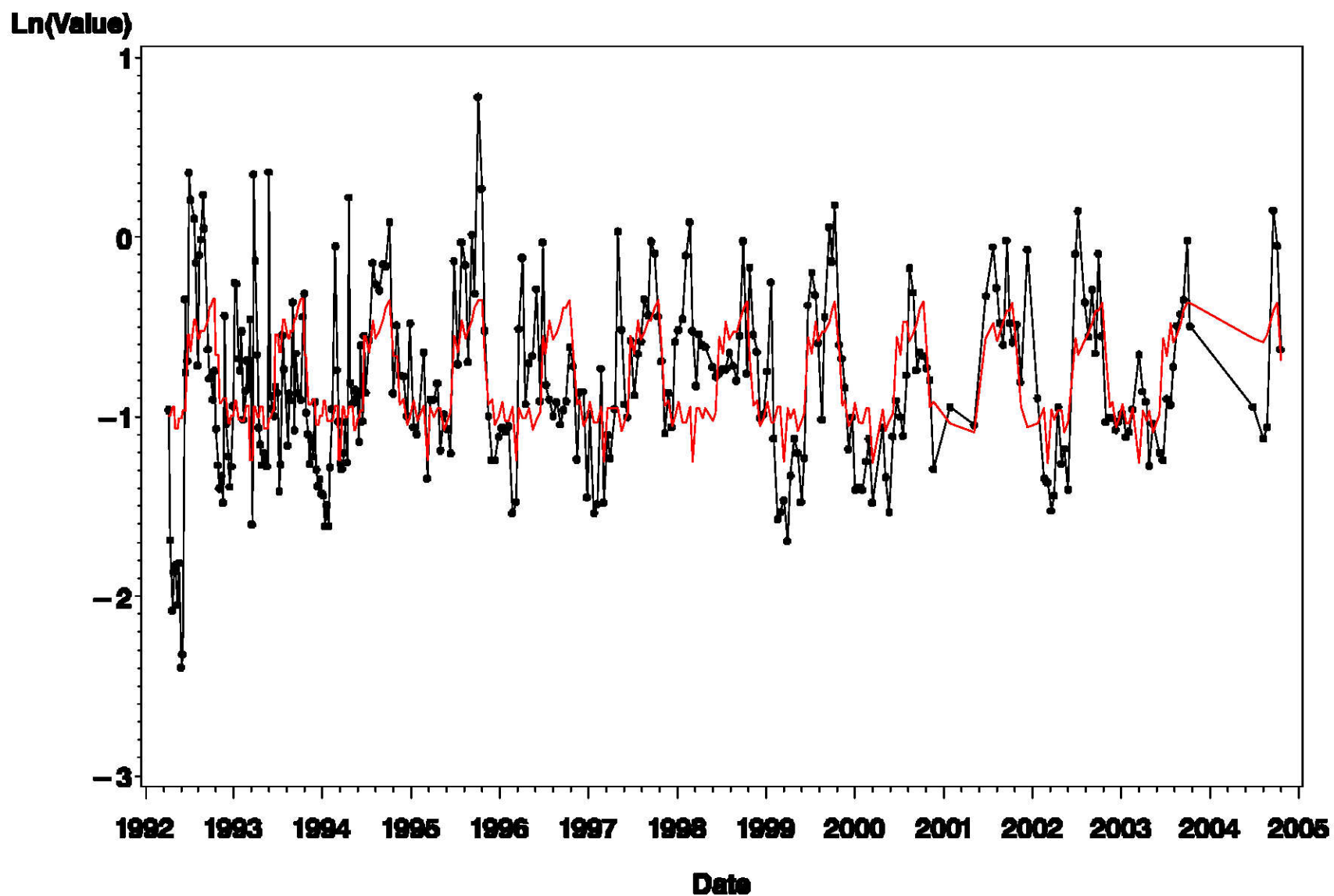


Figure A-39

Actual Data and Fitted Fixed Effects Model
Label=TCNS 230 TPO4

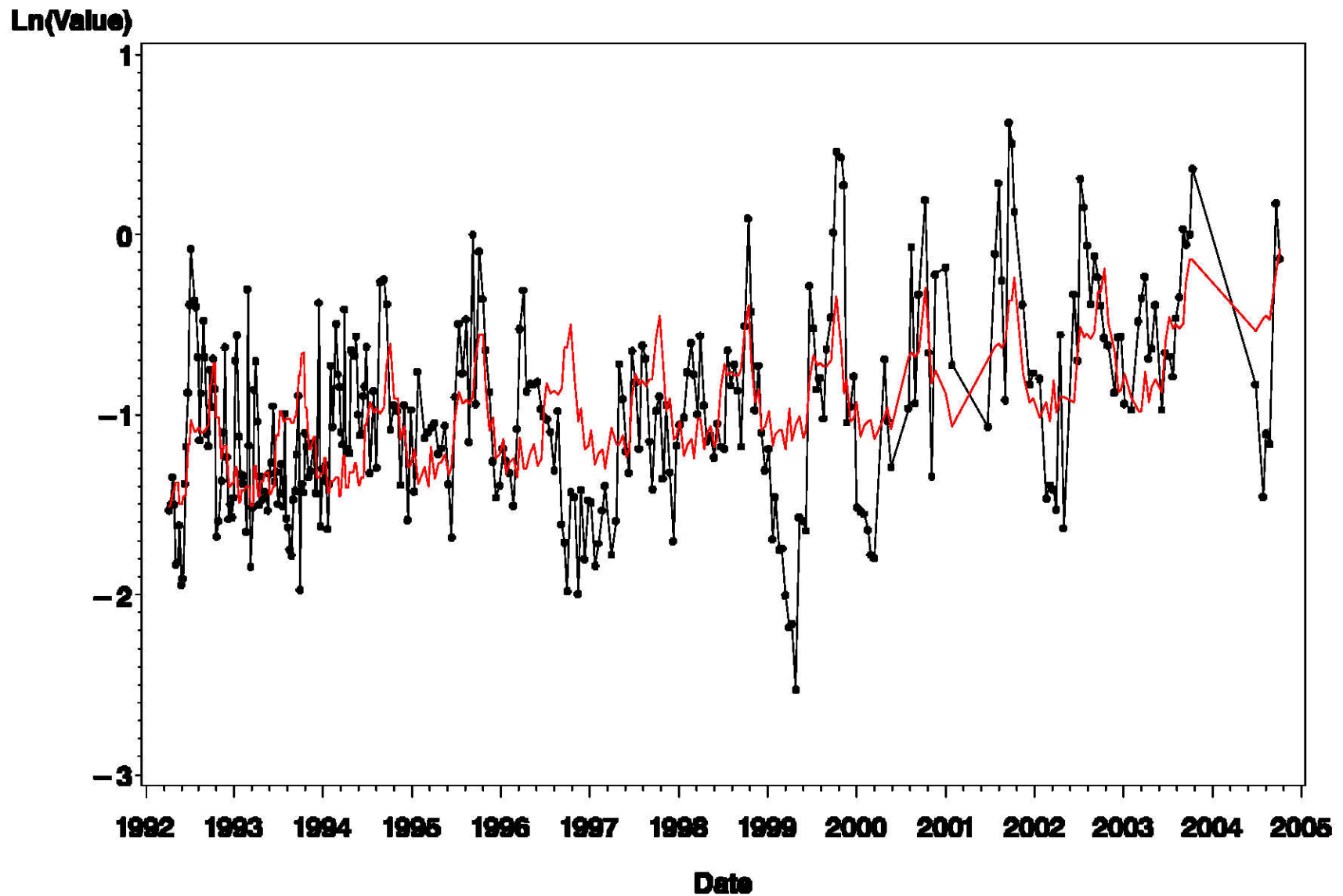


Figure A-40

Actual Data and Fitted Fixed Effects Model
Label=TCNS 233 TPO4

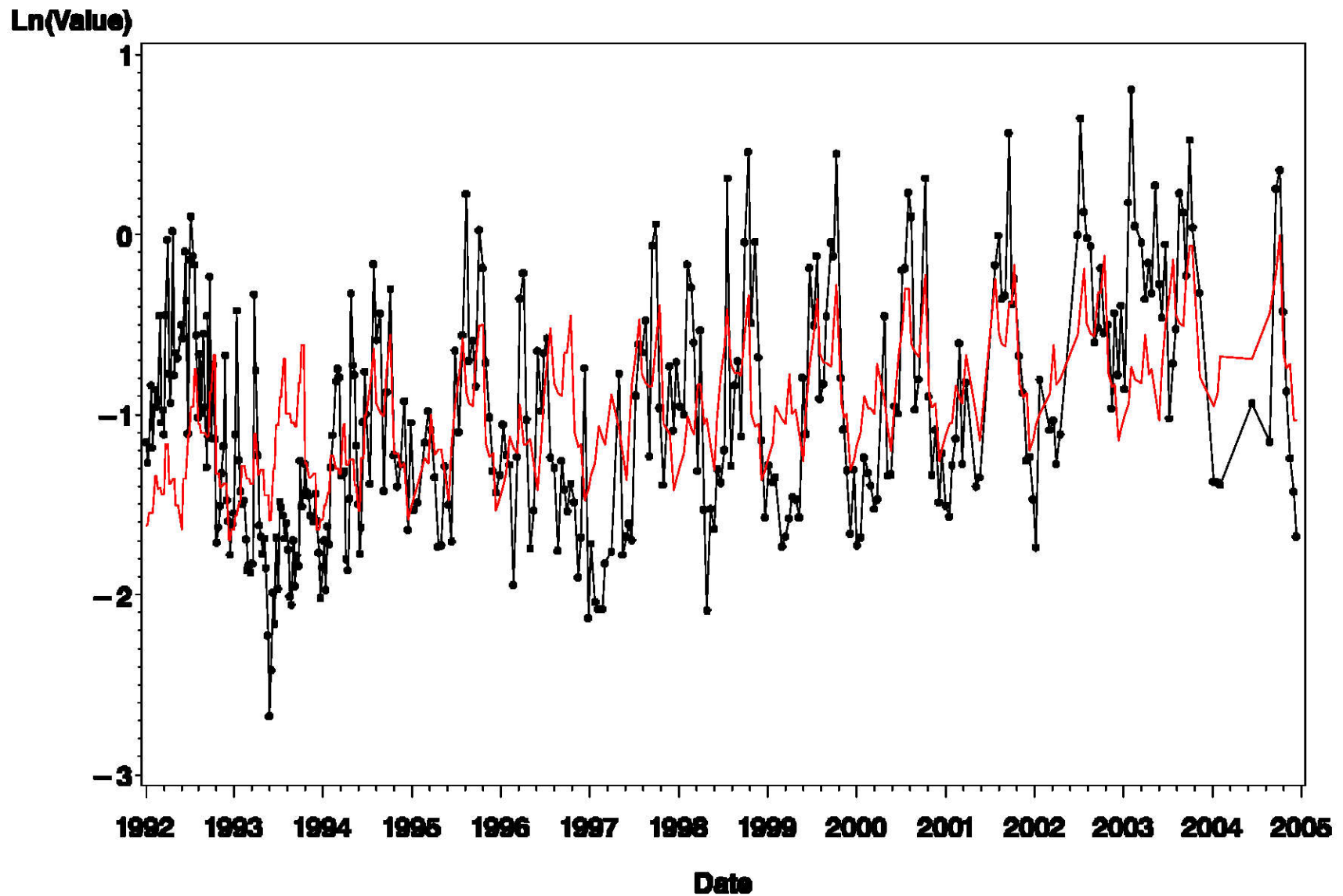


Figure A-41

Actual Data and Fitted Fixed Effects Model
Label=TCNS 249 TPO4

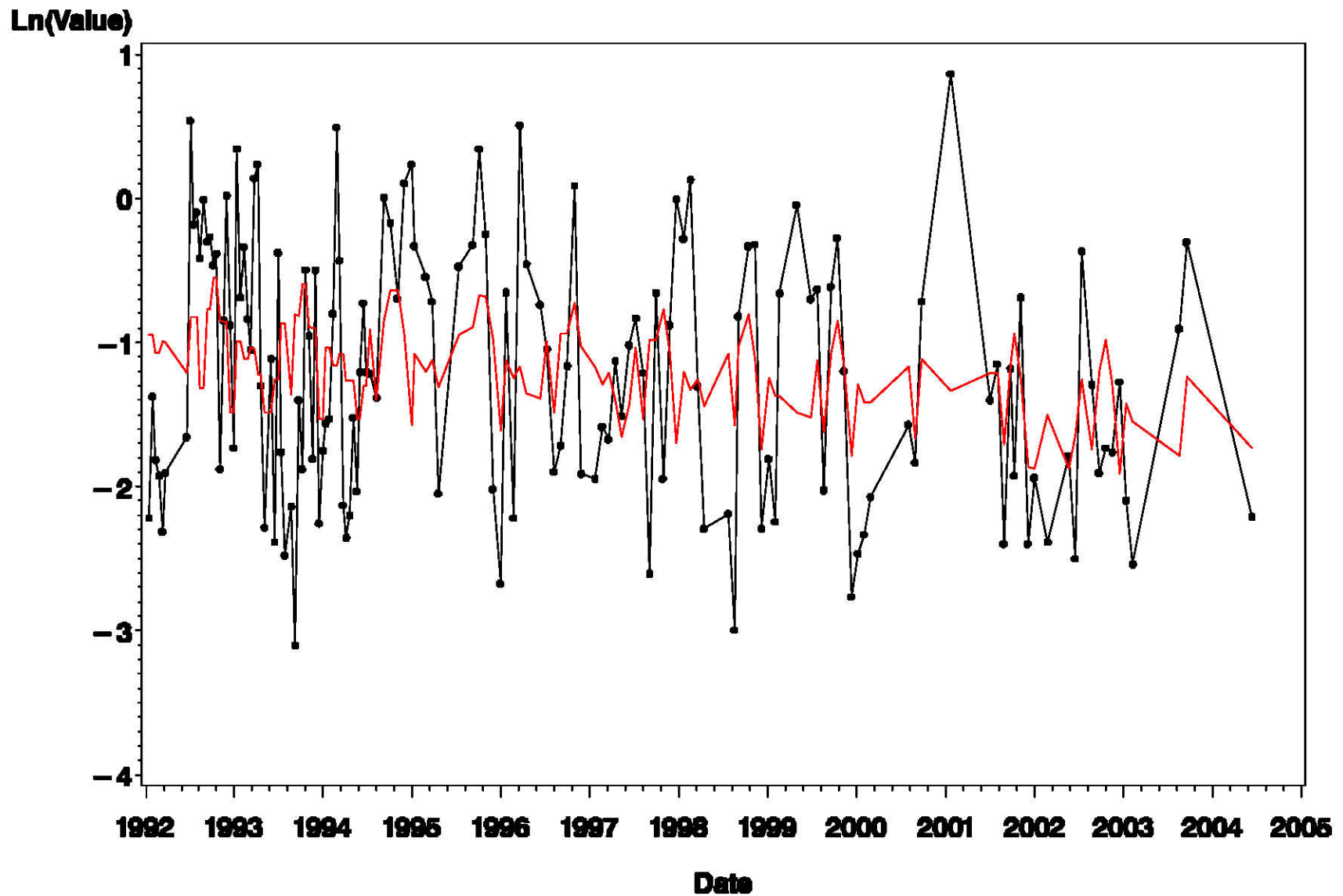


Figure A-42

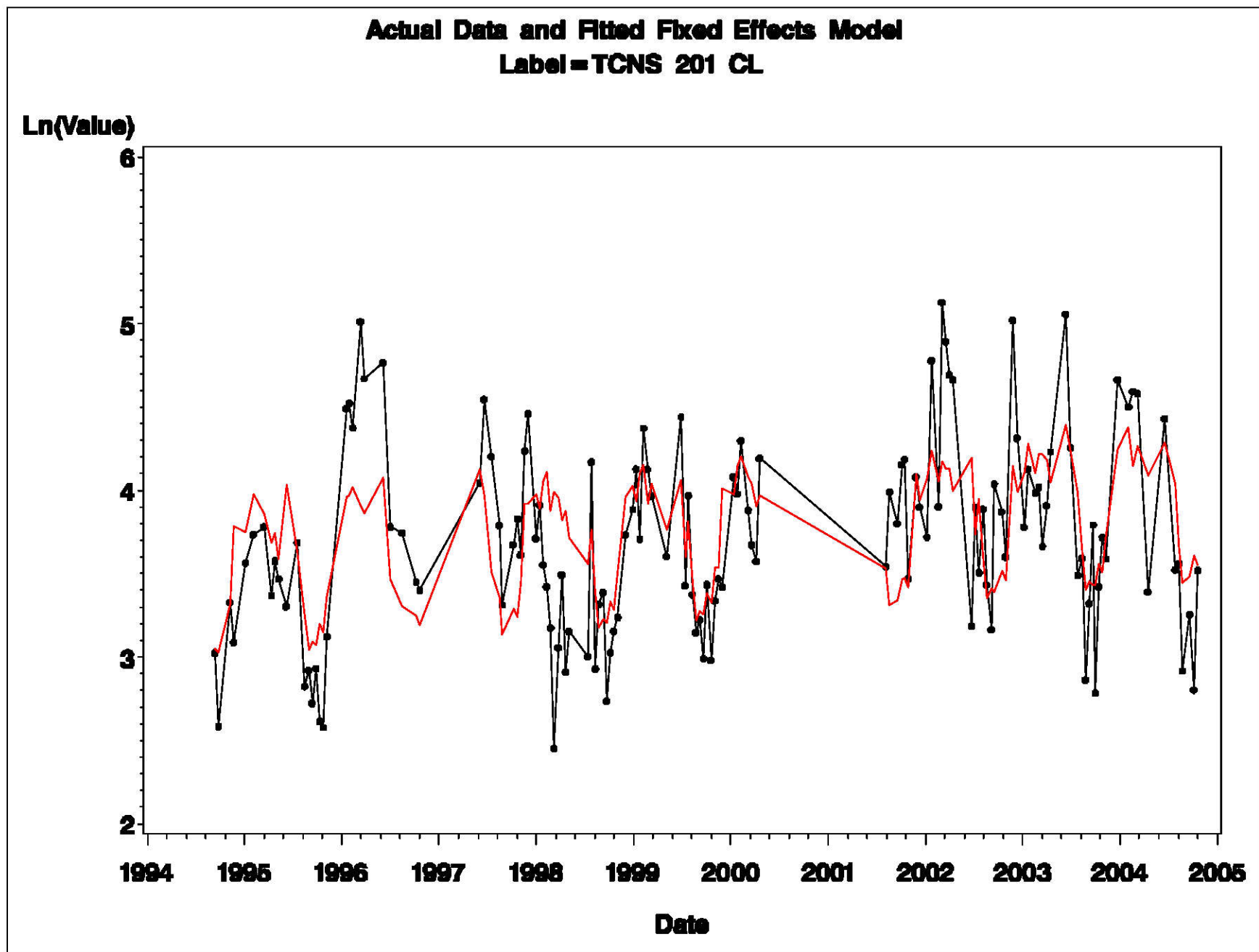


Figure A-43

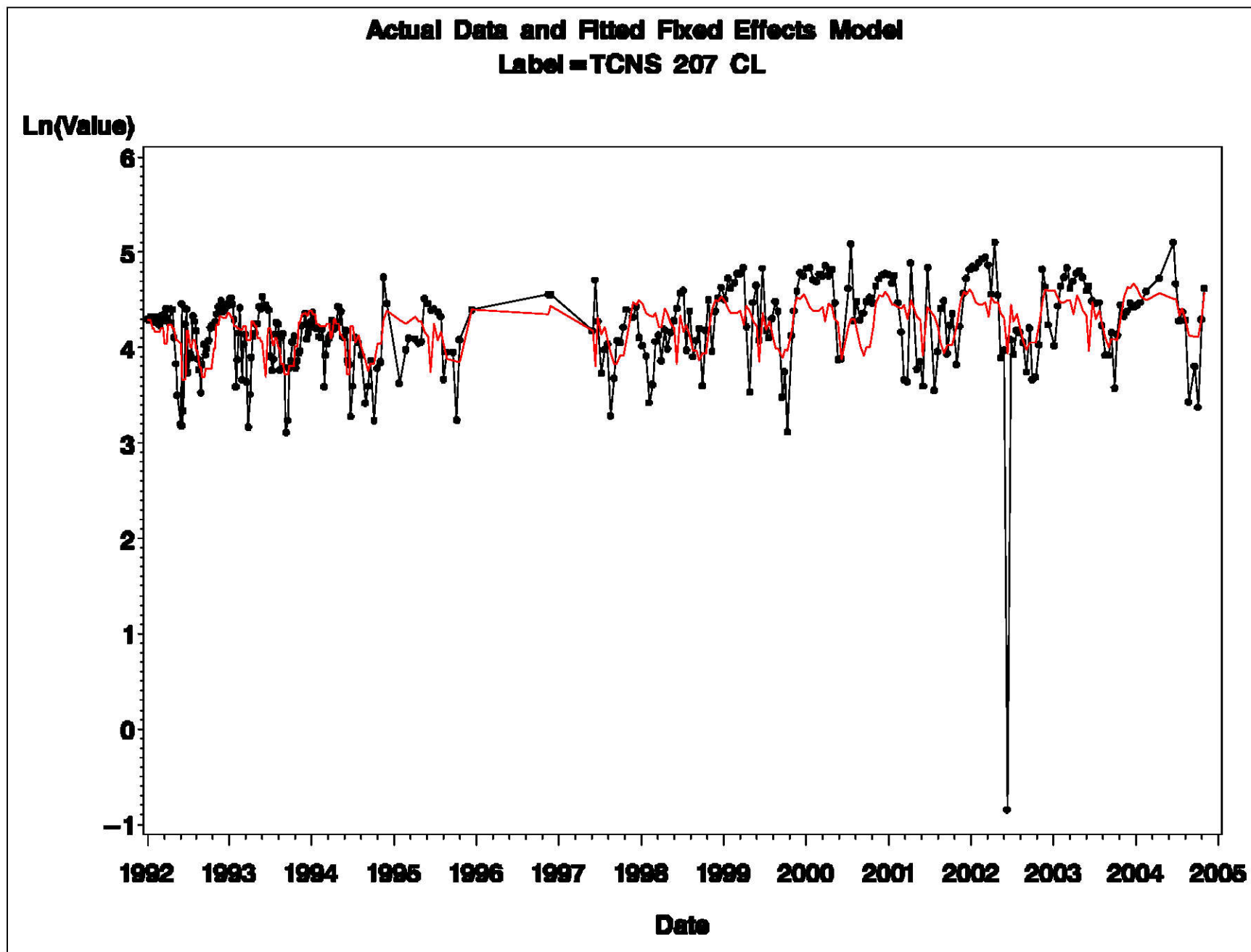


Figure A-44

Actual Data and Fitted Fixed Effects Model
Label = TCNS 209 CL

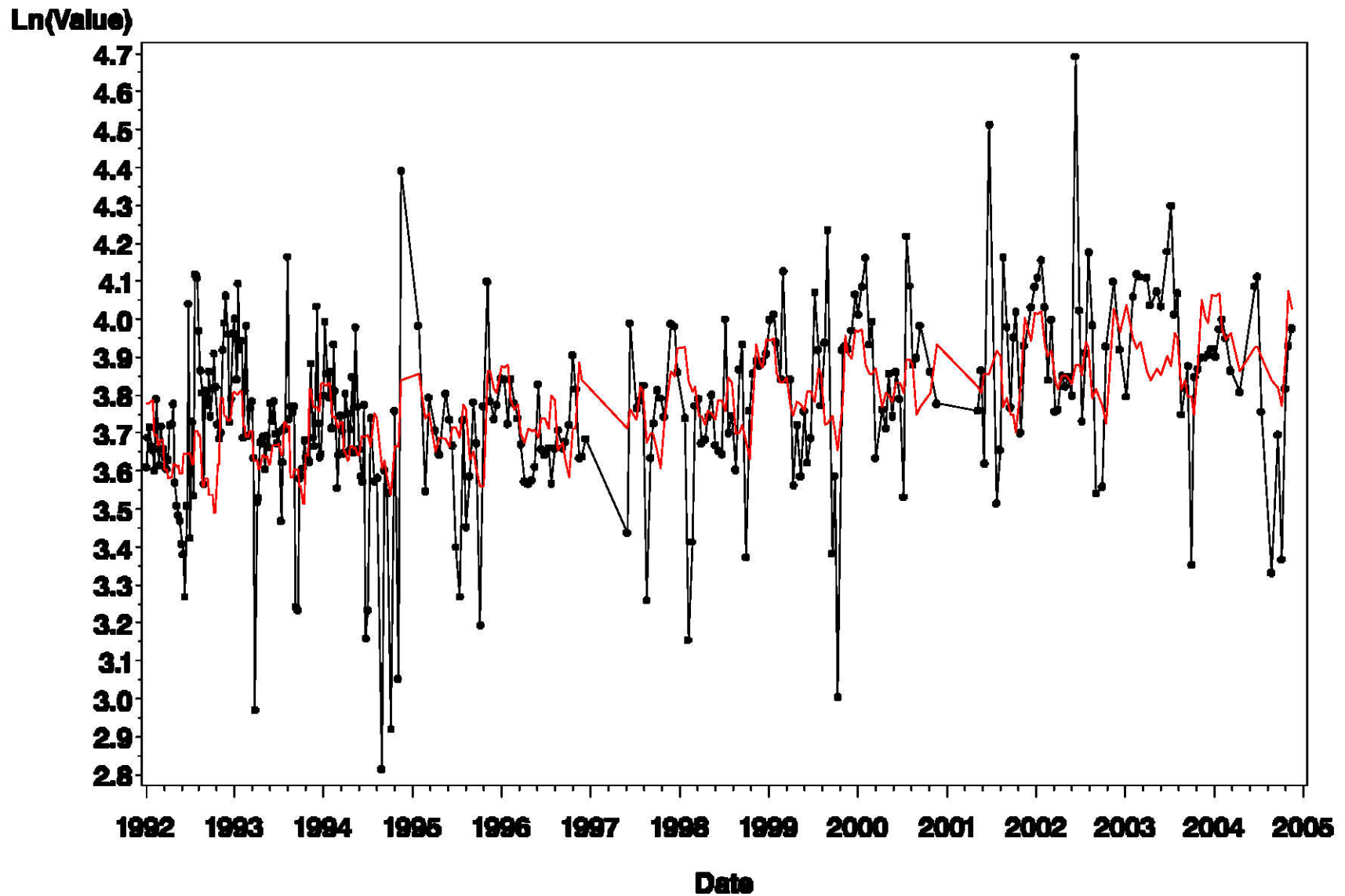


Figure A-45

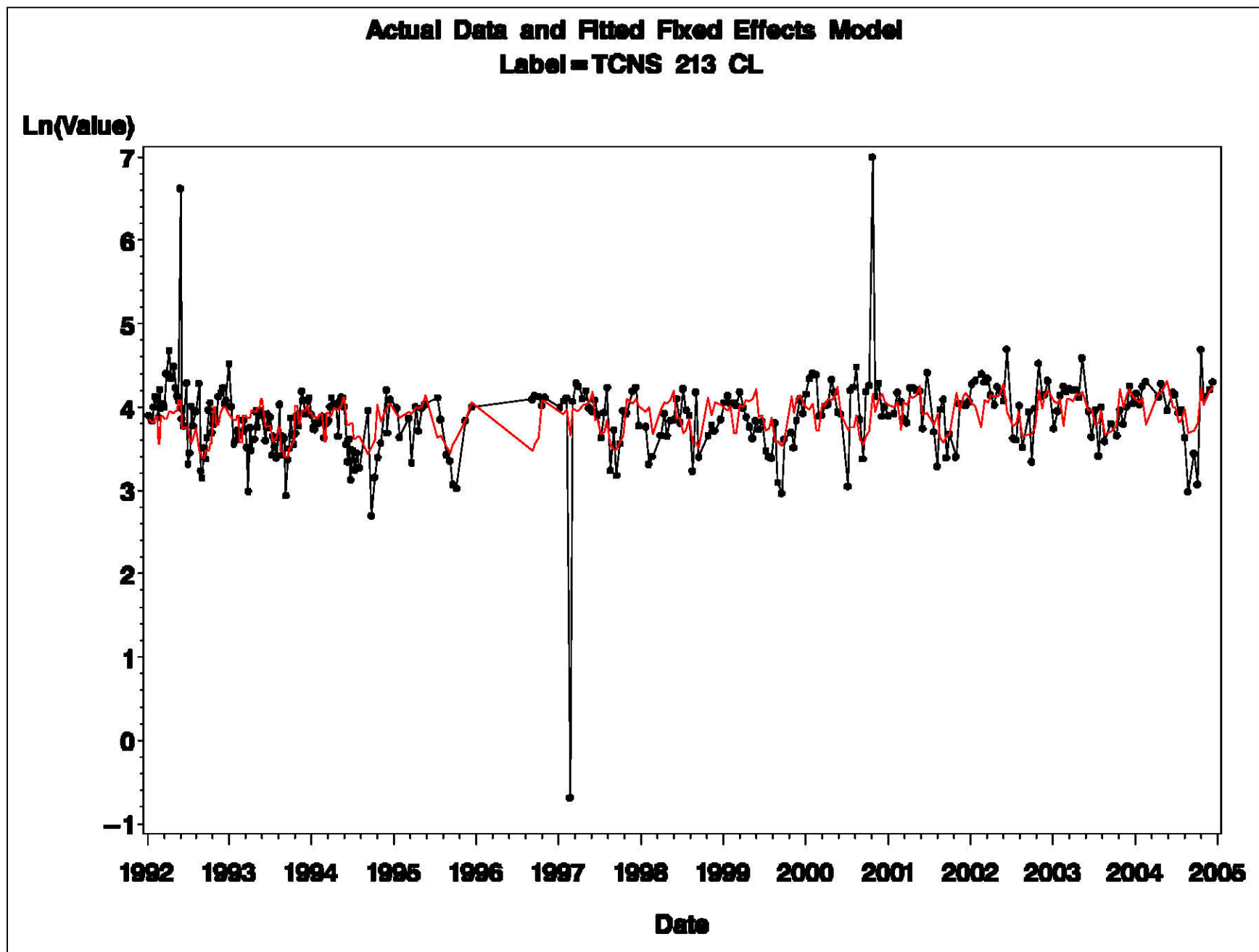


Figure A-46

Actual Data and Fitted Fixed Effects Model
Label=TCNS 214 CL

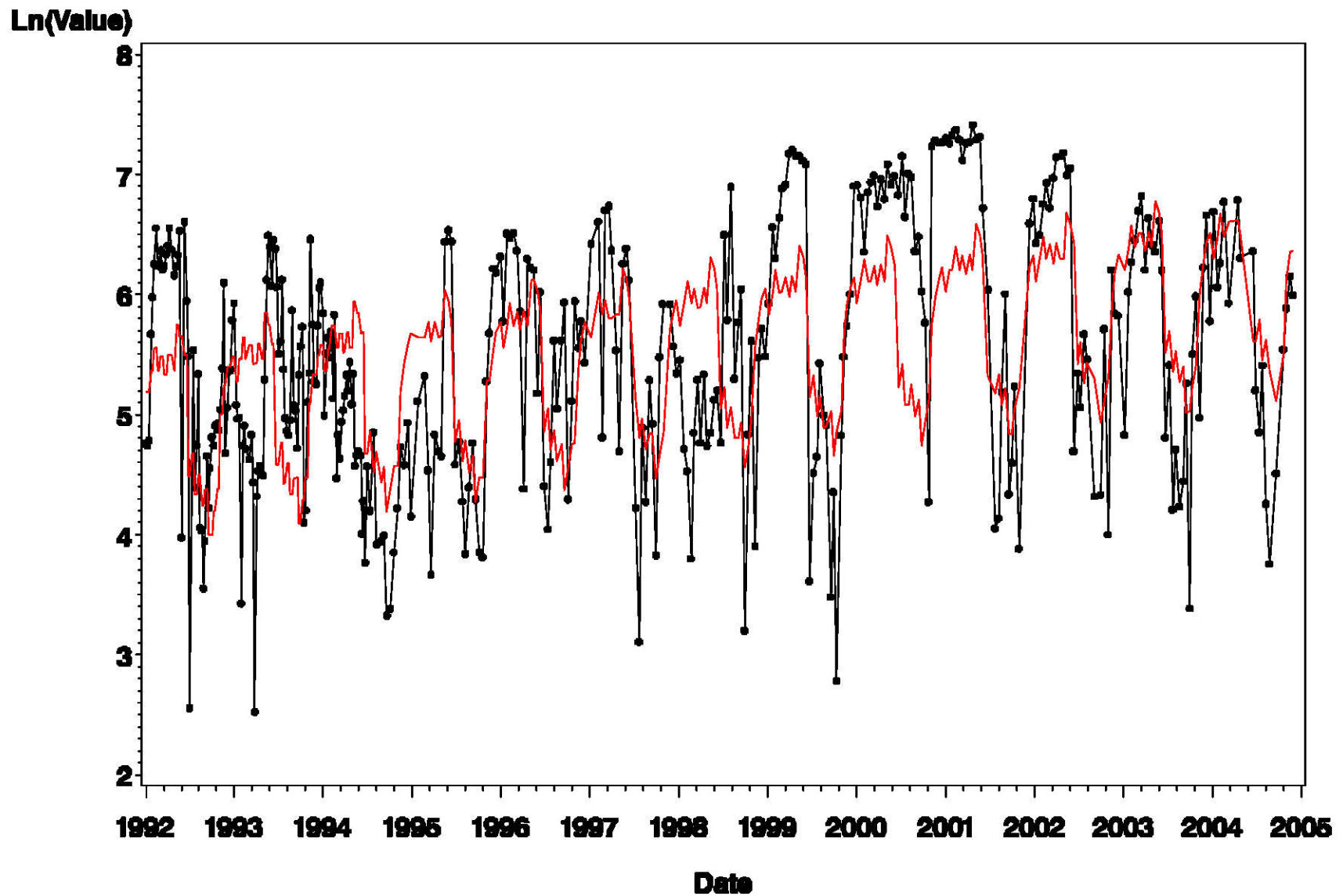


Figure A-47

Actual Data and Fitted Fixed Effects Model
Label=TCNS 217 CL

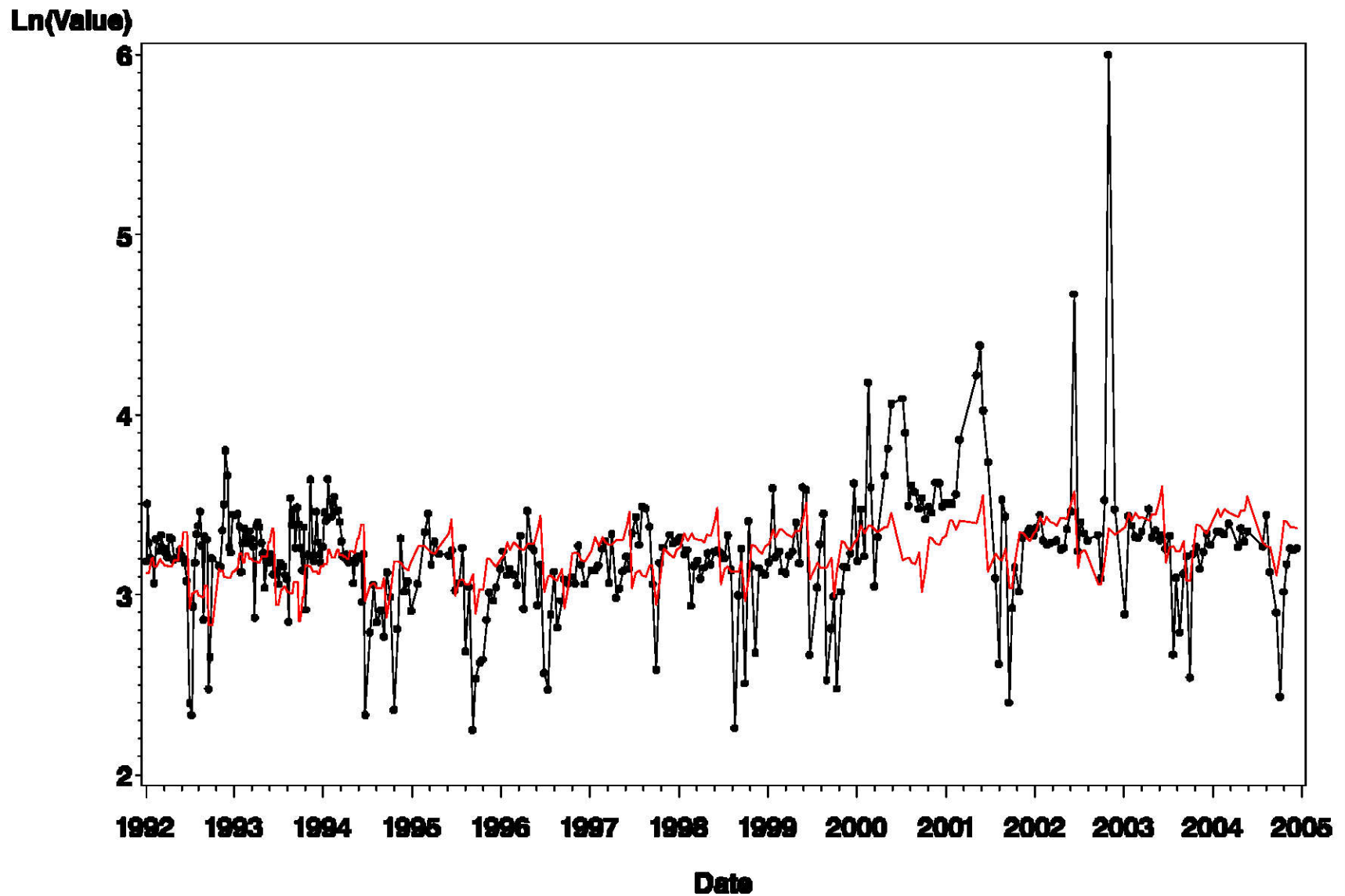


Figure A-48

Actual Data and Fitted Fixed Effects Model
Label = TCNS 222 CL

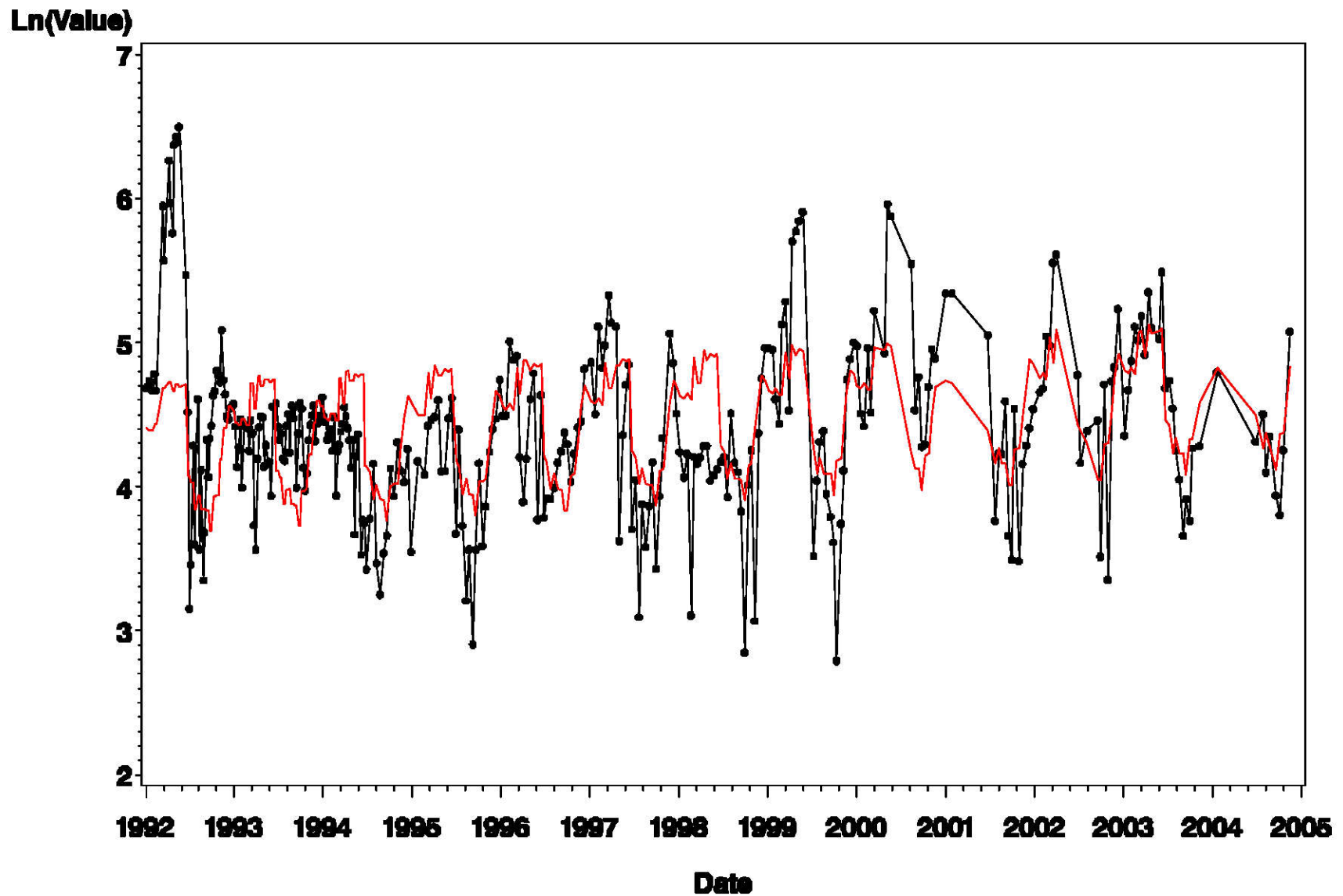


Figure A-49

Actual Data and Fitted Fixed Effects Model
Label = TCNS 228 CL

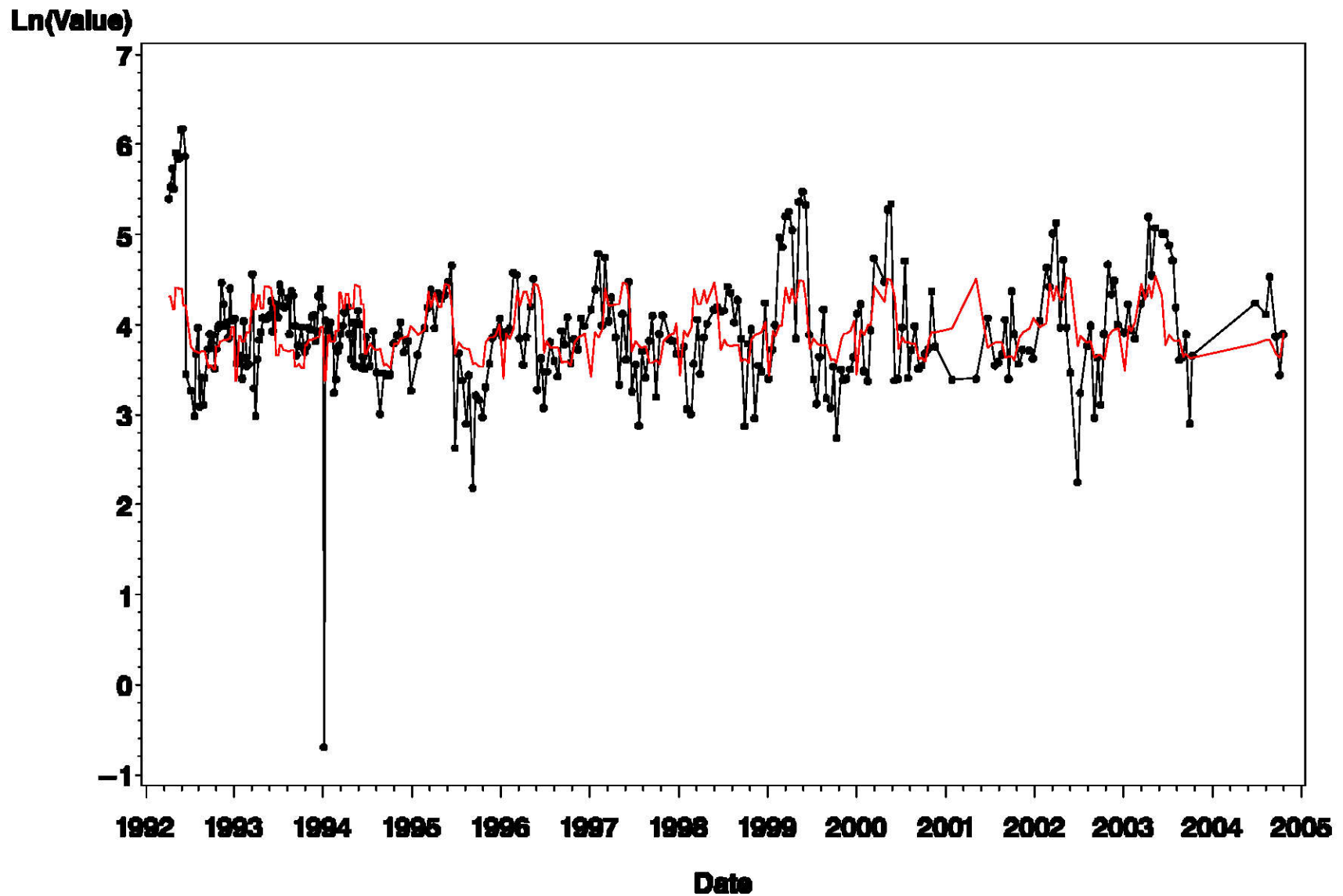


Figure A-50

Actual Data and Fitted Fixed Effects Model
Label = TCNS 230 CL

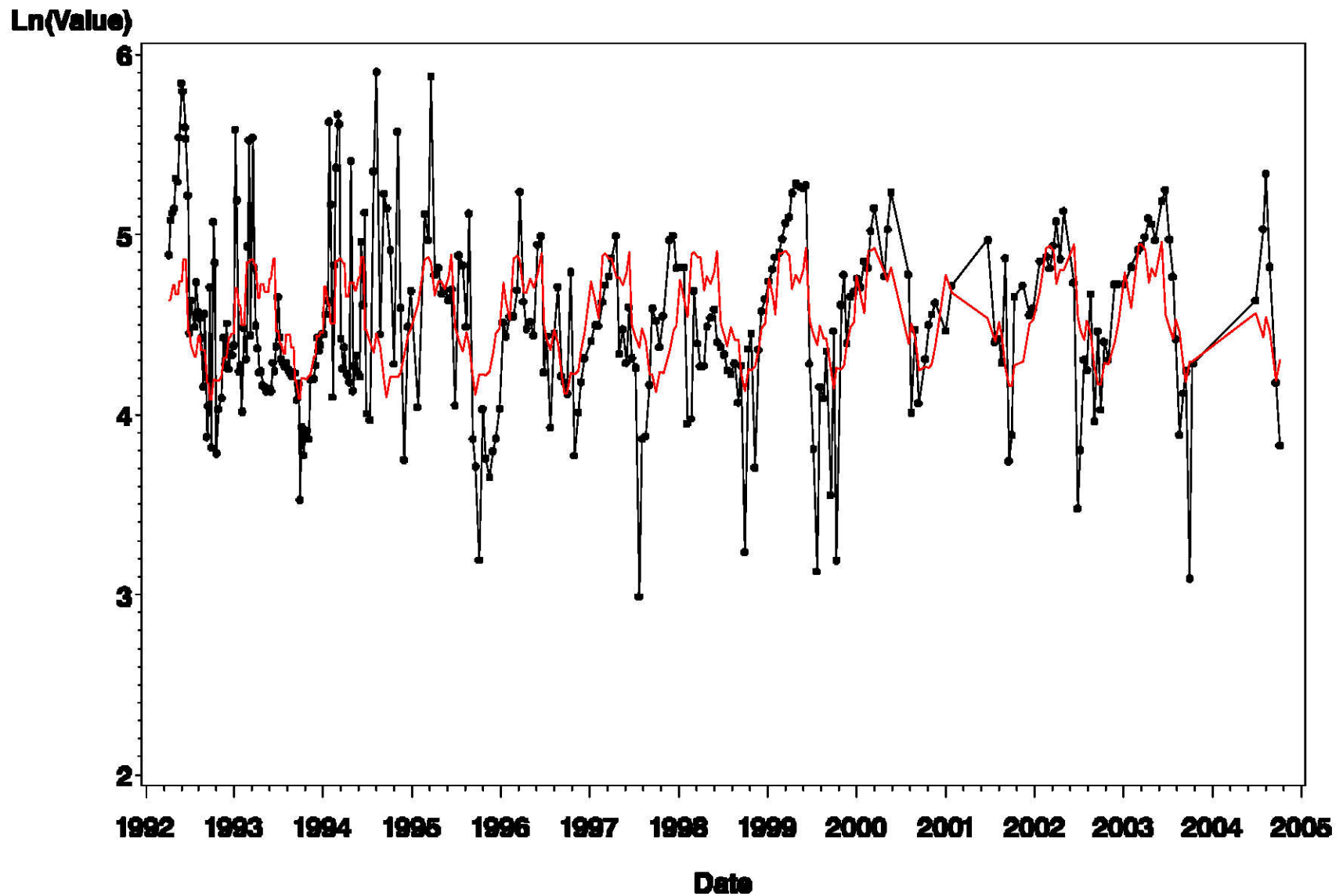


Figure A-51

Actual Data and Fitted Fixed Effects Model
Label = TCNS 233 CL

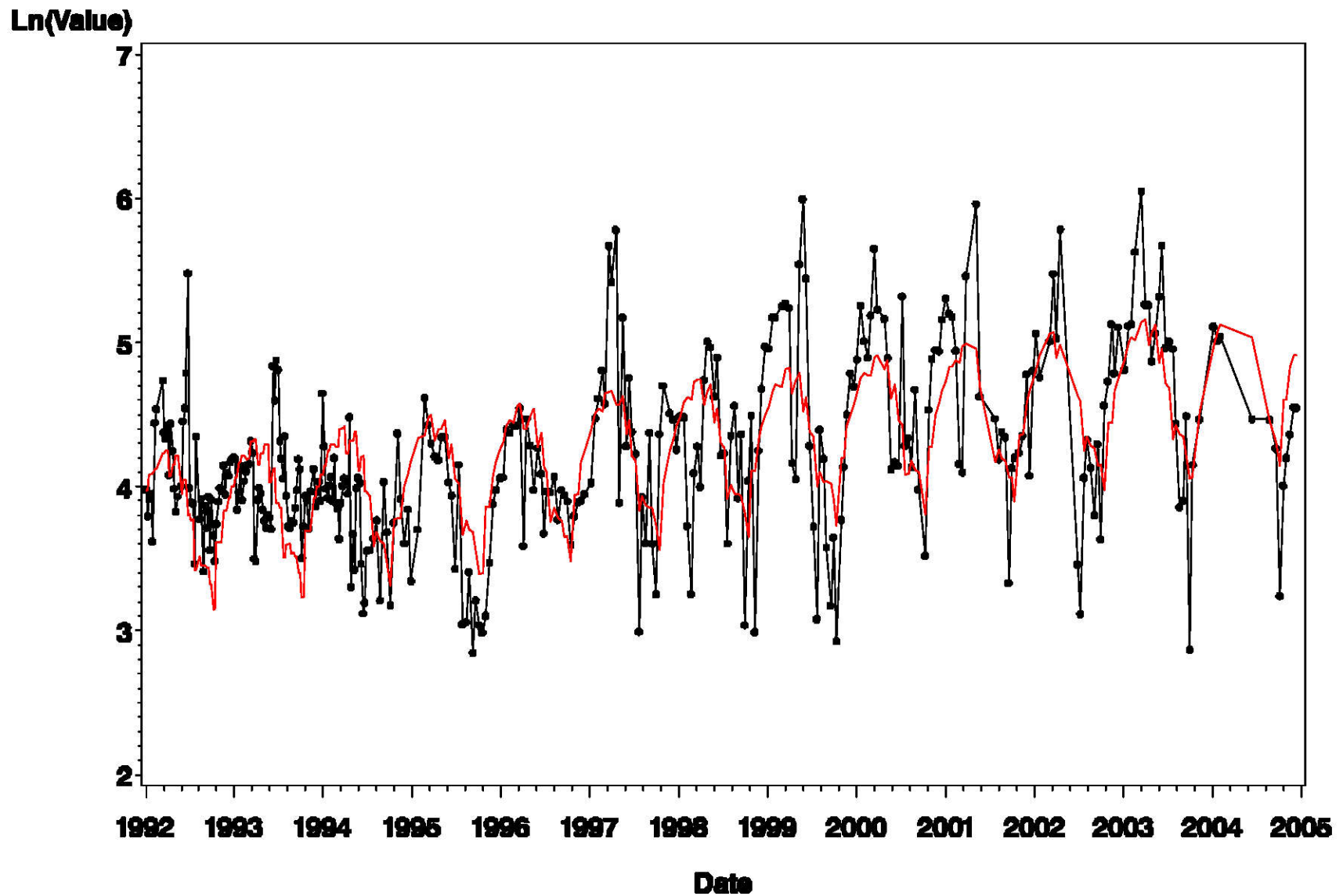


Figure A-52

APPENDIX B

SUMMARY OF SIMULATION RESULTS

Table B-1. Summary of Power Analysis Results

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| TCNS 201 | CL | 0.49 | 0.42 | 12 | 31% |
| TCNS 201 | CL | 0.49 | 0.42 | 24 | 24% |
| TCNS 201 | CL | 0.49 | 0.42 | 52 | 21% |
| TCNS 201 | DO | 0.61 | 0.26 | 12 | 35% |
| TCNS 201 | DO | 0.61 | 0.26 | 24 | 25% |
| TCNS 201 | DO | 0.61 | 0.26 | 52 | 20% |
| TCNS 201 | TKN | 0.30 | 0.30 | 12 | 17% |
| TCNS 201 | TKN | 0.30 | 0.30 | 24 | 12% |
| TCNS 201 | TKN | 0.30 | 0.30 | 52 | 10% |
| TCNS 201** | TPO4** | 0.49 | 0.24 | 12 | 28% |
| TCNS 201** | TPO4** | 0.49 | 0.24 | 24 | 20% |
| TCNS 201** | TPO4** | 0.49 | 0.24 | 52 | 16% |
| TCNS 204 | DO | 0.48 | 0.50 | 12 | 29% |
| TCNS 204 | DO | 0.48 | 0.50 | 24 | 25% |
| TCNS 204 | DO | 0.48 | 0.50 | 52 | 23% |
| TCNS 204 | TKN | 0.36 | 0.31 | 12 | 22% |
| TCNS 204 | TKN | 0.36 | 0.31 | 24 | 18% |
| TCNS 204 | TKN | 0.36 | 0.31 | 52 | 16% |
| TCNS 204 | TPO4 | 0.52 | 0.35 | 12 | 27% |
| TCNS 204 | TPO4 | 0.52 | 0.35 | 24 | 21% |
| TCNS 204 | TPO4 | 0.52 | 0.35 | 52 | 17% |
| TCNS 207** | CL** | 0.44 | 0.00 | 12 | 14% |
| TCNS 207** | CL** | 0.44 | 0.00 | 24 | 10% |
| TCNS 207** | CL** | 0.44 | 0.00 | 52 | 7% |
| TCNS 207 | DO | 0.57 | 0.36 | 12 | 27% |
| TCNS 207 | DO | 0.57 | 0.36 | 24 | 23% |
| TCNS 207 | DO | 0.57 | 0.36 | 52 | 21% |
| TCNS 207 | TKN | 0.41 | 0.00 | 12 | 13% |
| TCNS 207 | TKN | 0.41 | 0.00 | 24 | 9% |
| TCNS 207 | TKN | 0.41 | 0.00 | 52 | 6% |
| TCNS 207 | TPO4 | 0.66 | 0.52 | 12 | 29% |
| TCNS 207 | TPO4 | 0.66 | 0.52 | 24 | 27% |
| TCNS 207 | TPO4 | 0.66 | 0.52 | 52 | 25% |
| TCNS 209* | CL* | 0.21 | -0.03 | 12 | 8% |
| TCNS 209* | CL* | 0.21 | -0.03 | 24 | 5% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| TCNS 209* | CL* | 0.21 | -0.03 | 52 | 3% |
| TCNS 209 | DO | 0.57 | 0.26 | 12 | 25% |
| TCNS 209 | DO | 0.57 | 0.26 | 24 | 19% |
| TCNS 209 | DO | 0.57 | 0.26 | 52 | 16% |
| TCNS 209 | TKN | 0.43 | 0.37 | 12 | 19% |
| TCNS 209 | TKN | 0.43 | 0.37 | 24 | 16% |
| TCNS 209 | TKN | 0.43 | 0.37 | 52 | 14% |
| TCNS 209 | TPO4 | 0.73 | 0.50 | 12 | 37% |
| TCNS 209 | TPO4 | 0.73 | 0.50 | 24 | 32% |
| TCNS 209 | TPO4 | 0.73 | 0.50 | 52 | 29% |
| TCNS 212 | DO | 0.55 | 0.00 | 12 | 56% |
| TCNS 212 | DO | 0.55 | 0.00 | 24 | 35% |
| TCNS 212 | DO | 0.55 | 0.00 | 52 | 22% |
| TCNS 212 | TKN | 0.32 | 0.48 | 12 | 36% |
| TCNS 212 | TKN | 0.32 | 0.48 | 24 | 30% |
| TCNS 212 | TKN | 0.32 | 0.48 | 52 | 26% |
| TCNS 212 | TPO4 | 0.72 | 0.33 | 12 | 90% |
| TCNS 212 | TPO4 | 0.72 | 0.33 | 24 | 64% |
| TCNS 212 | TPO4 | 0.72 | 0.33 | 52 | 50% |
| TCNS 213** | CL** | 0.45 | 0.12 | 12 | 16% |
| TCNS 213** | CL** | 0.45 | 0.12 | 24 | 12% |
| TCNS 213** | CL** | 0.45 | 0.12 | 52 | 9% |
| TCNS 213 | DO | 0.35 | 0.08 | 12 | 12% |
| TCNS 213 | DO | 0.35 | 0.08 | 24 | 9% |
| TCNS 213 | DO | 0.35 | 0.08 | 52 | 7% |
| TCNS 213 | TKN | 0.31 | 0.00 | 12 | 10% |
| TCNS 213 | TKN | 0.31 | 0.00 | 24 | 7% |
| TCNS 213 | TKN | 0.31 | 0.00 | 52 | 5% |
| TCNS 213 | TPO4 | 0.55 | 0.00 | 12 | 19% |
| TCNS 213 | TPO4 | 0.55 | 0.00 | 24 | 13% |
| TCNS 213 | TPO4 | 0.55 | 0.00 | 52 | 9% |
| TCNS 214 | CL | 0.87 | 0.45 | 12 | 41% |
| TCNS 214 | CL | 0.87 | 0.45 | 24 | 36% |
| TCNS 214 | CL | 0.87 | 0.45 | 52 | 34% |
| TCNS 214 | DO | 0.66 | 0.40 | 12 | 32% |
| TCNS 214 | DO | 0.66 | 0.40 | 24 | 29% |
| TCNS 214 | DO | 0.66 | 0.40 | 52 | 27% |
| TCNS 214 | TKN | 0.42 | 0.40 | 12 | 19% |
| TCNS 214 | TKN | 0.42 | 0.40 | 24 | 17% |
| TCNS 214 | TKN | 0.42 | 0.40 | 52 | 16% |
| TCNS 214 | TPO4 | 0.40 | 0.29 | 12 | 15% |
| TCNS 214 | TPO4 | 0.40 | 0.29 | 24 | 12% |
| TCNS 214 | TPO4 | 0.40 | 0.29 | 52 | 11% |
| TCNS 217 | CL | 0.34 | 0.21 | 12 | 12% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| TCNS 217 | CL | 0.34 | 0.21 | 24 | 9% |
| TCNS 217 | CL | 0.34 | 0.21 | 52 | 8% |
| TCNS 217 | DO | 0.59 | 0.40 | 12 | 27% |
| TCNS 217 | DO | 0.59 | 0.40 | 24 | 23% |
| TCNS 217 | DO | 0.59 | 0.40 | 52 | 21% |
| TCNS 217 | TKN | 0.64 | 0.56 | 12 | 31% |
| TCNS 217 | TKN | 0.64 | 0.56 | 24 | 28% |
| TCNS 217 | TKN | 0.64 | 0.56 | 52 | 26% |
| TCNS 217 | TPO4 | 0.82 | 0.50 | 12 | 40% |
| TCNS 217 | TPO4 | 0.82 | 0.50 | 24 | 35% |
| TCNS 217 | TPO4 | 0.82 | 0.50 | 52 | 33% |
| TCNS 220 | DO | 0.40 | 0.20 | 12 | 20% |
| TCNS 220 | DO | 0.40 | 0.20 | 24 | 16% |
| TCNS 220 | DO | 0.40 | 0.20 | 52 | 14% |
| TCNS 220 | TKN | 0.41 | 0.12 | 12 | 20% |
| TCNS 220 | TKN | 0.41 | 0.12 | 24 | 15% |
| TCNS 220 | TKN | 0.41 | 0.12 | 52 | 13% |
| TCNS 220 | TPO4 | 0.39 | 0.23 | 12 | 21% |
| TCNS 220 | TPO4 | 0.39 | 0.23 | 24 | 17% |
| TCNS 220 | TPO4 | 0.39 | 0.23 | 52 | 14% |
| TCNS 222 | CL | 0.54 | 0.48 | 12 | 30% |
| TCNS 222 | CL | 0.54 | 0.48 | 24 | 24% |
| TCNS 222 | CL | 0.54 | 0.48 | 52 | 21% |
| TCNS 222 | DO | 0.28 | -0.04 | 12 | 13% |
| TCNS 222 | DO | 0.28 | -0.04 | 24 | 9% |
| TCNS 222 | DO | 0.28 | -0.04 | 52 | 5% |
| TCNS 222 | TKN | 0.24 | 0.20 | 12 | 11% |
| TCNS 222 | TKN | 0.24 | 0.20 | 24 | 8% |
| TCNS 222 | TKN | 0.24 | 0.20 | 52 | 6% |
| TCNS 222 | TPO4 | 0.36 | 0.24 | 12 | 17% |
| TCNS 222 | TPO4 | 0.36 | 0.24 | 24 | 13% |
| TCNS 222 | TPO4 | 0.36 | 0.24 | 52 | 10% |
| TCNS 228** | CL** | 0.61 | 0.31 | 12 | 31% |
| TCNS 228** | CL** | 0.61 | 0.31 | 24 | 25% |
| TCNS 228** | CL** | 0.61 | 0.31 | 52 | 21% |
| TCNS 228* | DO* | 0.36 | -0.03 | 12 | 16% |
| TCNS 228* | DO* | 0.36 | -0.03 | 24 | 11% |
| TCNS 228* | DO* | 0.36 | -0.03 | 52 | 7% |
| TCNS 228 | TKN | 0.31 | 0.14 | 12 | 14% |
| TCNS 228 | TKN | 0.31 | 0.14 | 24 | 10% |
| TCNS 228 | TKN | 0.31 | 0.14 | 52 | 8% |
| TCNS 228 | TPO4 | 0.42 | 0.24 | 12 | 20% |
| TCNS 228 | TPO4 | 0.42 | 0.24 | 24 | 15% |
| TCNS 228 | TPO4 | 0.42 | 0.24 | 52 | 12% |

| Station ID | Parameter | Standard Deviation | Autocorrelation Coefficient | Samples Per Year | Detectable Annual Percentage Change |
|------------|-----------|--------------------|-----------------------------|------------------|-------------------------------------|
| TCNS 230 | CL | 0.45 | 0.26 | 12 | 23% |
| TCNS 230 | CL | 0.45 | 0.26 | 24 | 18% |
| TCNS 230 | CL | 0.45 | 0.26 | 52 | 14% |
| TCNS 230* | DO* | 0.40 | -0.05 | 12 | 20% |
| TCNS 230* | DO* | 0.40 | -0.05 | 24 | 13% |
| TCNS 230* | DO* | 0.40 | -0.05 | 52 | 8% |
| TCNS 230 | TKN | 0.26 | 0.19 | 12 | 12% |
| TCNS 230 | TKN | 0.26 | 0.19 | 24 | 9% |
| TCNS 230 | TKN | 0.26 | 0.19 | 52 | 7% |
| TCNS 230 | TPO4 | 0.48 | 0.41 | 12 | 26% |
| TCNS 230 | TPO4 | 0.48 | 0.41 | 24 | 20% |
| TCNS 230 | TPO4 | 0.48 | 0.41 | 52 | 17% |
| TCNS 233 | CL | 0.48 | 0.17 | 12 | 19% |
| TCNS 233 | CL | 0.48 | 0.17 | 24 | 15% |
| TCNS 233 | CL | 0.48 | 0.17 | 52 | 12% |
| TCNS 233 | DO | 0.36 | 0.00 | 12 | 14% |
| TCNS 233 | DO | 0.36 | 0.00 | 24 | 10% |
| TCNS 233 | DO | 0.36 | 0.00 | 52 | 7% |
| TCNS 233 | TKN | 0.34 | 0.31 | 12 | 15% |
| TCNS 233 | TKN | 0.34 | 0.31 | 24 | 13% |
| TCNS 233 | TKN | 0.34 | 0.31 | 52 | 11% |
| TCNS 233 | TPO4 | 0.54 | 0.00 | 12 | 22% |
| TCNS 233 | TPO4 | 0.54 | 0.00 | 24 | 15% |
| TCNS 233 | TPO4 | 0.54 | 0.00 | 52 | 10% |
| TCNS 249 | DO | 0.36 | 0.51 | 12 | 32% |
| TCNS 249 | DO | 0.36 | 0.51 | 24 | 25% |
| TCNS 249 | DO | 0.36 | 0.51 | 52 | 22% |
| TCNS 249 | TKN | 0.44 | 0.33 | 12 | 40% |
| TCNS 249 | TKN | 0.44 | 0.33 | 24 | 30% |
| TCNS 249 | TKN | 0.44 | 0.33 | 52 | 25% |
| TCNS 249 | TPO4 | 0.88 | 0.29 | 12 | 88% |
| TCNS 249 | TPO4 | 0.88 | 0.29 | 24 | 61% |
| TCNS 249 | TPO4 | 0.88 | 0.29 | 52 | 46% |

* Model assumptions may be violated

** Time series data may contain overly influential outliers

Kissimmee River Structures
Optimization Leader: Steve Rust, Battelle
Statistician: Steve Rust, Battelle

Project Code: V

Type: Type II

Mandate or Permit:

- Lake Okeechobee Protection Act (LOPA)
- Lake Okeechobee Operating Permit (LOOP)
- Surface Water Improvement and Management Act (SWIM)
- WRDA 2000
- Florida Watershed Restoration Act (TMDLs/MFLs/PLRGs)
- Safe Drinking Water Act
- Clean Water Act

Project Start Date: 1973

Division Manager: Okeechobee Division: Susan Gray

Program Manager: Brad Jones

Points of Contact: Steffany Gornak, Brad Jones, Patrick Davis

Field Point of Contact: Patrick Davis

Spatial Description

Sampling locations for Project V are located in Polk and Okeechobee counties along the Kissimmee River from Lake Kissimmee to Lake Okeechobee. Five locations are sampled as part of Project LKR. These 5 locations correspond to five of the seven autosampler locations sampled for project LKR. These stations include: S65 (the structure at the southern end of Lake Kissimmee where the lake drains into the Kissimmee River, the S65A structure, downstream of S65, the S65C structure, downstream of the confluence of the Kissimmee River with the Lake Istopoga Canal, S65D and S65E structures, downstream of S65C above the confluence of the Kissimmee River with the C41A canal.

Discussions with District staff familiar with the project mentioned that Station S65E overlaps with Project X. This station is considered Type I for Project X.

District staff also suggested the potential addition of a station. Flow is to be diverted to the structure S65DX. Eventually, the culvert will be removed from S65D and S65DX will take its place. Future monitoring may need to be conducted at the new structure (i.e., S65DX).

Project Purpose, Goals and Objectives

The primary purpose of Project V is to assess tributary and basin loading and concentration inputs to the Kissimmee River and Lake Okeechobee and to identify trends in total phosphorus and other water quality indicators over time. Specific objectives of the project are to:

- A. Assess inputs to Lake Okeechobee by:

1. Providing concentration measurements from inflows to Lake Okeechobee to compare with the 0.18 mg/l total phosphorus SWIM standard, and for use in basin loading calculations.
 2. Providing concentration measurements that will help evaluate the efficacy of the Kissimmee River restoration project.
 3. Providing data to evaluate compliance with Lake Okeechobee Total Maximum Daily Loads (TMDL).
- B. Develop basin and spatial scale models to predict changes in loads to Lake Okeechobee as a function of land use by:
1. Providing data for determining statistical or mechanistic relationships between rainfall, land use (or land type), and nutrient runoff.
 2. Providing data to help identify the reason for high episodic phosphorus events.

Sampling Frequency and Parameters Sampled

Samples are collected on a bi-weekly basis via grab samples at five stations: S65, S65A, S65C, S65D and S65E. All five stations are on the Kissimmee River. The collected samples are analyzed for TPO4 concentration. In addition the samples are analyzed for DO, PH, H2OT, SCOND, CHLA, CHLA2, PHAEO, COLOR, TSS, TURB, ALKA, TOC, DOC, NH4, TKN, NO2, NOX, OPO4, SIO2, SO4, CL. On a quarterly basis, samples are analyzed for CA, K, MG, and NA. The relevance of the five stations is described below.

- S65 – located at the southern end of Lake Kissimmee where it drains into the Kissimmee River
- S65A – located on the Kissimmee River south of station S65 at southern end of drainage basin S65A
- S65C – located on the Kissimmee River south of station S65A at southern end of drainage basin S65C; also south of the confluence of the Lake Istokpoga Canal and the Kissimmee River
- S65D – located on the Kissimmee River south of station S65C at southern end of drainage basin S65D
- S65E – located on the Kissimmee River south of station S65D at southern end of drainage basin S65E; also just north of the confluence of the C41A Canal with the Kissimmee River

Structure S65D is scheduled to be replaced by a new S65DX structure. When flow is diverted, sampling at the new structure may be appropriate.

While station S65E is considered a Type I station for Project X, all five stations monitored for project V are considered to be Type II stations.

Station locations are illustrated on the map in Figure 1. Sampling frequencies for V station-parameter combinations are reported in Table 2.

Each of the five stations is representative of a geographical domain as indicated in the table below.

Table 1. Geographical Domain of Monitoring Stations

| Station | Geographical Domain |
|-----------------|-------------------------------|
| S65 | Lake Kissimmee |
| S65A minus S65 | S65A Drainage Basin |
| S65C minus S65A | S65B and S65C Drainage Basins |
| S65D minus S65C | S65D Drainage Basin |
| S65E minus S65D | S65E Drainage Basin |

Project LKR has been monitoring TPO4 in grab samples during CY2004 at S191, S65, S65A, S65C, and S65D. Since this data is not part of the current monitoring plan, it has been ignored.

Project LKR monitors TPO4 in time proportional autosamples collected at all five V stations on a weekly basis.

Project X monitors TPO4 in grab samples collected at stations S154, S191 and S65E. Over the past 13 years samples have been collected at the following average rates: S154 (~40 per year), S191 (~45 per year), and S65E (~8 per year).

Current and Future Data Uses

Like the LKR data, the V data are used in several District reports including the South Florida Environmental Report, and all reports pertaining to the Kissimmee River Restoration. The Lake Okeechobee watershed modeling activities (CREAMS and FHANTM models) may also use this information. In the future, this data will be used for TMDL development in cooperation with DEP. Additionally, The CERP RECOVER Monitoring and Assessment Plan may use the S65E site from Project X which is also sampled for Project V as a long-term monitoring station.

Optimization Analyses

Perhaps the most significant water quality monitoring objective that motivates V monitoring is detection of an increasing or decreasing trend in TPO4 concentrations over time. The Lake Okeechobee Protection Plan (LOPP) calls for a 70% reduction in the TPO4 load to Lake Okeechobee by 2015 and a near-shore TPO4 concentration of less than 40 ppb ($\mu\text{g/L}$). The LOPP also specifies construction projects, management projects, and a myriad of best management practices that are designed to achieve these TPO4 goals. Over the next decade, the District will use its V monitoring data and statistical trend analysis procedures to assess the effectiveness of LOPP implementation toward meeting the 2015 TPO4 goals.

A key question related to the V monitoring project is whether or not the monitoring data collected will be sufficient to assess the effectiveness of projects and practices implemented to control and improve water quality and determine whether or not sufficient progress is being made toward water quality goals and objectives. One way to address this question is to perform statistical power analyses to determine the smallest water quality trends that will be detectable with high probability based on water quality data collected according to current monitoring plans. Using the resulting detectable trends, District staff will be able to determine whether the trends necessary to achieve long-term goals will be discernable from trends that fail to achieve the long-term goals. The same statistical power analysis procedures can be used to identify detectable water quality trends for alternatives to the current monitoring design. With power analysis results for both the current and alternative monitoring designs in hand, District staff will be able to optimize the V monitoring design for achievement of long-term goals and objectives.

Optimization Analysis Procedures

Six primary parameters were selected for which to perform V optimization analyses. They are DO, TURB, TKN, TPO4, CL, and CHLA2 with DBHYDRO codes 8, 12, 21, 25, 32 and 112, respectively. Power analyses for each station-parameter combination were performed by carrying out the following power analysis steps:

- Fit a statistical model to the water quality parameter data in order to have a basis for generating simulated data to support a Monte Carlo based power analysis procedure
- Generate multiple replicate simulated water quality time series data sets; for all power analyses reported here, each time series generated was for a 5-year monitoring period
- Perform a Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) for each simulated time series data set; in particular, obtain a point estimate of the slope vs. time for the log-transformed water quality parameter values
- Estimate the *annual proportion change* (APC) in water quality parameter values that is detectable with 80% power using a simple two-sided test based on the Seasonal Kendall's Tau slope estimate performed at a 5% significance level

Parameter values were natural log-transformed for statistical modeling because the log-transformed data was more nearly normally distributed than were the untransformed data. The fitted statistical model contains the following components:

- Fixed seasonal effects that repeat themselves in an annual cycle
- A long-term linear trend in the log-transformed parameter concentrations; this corresponds to a fixed percentage increase or decrease in the water quality parameter each year
- A random error term representing temporal variability in true water quality parameter values; these error terms are allowed to be correlated from one time point to the next in order to capture any serial autocorrelation that is present in the monitoring data
- A random error term representing sampling and chemical analysis variability; these error terms are assumed to be stochastically independent from one time point to the next

The fitted statistical model is used to perform a Monte Carlo simulation analysis in which multiple TPO4 time series data sets are simulated and used to determine the anticipated statistical properties of trend detection procedures that will be used by the District. All statistical trend analyses performed on the simulated data were based on the Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) preferred by the District.

In the course of performing the power analyses for the District, it was determined that the basic Seasonal Kendall's Tau trend detection procedures do not necessarily control the true significance level of the hypothesis test for trend when there is serial autocorrelation exhibited in the data. This was found to be true even for procedures that attempt to correct for serial autocorrelation. For this reason, all power analysis results reported here are for a simple hypothesis test procedure based on the median slope estimator that accompanies the Seasonal Kendall's Tau test procedure.

The median slope estimator is assumed to follow a normal distribution and power results are obtained by performing a simple z-test with this estimator.

Power analyses were performed for each of 30 station-parameter combinations. For each combination, an attempt was made to simulate the following three monitoring designs:

- The current monitoring frequency of bi-weekly samples (24 samples per year)
- An alternative reduced sampling design of monthly samples (12 samples per year)
- A second alternative increased sampling design of weekly samples (52 samples per year)

In total, 90 station-parameter-design combinations were explored. For each station-parameter-design combination analyzed, an estimate was obtained of the minimum annual percentage change (APC) in parameter value that is detectable with 80% power using the median slope estimator z-test procedure performed at a two-sided significance level of 0.05.

Analysis of the data from DBHYDRO indicates that it was sometimes not possible to obtain one of the weekly autosamples called for by the current monitoring design. By analyzing TPO4 records from DBHYDRO along with “No Bottle Sample” records, it was possible to estimate the proportion of attempted sampling occasions for which no sample was obtained. This procedure was carried out for sampling dates during the period from January 1, 2000 through September 30, 2004 in order to estimate the proportion of the time that no sample was obtained. In the Monte Carlo procedure used to generate simulated monitoring data, sampling results were set equal to missing values with probability equal to the proportion of “No Bottle Samples”.

Rust (2005) describes the power analysis procedure and underlying statistical model employed here in detail. Rust (2005) also documents the SAS program used to carry out the power analyses for which results are reported here.

Optimization Analysis Results

Appendix A contains a figure corresponding to each of the time series data sets for which power analyses were performed. For the V project, that is 30 station-parameter combinations. Table A-1 contains a row identifying each of the 30 figures in Appendix A. The last three columns of Table A-1 identify the following:

- The number of samples per year called for in the current monitoring plan
- The number of seasons assumed in the mixed model fitted to the data and used to simulate monitoring data
- The proportion of “No Bottle Samples” during the period January 1, 2000 through September 30, 2004 which was used as a probability for generating missing data when the Monte Carlo simulation was performed

Each figure in Appendix A displays the actual water quality parameter time series for an individual station as black dots connected by black lines. The plotted values are the natural logarithm of water quality parameter values. The fixed portion of the fitted mixed model is illustrated as a red curve. As illustrated in the figures in Appendix A, data sets for all parameters but CHLA2 go back as far as early 1992 and the CHLA2 data sets go back as far as early 1996.

A summary of the power analysis results are reported in Table B-1. Table B-1 contains a row for each of the 90 power analyses performed, three power analyses per station-parameter combination. A power analysis was performed for the current sampling frequency. In addition, alternative monitoring designs calling for sampling at half the current rate and double the current rate were also investigated.

For each station, the standard deviation of the monitoring data about the fitted fixed effects model and the correlation coefficient for two measurements taken exactly one month apart are reported. These two quantities are key drivers of the power analysis results. In addition, the number of samples per year simulated and the detectable annual percentage change for that monitoring scenario are reported in the last two columns of Table B-1.

The detectable annual percentage change (detectable APC) is the minimum true percentage change per year that would be consistently detected by the test for trend based on the median slope estimator that accompanies the Seasonal Kendall's Tau procedure. Consistently detected means that the null hypothesis of no trend would be rejected 80% of the time.

The detectable APC results reported in Table B-1 are illustrated graphically in Figures 2-7, one figure for each of the four parameters examined. The following conclusions related to TPO4 concentrations may be drawn from Figure 6 and the corresponding rows of Table B-1.

- Detectable APC value for station S65 is considerable larger than those for other V stations; this result is apparently due to the fact that this station exhibits the highest variability and the highest serial autocorrelation among the V stations
- Detectable APC values for stations other than S65 at the current monitoring frequency of 24 samples per year are in the range of 12%-15%
- The effect of reduced sampling frequencies on detectable APC values is much smaller than would be expected for independent time series data; if the monitoring data exhibited no serial autocorrelation, one would expect an increase in the sampling frequency to 52 samples per year to cause the detectable APC to decrease by a multiplicative factor of 1.4; in this case, the detectable APC values decrease by a multiplicative factor less than 1.1 for all V stations; the smaller effect associated with sample frequency reduction is due the significant autocorrelation exhibited in the TPO4 time series data

The following conclusions related to CHLA2, CL, DO, TKN, and TURB water quality values may be drawn from Figures 2-5 and 7 and the corresponding rows of Table B-1.

- CHLA2: Station S65 has a very small detectable APC values compared to the other V stations; for other stations, current sampling frequencies result in detectable APC values in the range 26%-34%; changing the sampling frequency has a moderate effect on detectable APC values since the V stations exhibit moderate levels of serial autocorrelation in CHLA2 values
- CL: Station S65 has a large detectable APC values compared to the other V stations; for other stations, current sampling frequencies result in detectable APC values in the range 11%-15%; changing the sampling frequency has little effect on detectable APC values since the V stations exhibit high levels of serial autocorrelation in CL values

- DO: Current sampling frequencies result in detectable APC values in the range 8%-17%; changing the sampling frequency has a moderate effect on detectable APC values since the V stations exhibit moderate levels of serial autocorrelation in DO values
- TKN: Current sampling frequencies result in detectable APC values in the range 6%-9%; changing the sampling frequency has a moderate effect on detectable APC values since the V stations exhibit moderate levels of serial autocorrelation in TKN values
- TURB: Current sampling frequencies result in detectable APC values in the range 20%-43%; changing the sampling frequency has little effect on detectable APC values since the V stations exhibit high levels of serial autocorrelation in TURB values

Recommendations for Current Monitoring Plans

A 70% reduction in TPO4 loads to Lake Okeechobee, if accomplished smoothly over the next decade, would require an 11.3% reduction in phosphorus load each year. In annual percentage change terminology that translates to a APC of 12.7%. For the purposes of evaluating the current and alternative monitoring designs for which power analysis results were generated, it seems reasonable to expect a design to have a detectable APC of 12.7% or smaller. If this requirement is satisfied by a monitoring design, then a smooth 11.3% annual reduction in TPO4 concentrations over a 5-year monitoring period would have an 80% chance of being declared a statistically significant trend.

Requiring a detectable APC of 12.7% is not a very restrictive requirement. Stated another way, the absolute error in estimating the annual percentage change in TPO4 concentrations would be on the order of 7.5%. If there was no change in the average TPO4 concentration over a 5-year monitoring period (observed annual percentage change of 0%), then a 95% confidence interval for the true annual percentage change in TPO4 concentrations would be (-8.1%, +8.8%). Projecting the uncertainty in the annual percentage change over a 10-year time period, the 95% confidence interval for the percentage change over a 10-year time period would be (-57%, +132%). Therefore, a detectable APC of 12.7% still leaves the district in a position of some considerable uncertainty regarding 10-year trends in TPO4 concentrations.

The following recommendations are made regarding the monitoring plans for V monitoring stations:

1. Regarding detectable APC values for TPO4
 - A. Four V stations (S65A, S65C, S65D, S65E) have detectable near the target value of 12.7% and no changes are recommended for these stations; because increased sampling frequency has little effect on detectable APC values, no changes are recommended for these stations
 - B. Stations S65 fails to come near the detectable APC target value of 12.7% but also does not exhibit benefits from an increased sampling frequency due to high serial autocorrelation; because there does not seem to be a simple monitoring change that will result in achievement of the target detectable APC at these stations, it is recommended that the District

- Investigate alternative more sophisticated methods for analyzing the TPO4 concentration data in an attempt to better explain the systematic variations over time and produce more precise estimates of trend, and/or
2. Detectable APC values for TKN concentrations are better than those for TPO4; therefore, it is concluded that any monitoring plan that produces precise enough estimates of TPO4 trends will at the same time produce adequate estimates of TKN trends, allowing precise estimates of trends in TPO4 to TKN ratios to be determined as well; therefore, separate optimization recommendations for TKN will not be required
 3. Detectable APC values for DO and CL at all but station S65 are good for the V stations; no recommendations for monitoring changes are motivated by the DO and CL parameters
 4. Detectable APC values for CHLA2 and TURB (and CL at station S65) are not very good; it is recommended that the District assess the importance of detecting trends in these parameters before considering monitoring changes motivated by the CHLA2 and TURB parameters
 5. It is recommended that the data sets with potential outliers be re-analyzed to produce robust power analysis results for these data sets; however, it is doubtful that such re-analyses would change the general recommendations just offered above.

References

Reckhow KH, Kepford K, and Hicks WW (1993). Methods for the Analysis of Lake Water Quality Trends. EPA 841-R-93-003.

Rust SW (2005). Power Analysis Procedure for Trend Detection with Accompanying SAS Software. Battelle Report to South Florida Water Management District, November 2005.

Table 2. Parameters Measured from Grab Samples and In Situ for Project V

| Station | DO | PH | TEMP | SCOND | CHLA | CHLA2 | PHAEO | COLOR | TSS | TURBI | ALKA | TORGC | DORC |
|---------|----|----|------|-------|------|-------|-------|-------|-----|-------|------|-------|------|
| S65 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| S65A | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| S65C | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| S65D | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |
| S65E | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw |

| Station | NH4 | TKN | NO2 | NOX | TPO4 | OPO4 | SIO2 | SO4 | CA | CL | K | MG | NA |
|---------|-----|-----|-----|-----|------|------|------|-----|----|----|-----|-----|-----|
| S65 | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | qrt | qrt | qrt |
| S65A | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | qrt | qrt | qrt |
| S65C | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | qrt | qrt | qrt |
| S65D | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | qrt | qrt | qrt |
| S65E | bw | bw | bw | bw | bw | bw | bw | bw | bw | bw | qrt | qrt | qrt |

bw = bi-weekly; qtr = quarterly; gray shading indicates a Type II station; No shading indicates a Type 1 station

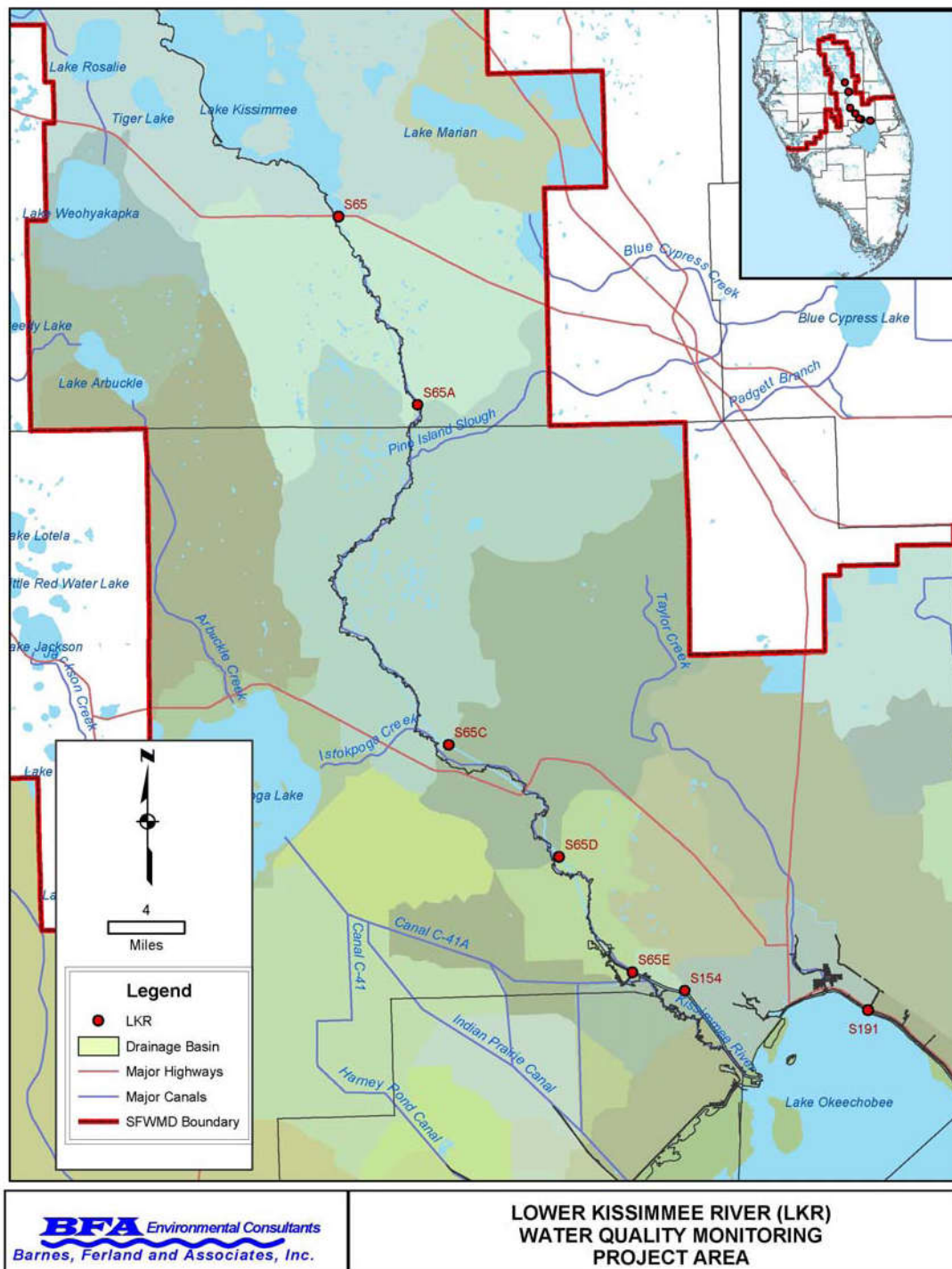


Figure 1. V Station Locations

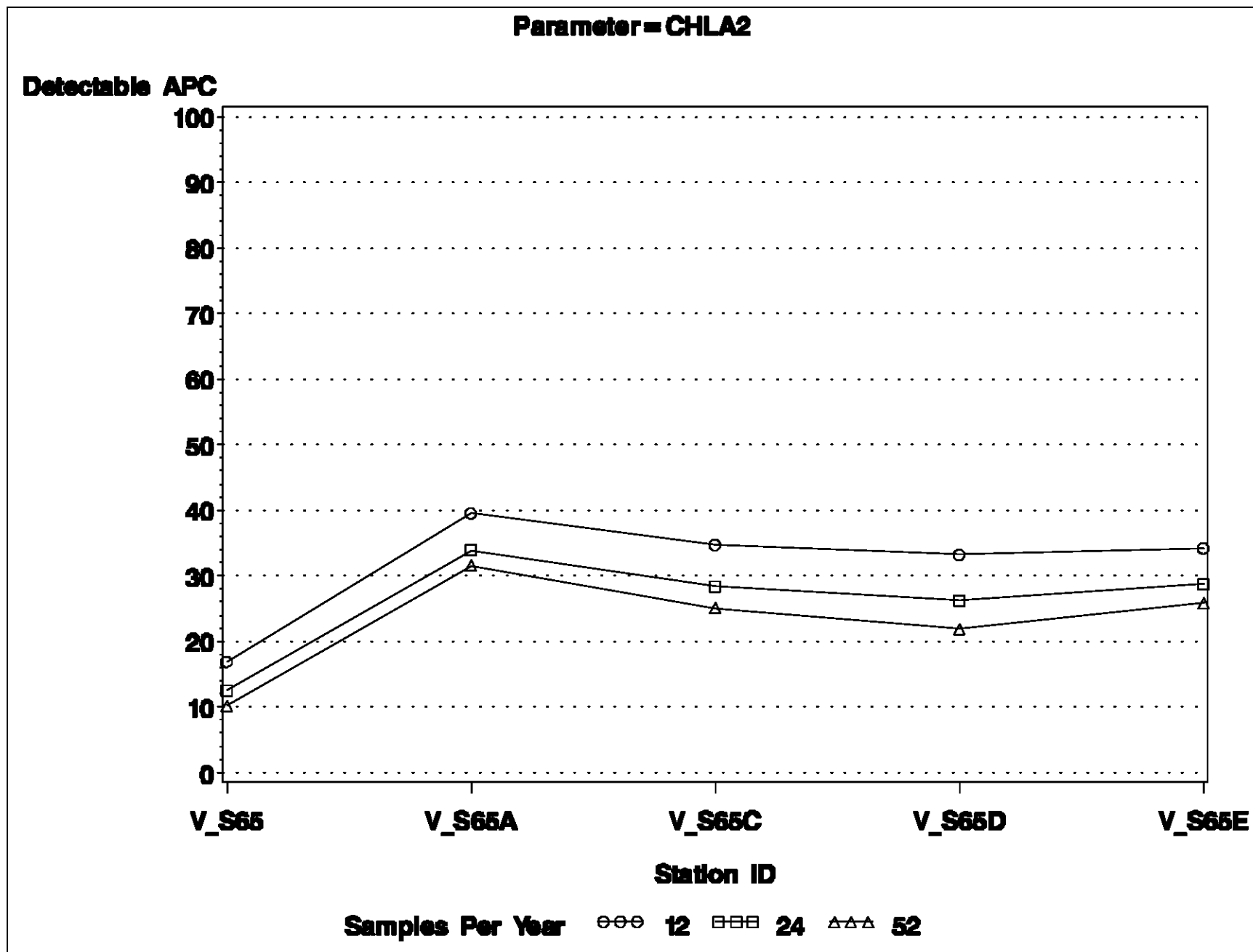


Figure 2

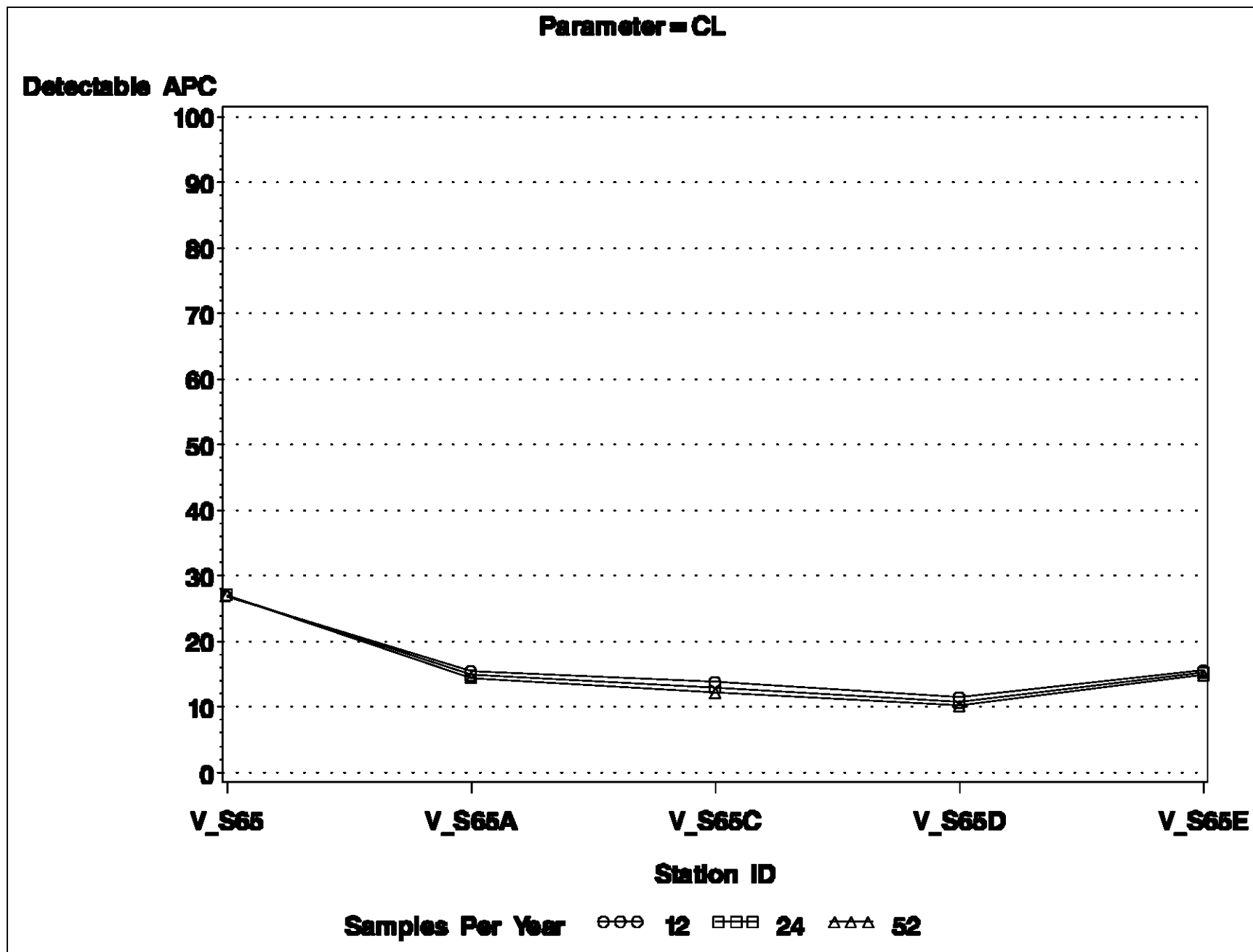


Figure 3

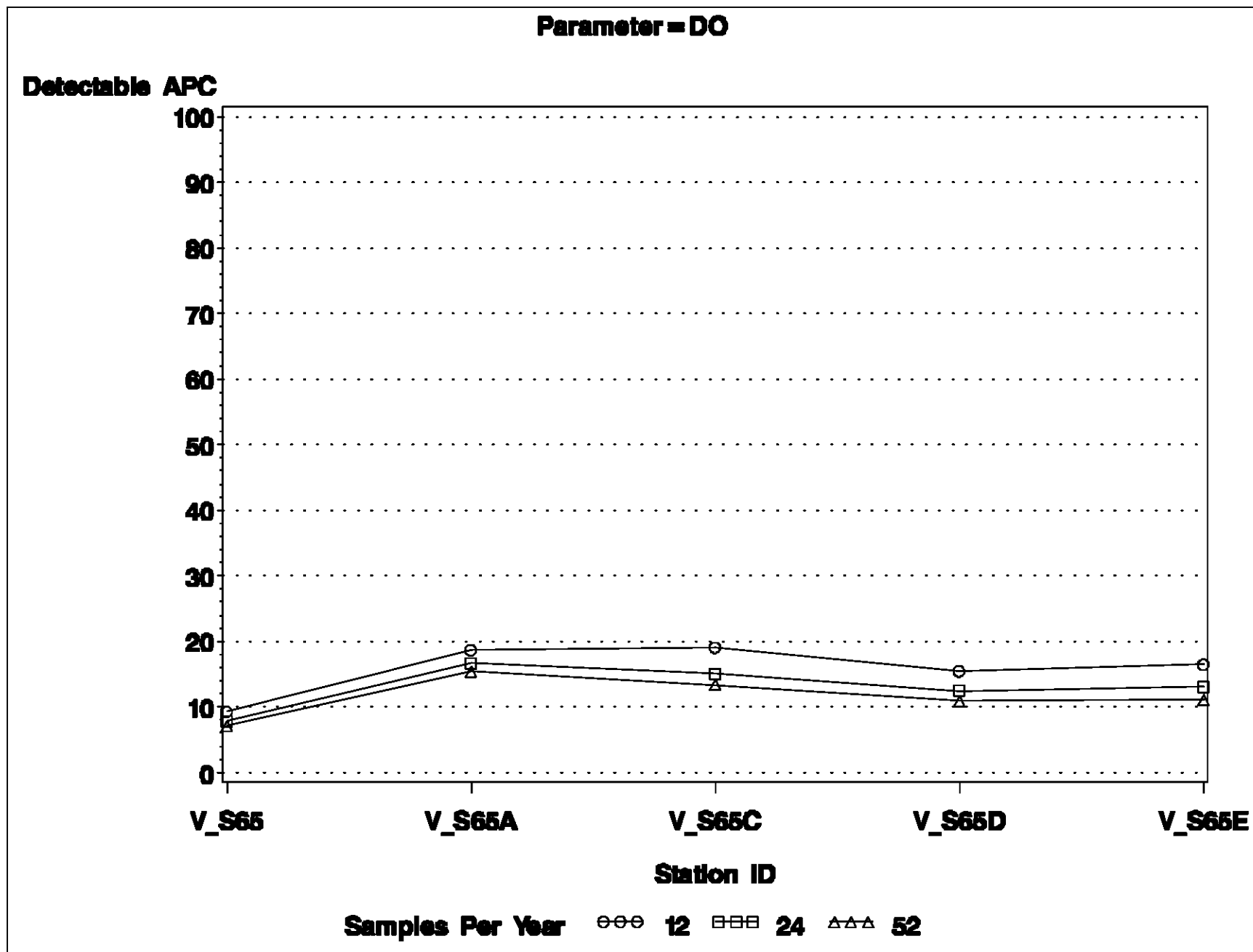


Figure 4

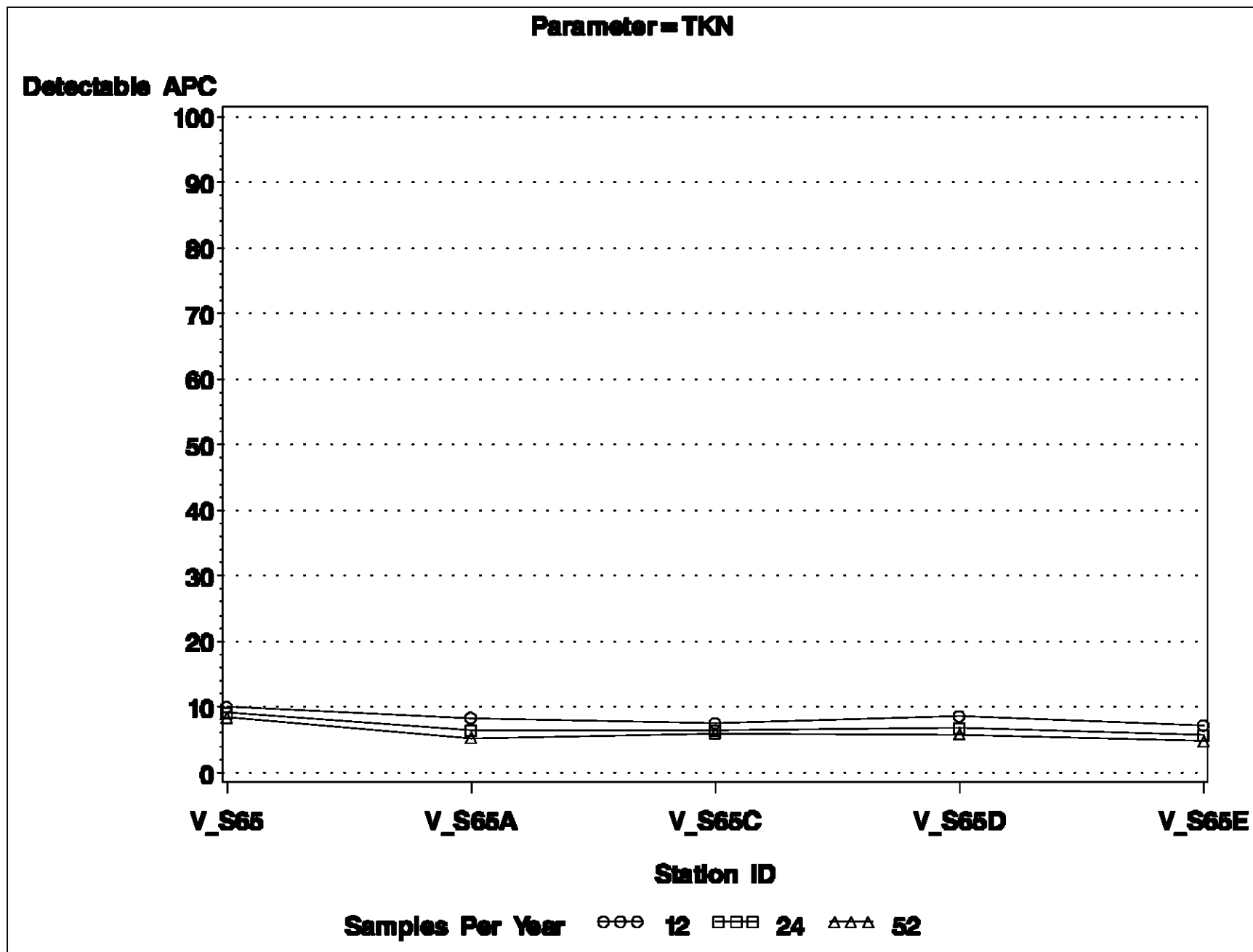


Figure 5

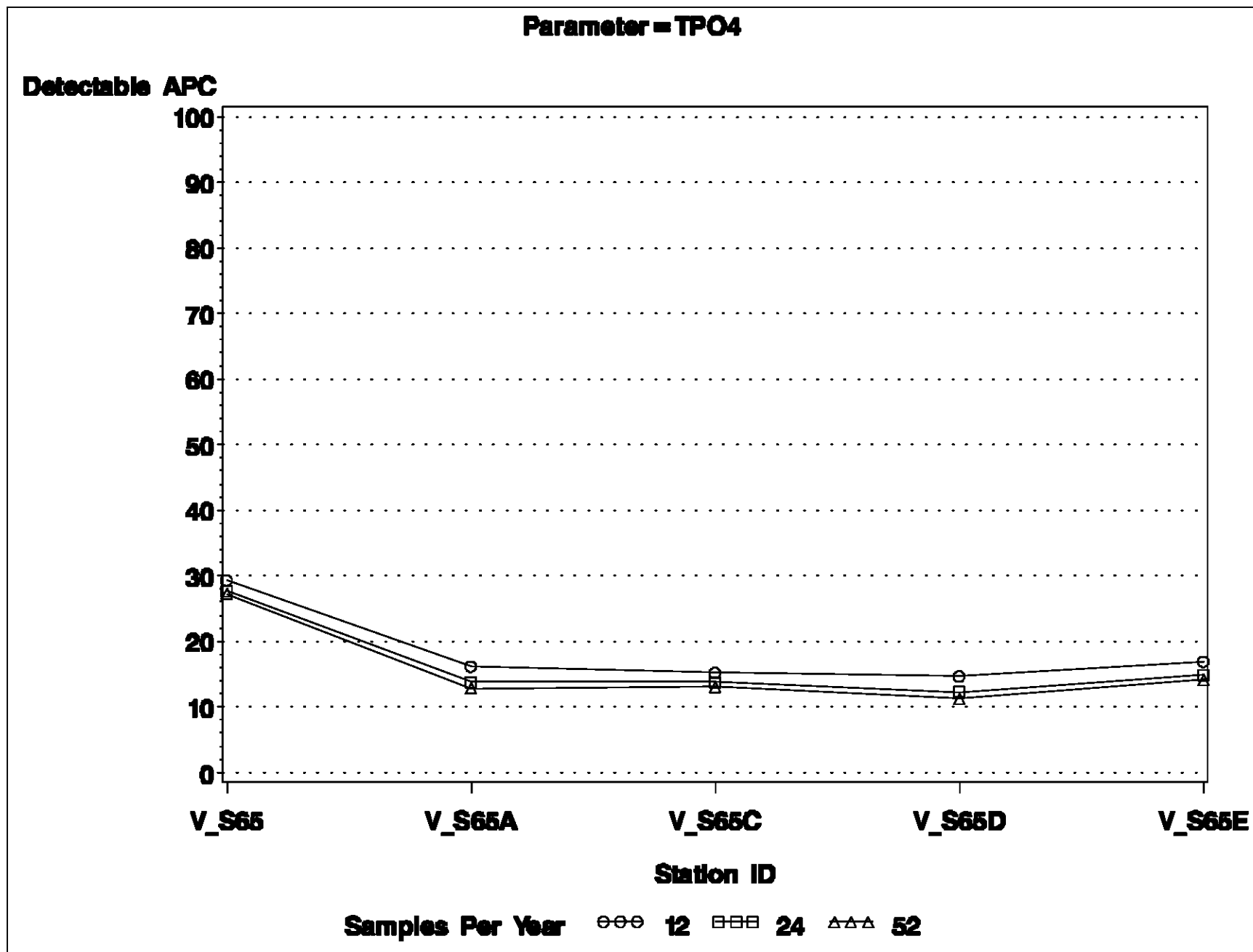


Figure 6

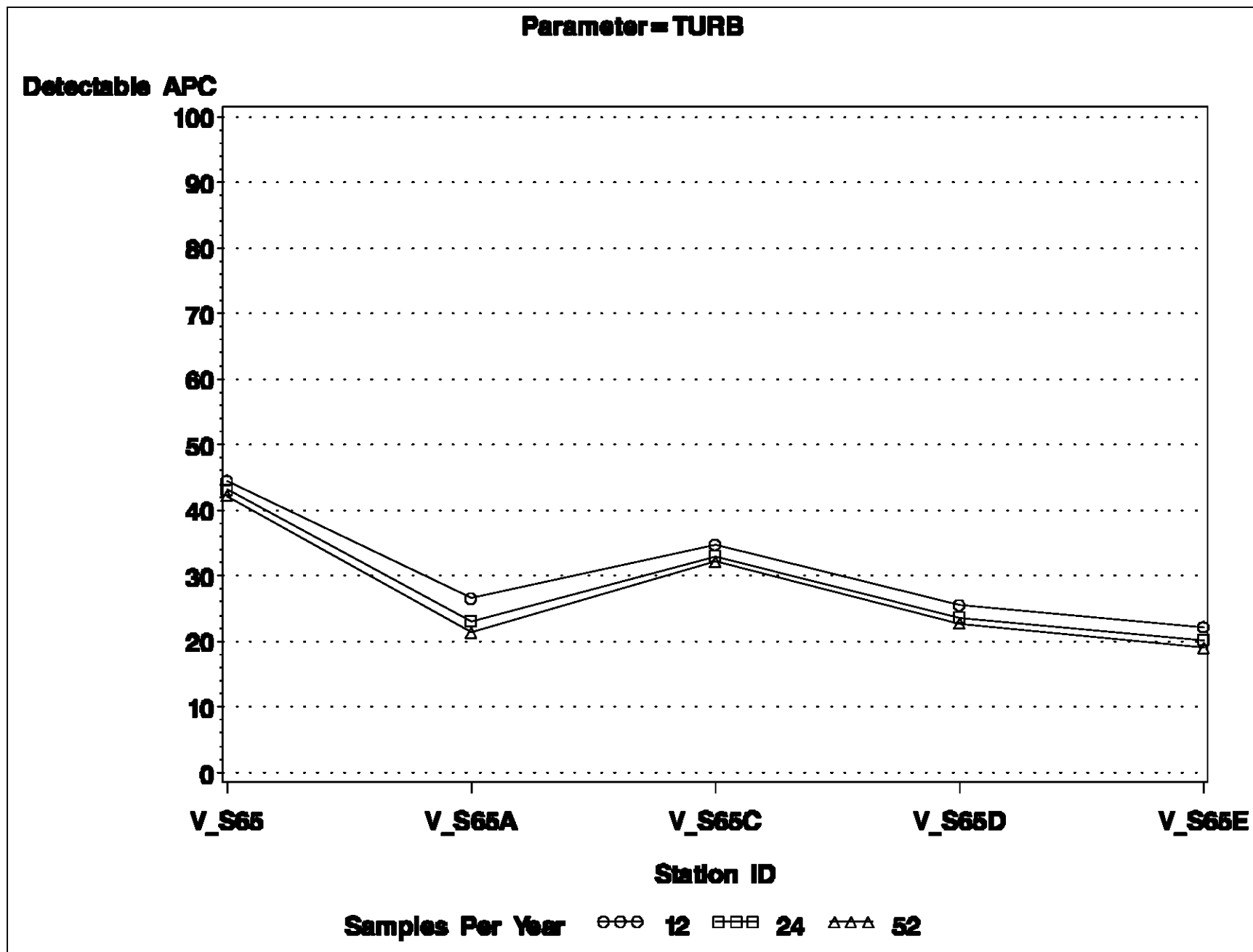


Figure 7

APPENDIX A

TIME SERIES PLOTS OF WATER QUALITY PARAMETERS OVERLAID WITH FITTED FIXED EFFECTS MODEL

| Figure Number | Station ID | Parameter | Current Number of Samples Per Year | Number of Seasons | Proportion of No Bottle Samples |
|---------------|------------|-----------|------------------------------------|-------------------|---------------------------------|
| 1 | V_S65 | DO | 24 | 24 | 0.01 |
| 2 | V_S65A | DO | 24 | 24 | 0.02 |
| 3 | V_S65C | DO | 24 | 24 | 0.00 |
| 4 | V_S65D | DO | 24 | 24 | 0.00 |
| 5 | V_S65E | DO | 24 | 24 | 0.00 |
| 6 | V_S65 | TURB | 24 | 24 | 0.01 |
| 7 | V_S65A | TURB | 24 | 24 | 0.02 |
| 8 | V_S65C | TURB | 24 | 24 | 0.00 |
| 9 | V_S65D | TURB | 24 | 24 | 0.00 |
| 10 | V_S65E | TURB | 24 | 24 | 0.00 |
| 11 | V_S65 | TKN | 24 | 24 | 0.01 |
| 12 | V_S65A | TKN | 24 | 24 | 0.02 |
| 13 | V_S65C | TKN | 24 | 24 | 0.00 |
| 14 | V_S65D | TKN | 24 | 24 | 0.00 |
| 15 | V_S65E | TKN | 24 | 24 | 0.00 |
| 16 | V_S65 | TPO4 | 24 | 24 | 0.01 |
| 17 | V_S65A | TPO4 | 24 | 24 | 0.02 |
| 18 | V_S65C | TPO4 | 24 | 24 | 0.00 |
| 19 | V_S65D | TPO4 | 24 | 24 | 0.00 |
| 20 | V_S65E | TPO4 | 24 | 24 | 0.00 |
| 21 | V_S65 | CL | 24 | 24 | 0.01 |
| 22 | V_S65A | CL | 24 | 24 | 0.02 |
| 23** | V_S65C | CL | 24 | 24 | 0.00 |
| 24** | V_S65D | CL | 24 | 24 | 0.00 |
| 25 | V_S65E | CL | 24 | 24 | 0.00 |
| 26 | V_S65 | CHLA2 | 24 | 24 | 0.01 |
| 27 | V_S65A | CHLA2 | 24 | 24 | 0.02 |
| 28 | V_S65C | CHLA2 | 24 | 24 | 0.00 |
| 29 | V_S65D | CHLA2 | 24 | 24 | 0.00 |
| 30 | V_S65E | CHLA2 | 24 | 24 | 0.00 |

** Time series data may contain overly influential outliers

Actual Data and Fitted Fixed Effects Model
Label=V_S65 DO

Ln(Value)

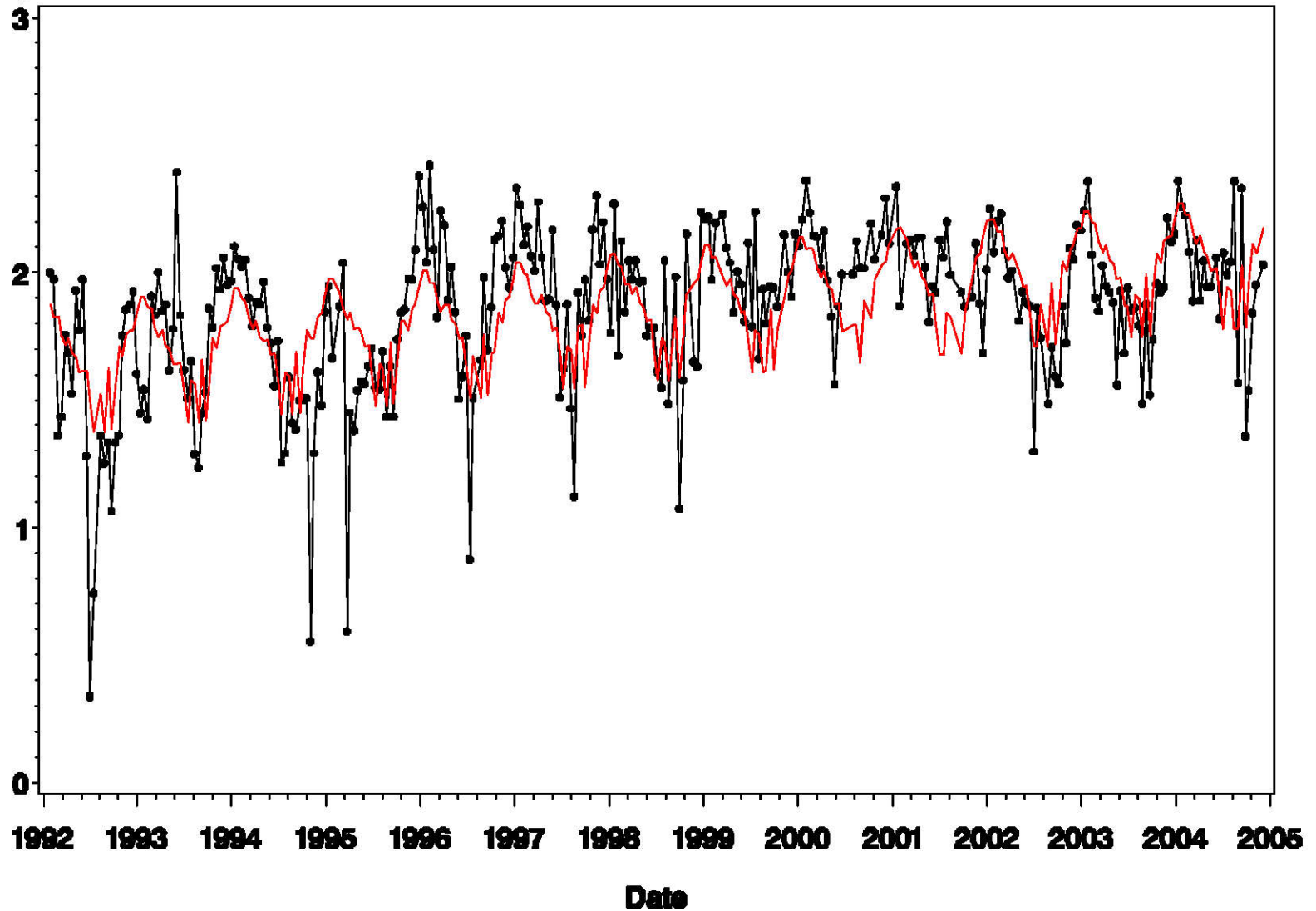


Figure A-1

Actual Data and Fitted Fixed Effects Model
Label=V_S65A DO

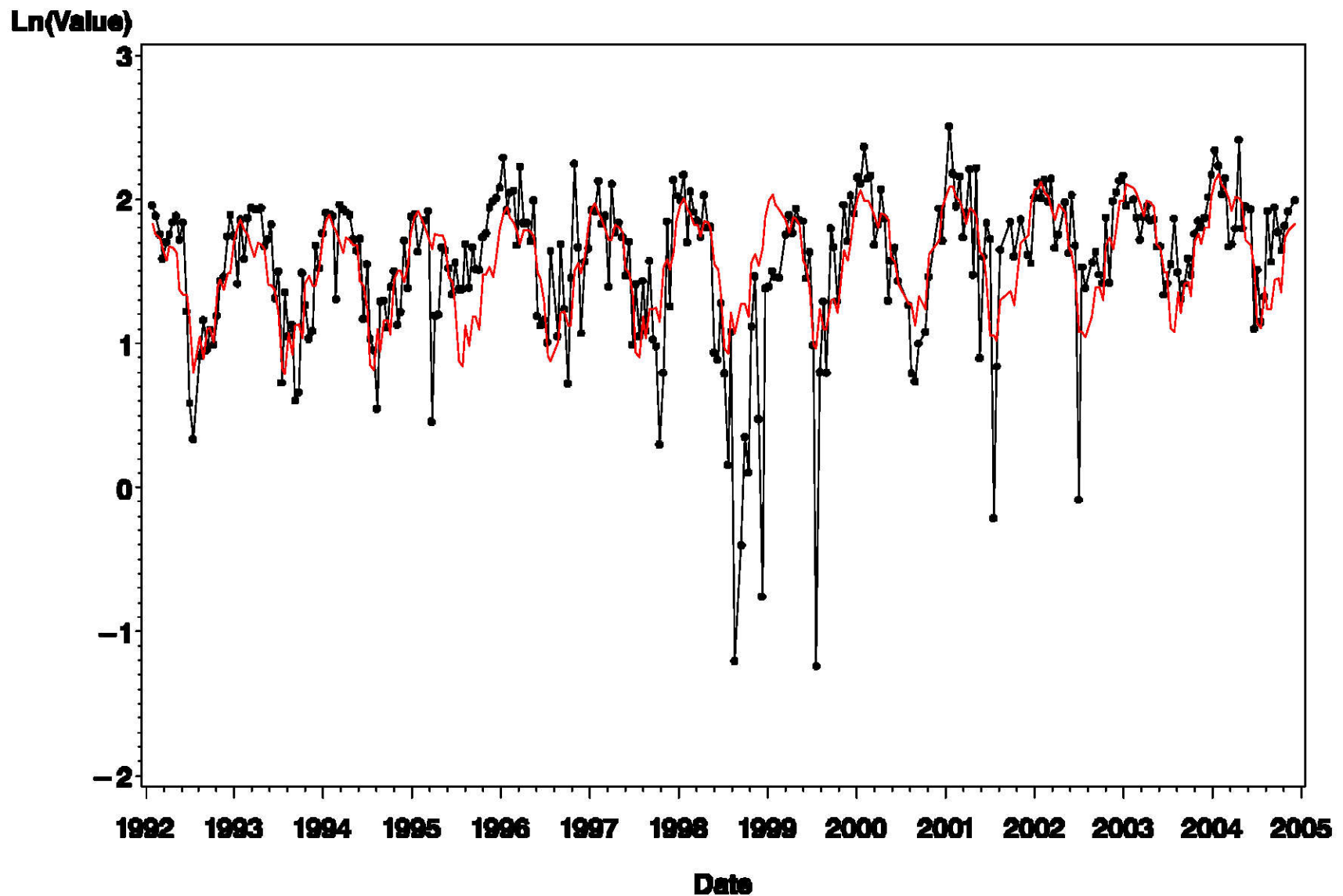


Figure A-2

Actual Data and Fitted Fixed Effects Model
Label=V_S65C DO

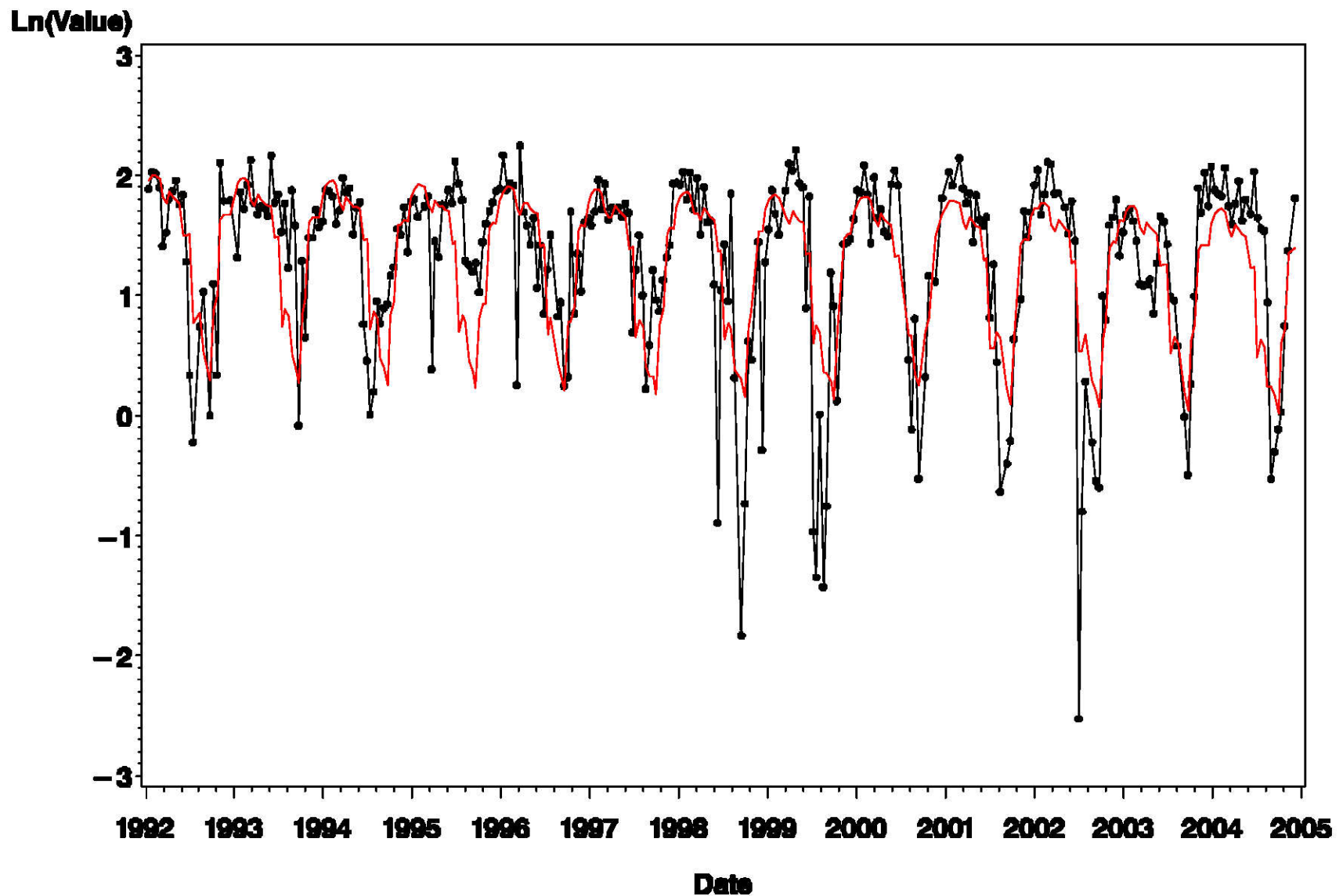


Figure A-3

Actual Data and Fitted Fixed Effects Model
Label=V_S65D DO

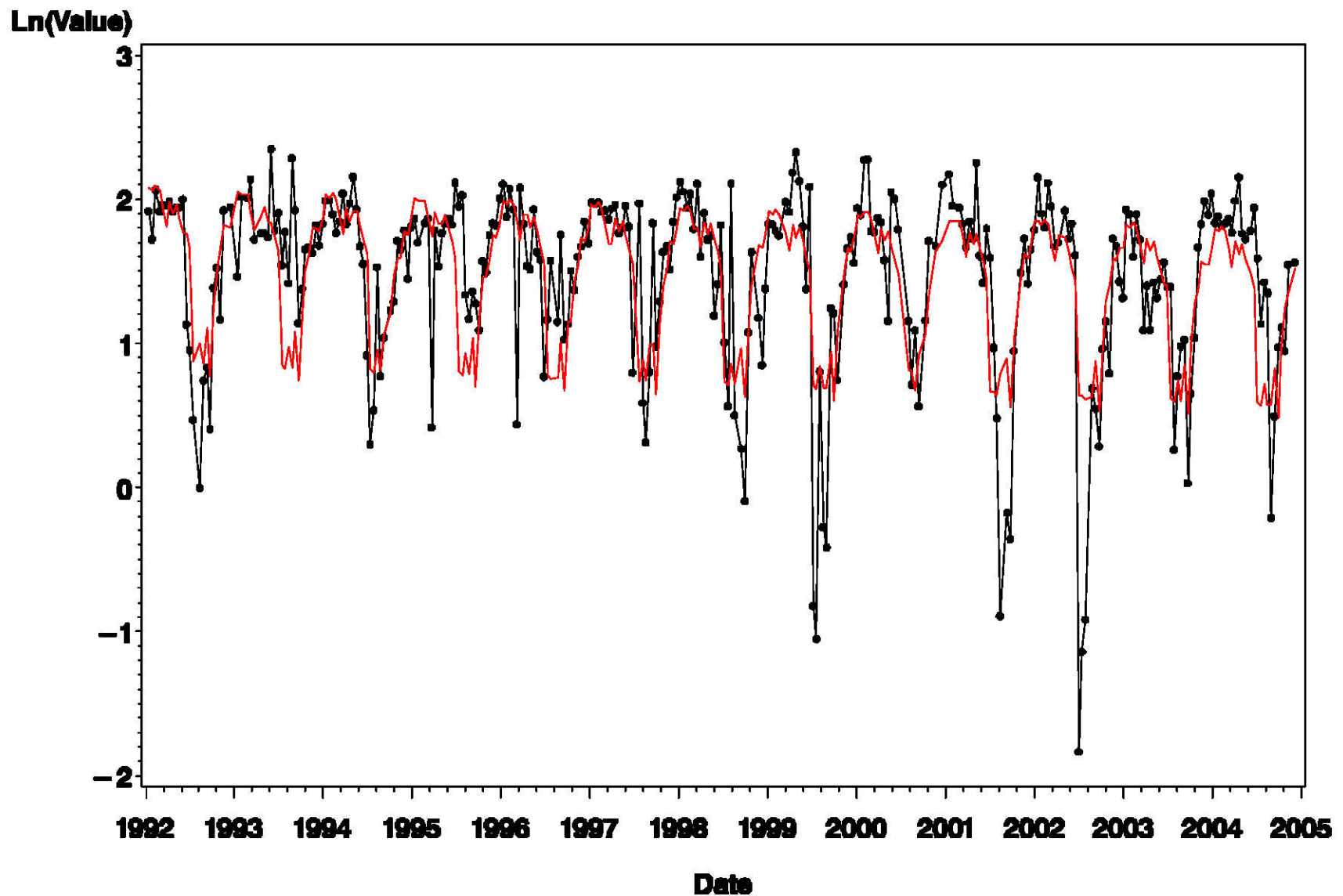


Figure A-4

Actual Data and Fitted Fixed Effects Model
Label=V_S65E DO

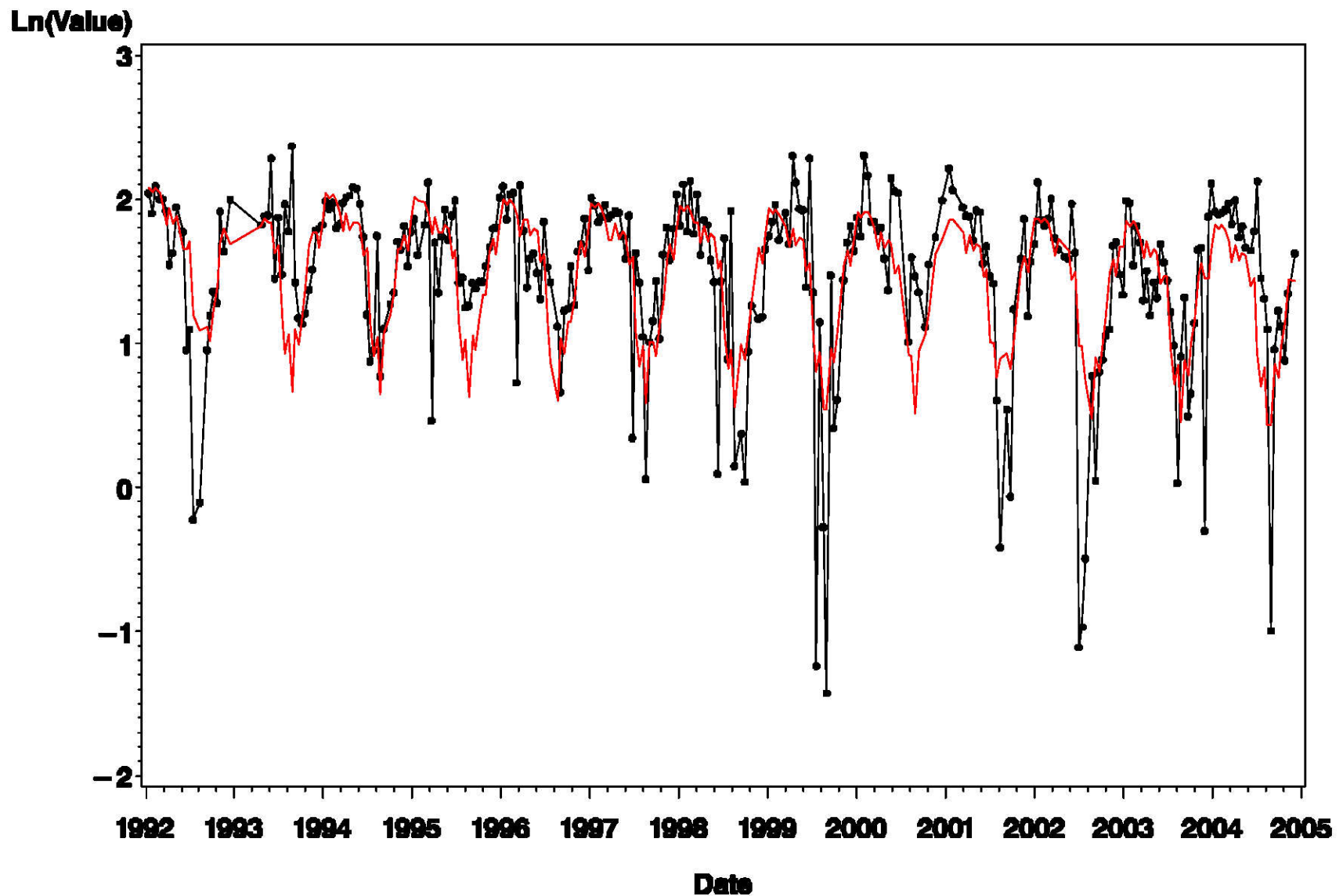


Figure A-5

Actual Data and Fitted Fixed Effects Model
Label=V_S65 TURB

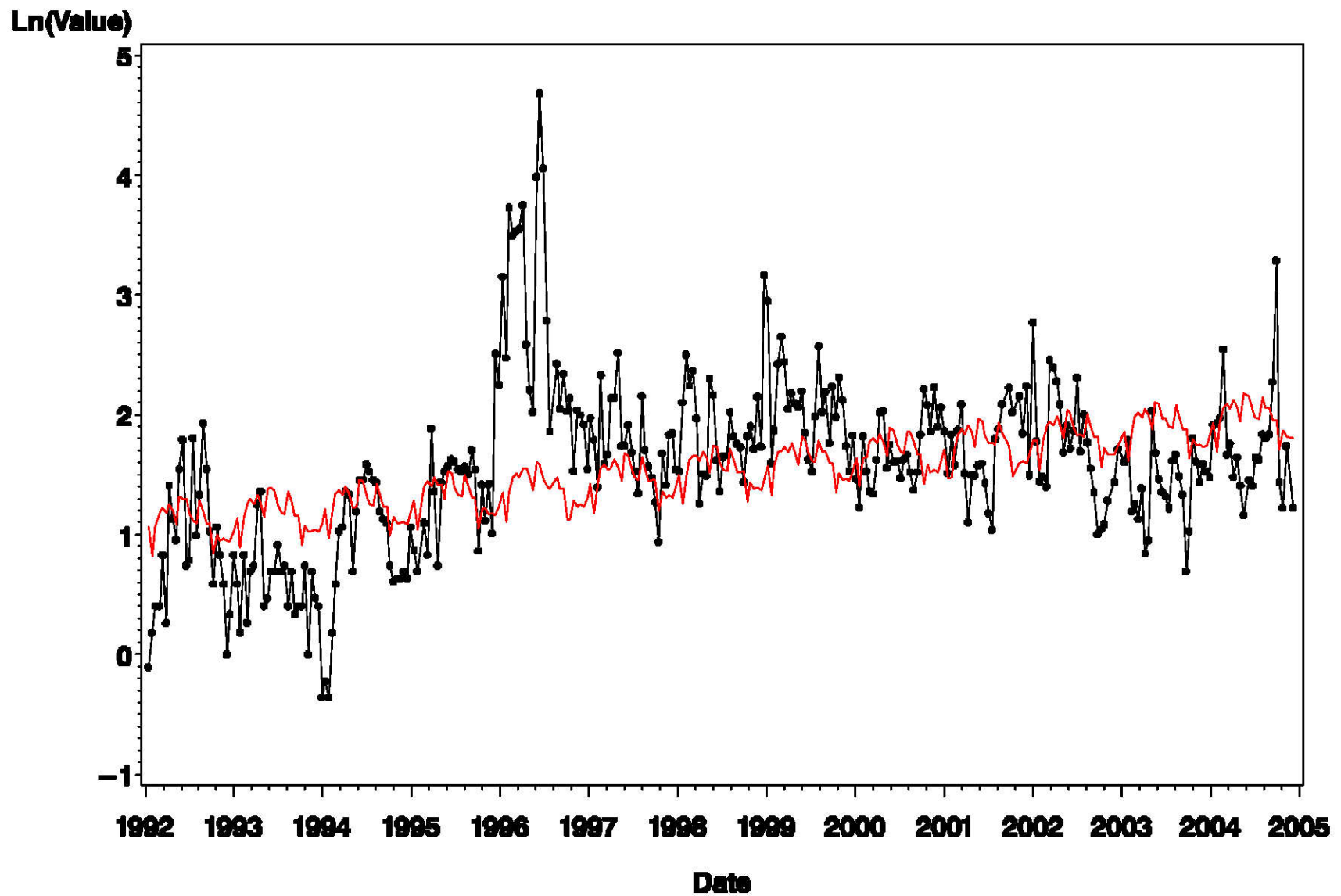


Figure A-6

Actual Data and Fitted Fixed Effects Model
Label=V_S65A TURB

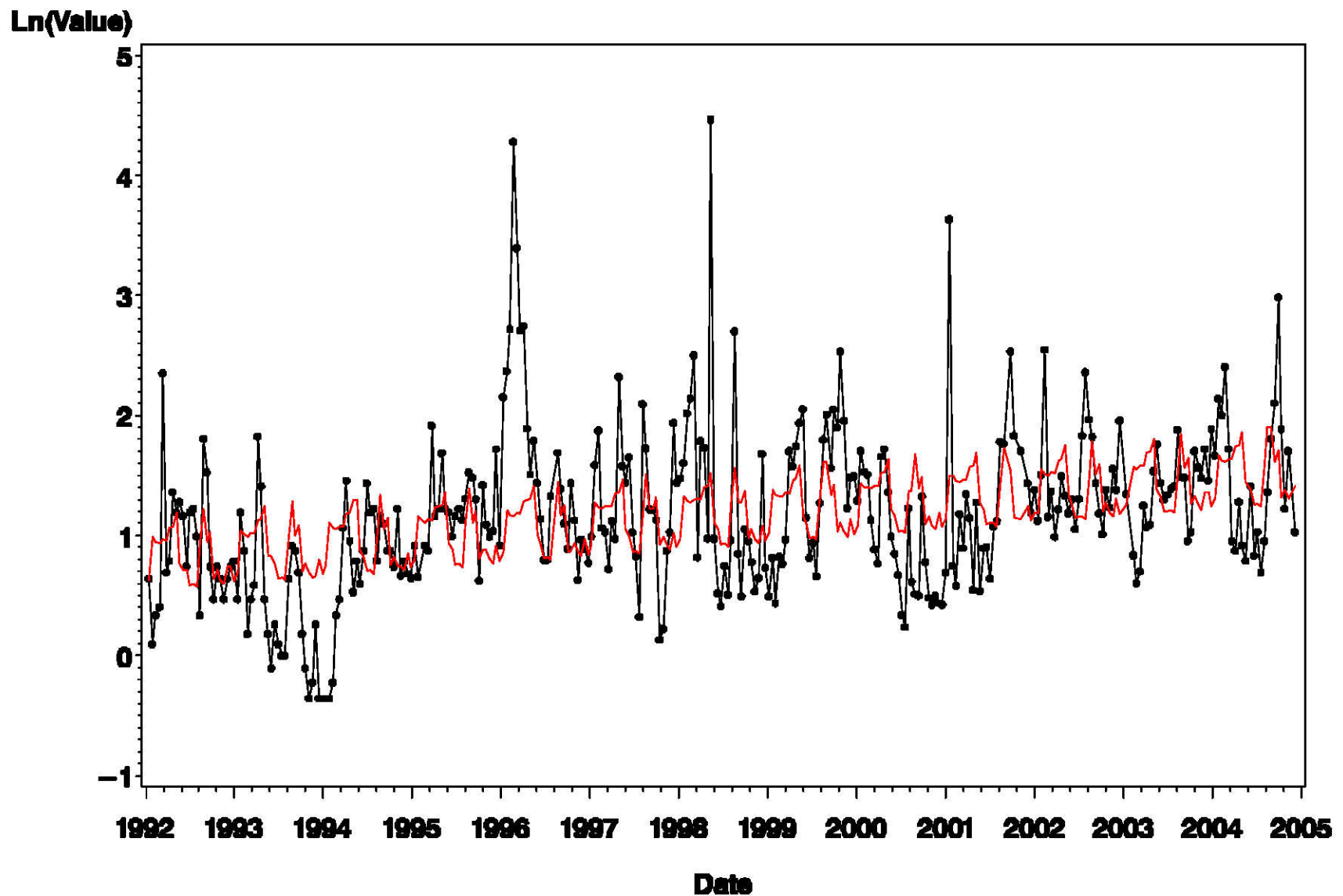


Figure A-7

Actual Data and Fitted Fixed Effects Model
Label=V_S65C TURB

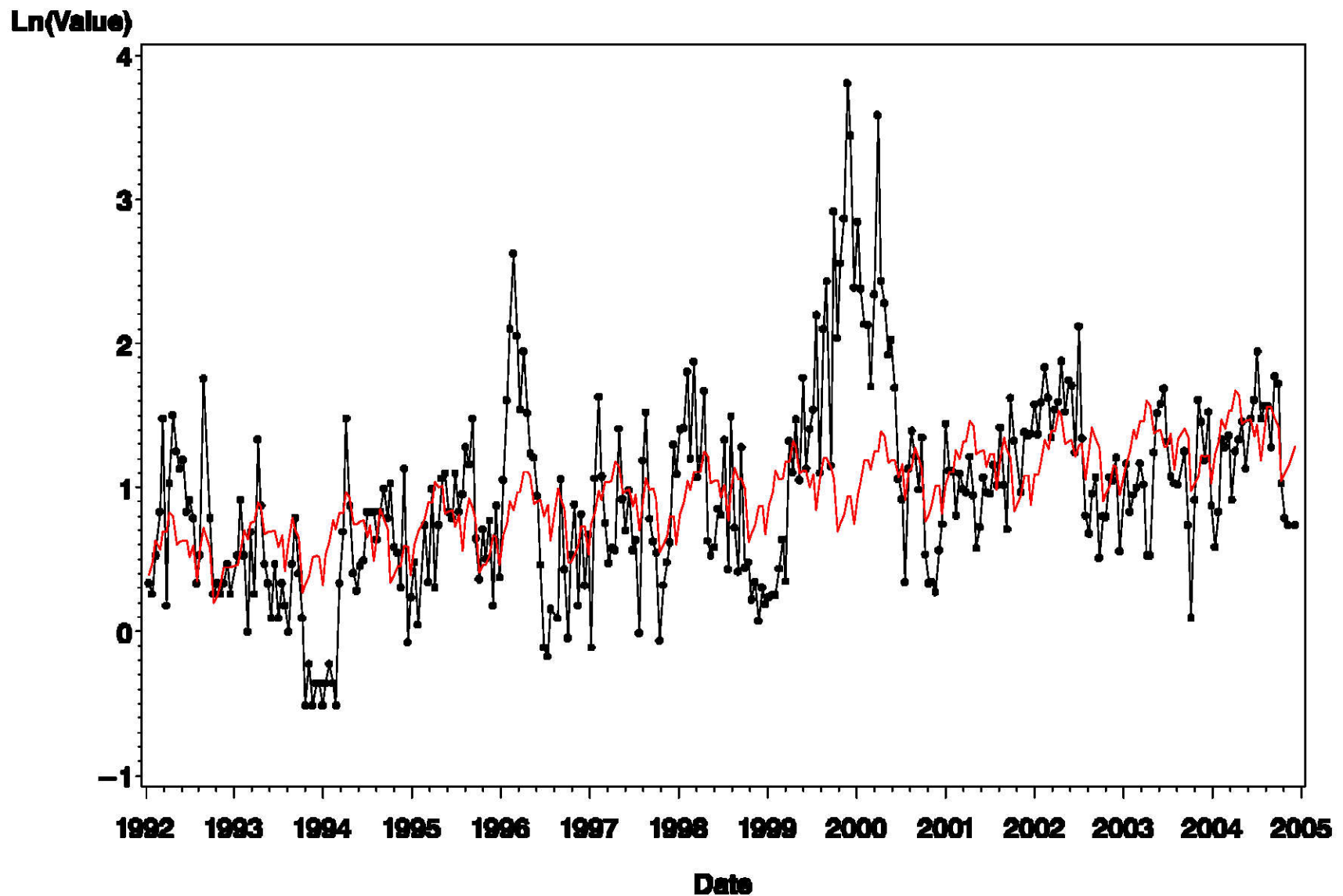


Figure A-8

Actual Data and Fitted Fixed Effects Model
Label=V_S65D TURB

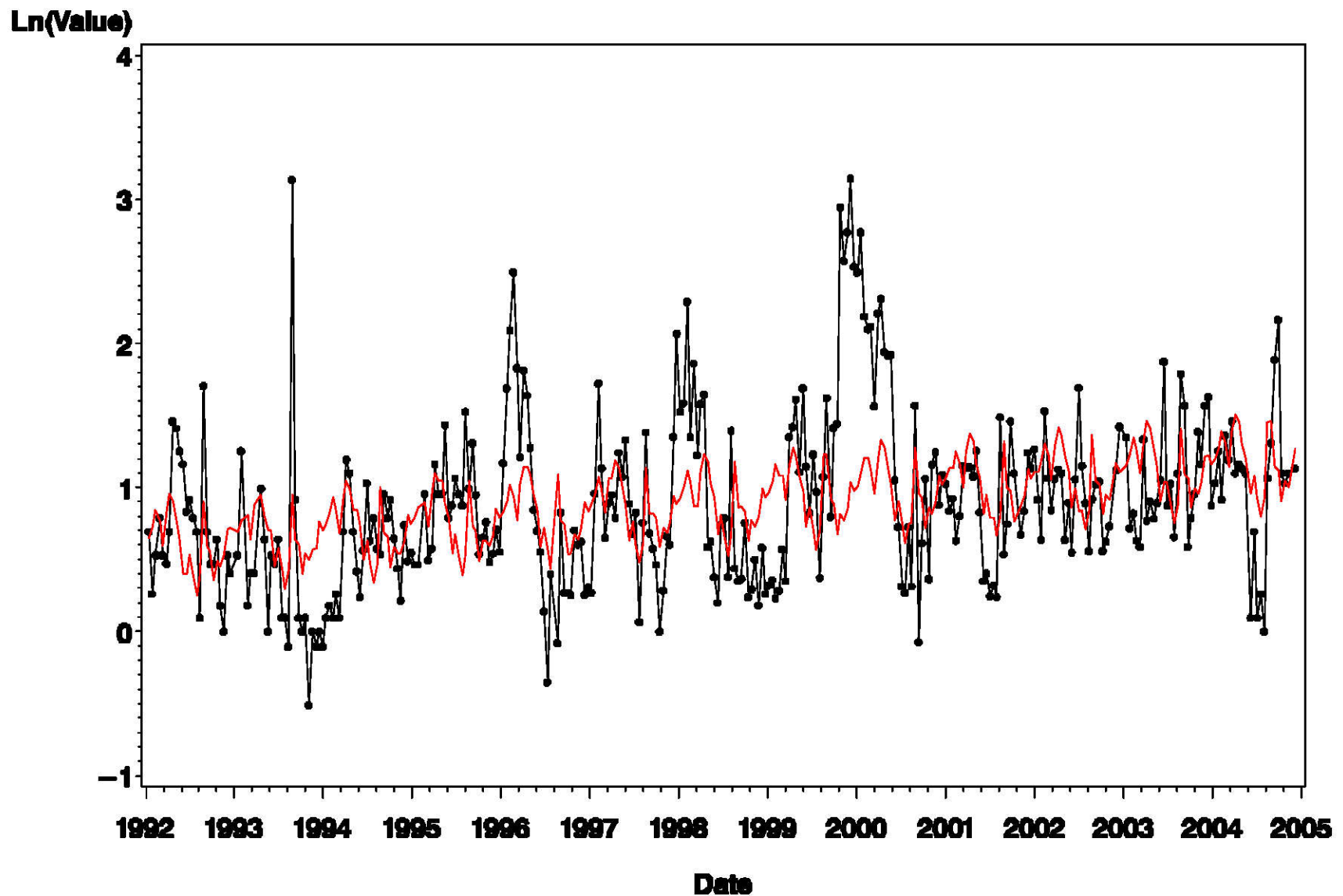


Figure A-9

Actual Data and Fitted Fixed Effects Model
Label=V_S65E TURB

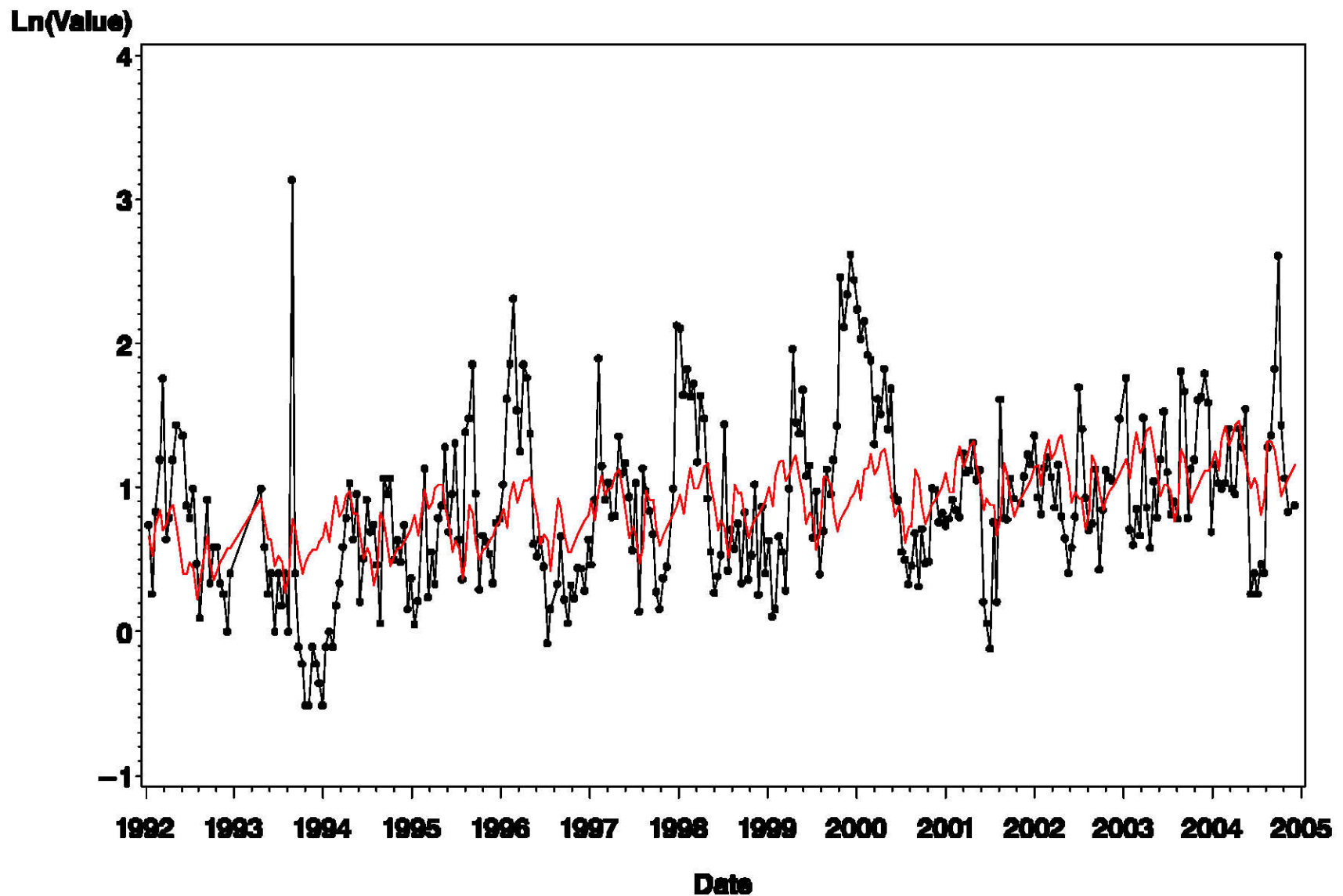


Figure A-10

Actual Data and Fitted Fixed Effects Model
Label = V_S65 TKN

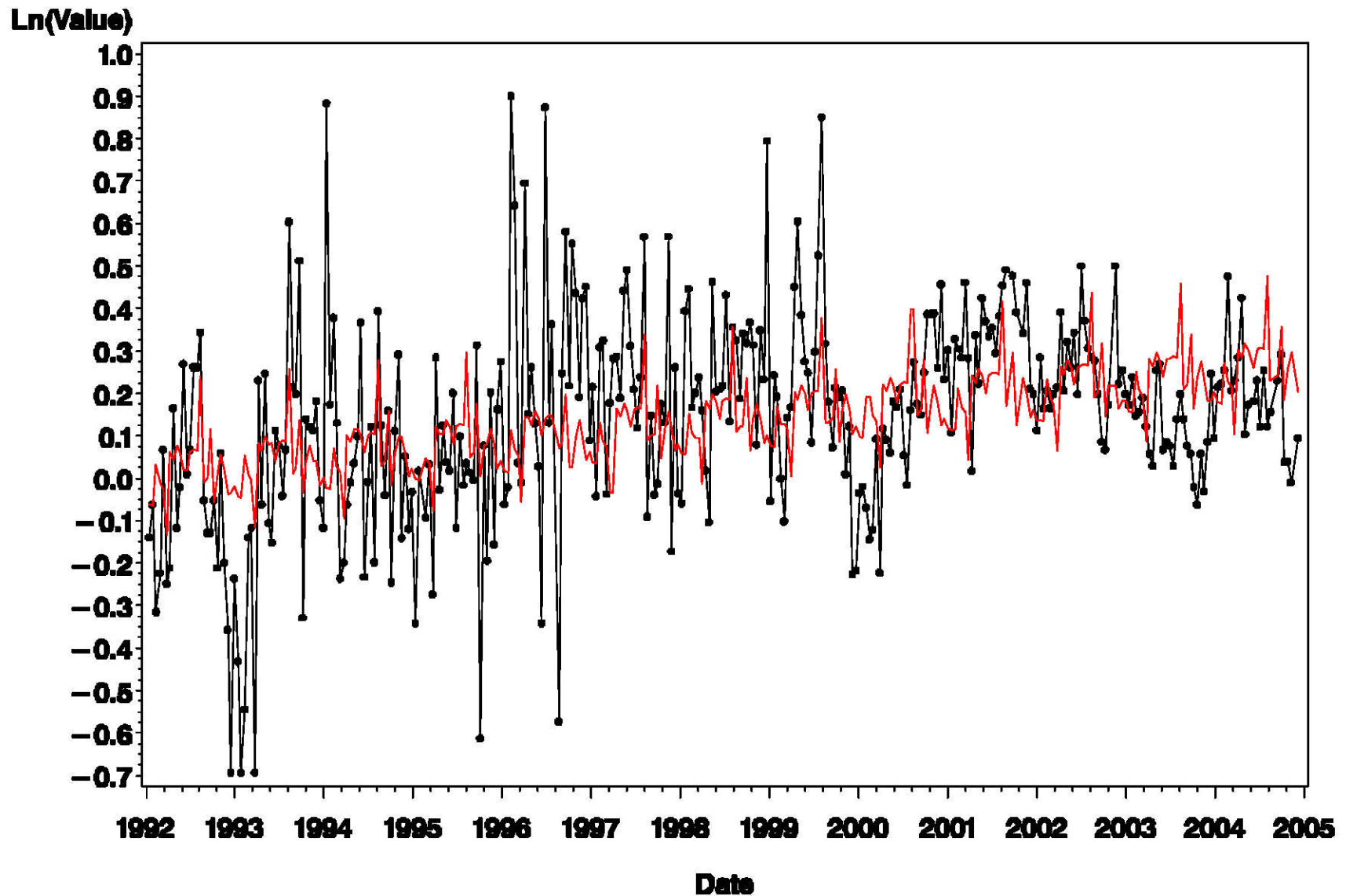


Figure A-11

Actual Data and Fitted Fixed Effects Model
Label=V_S65A TKN

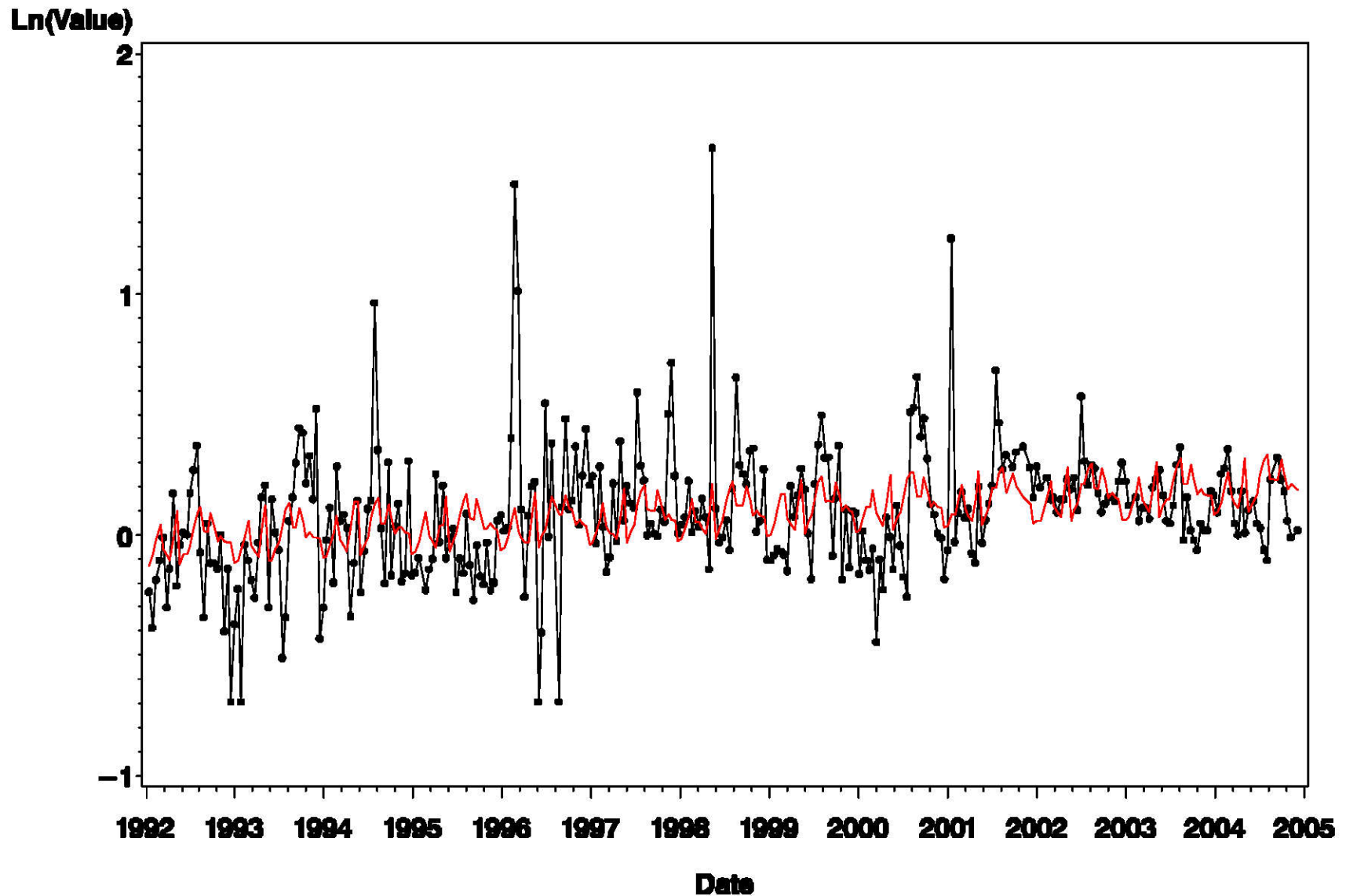


Figure A-12

Actual Data and Fitted Fixed Effects Model
Label=V_S65C TKN

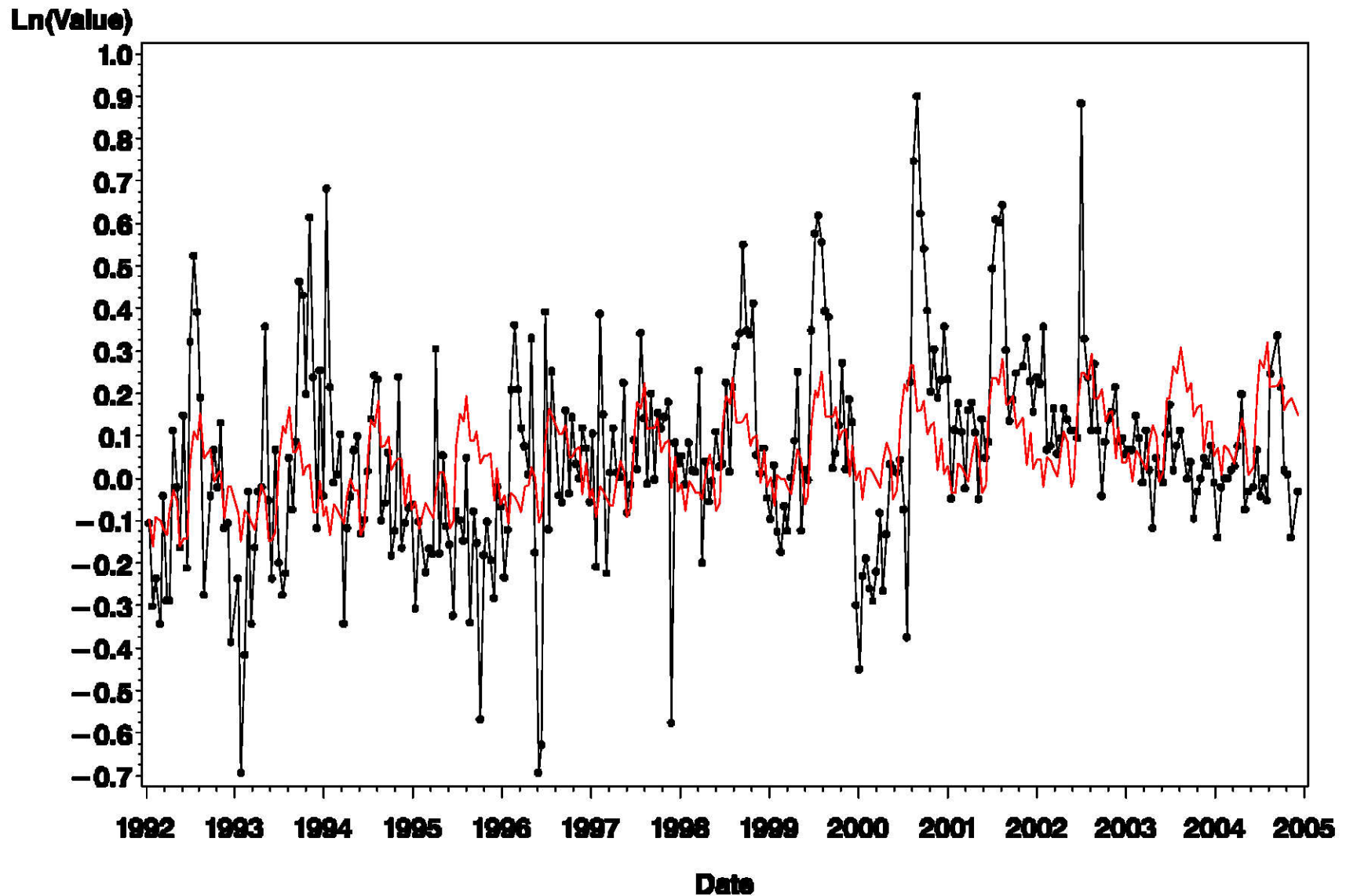


Figure A-13

Actual Data and Fitted Fixed Effects Model
Label=V_S65D TKN

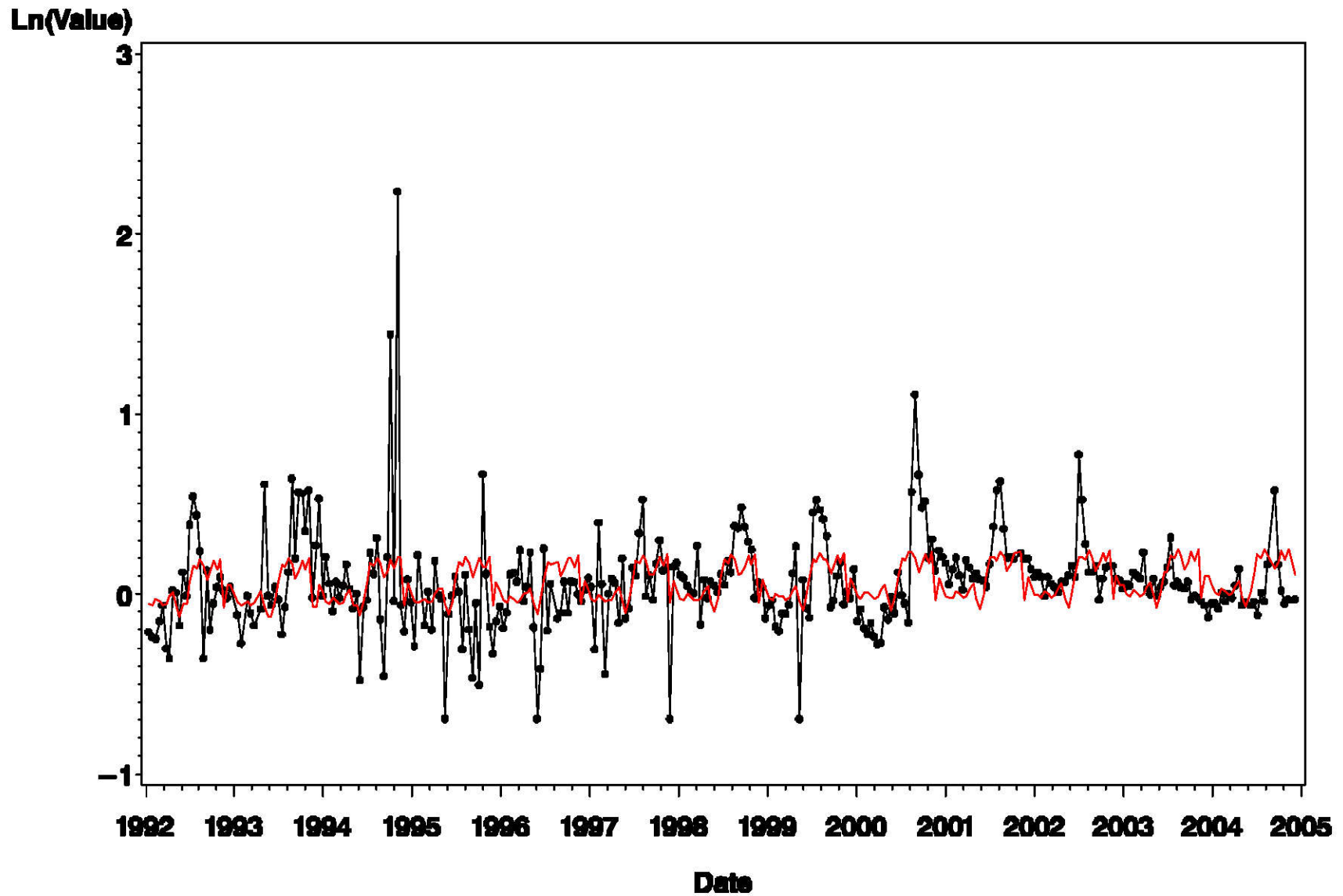


Figure A-14

Actual Data and Fitted Fixed Effects Model
Label=V_S65E TKN

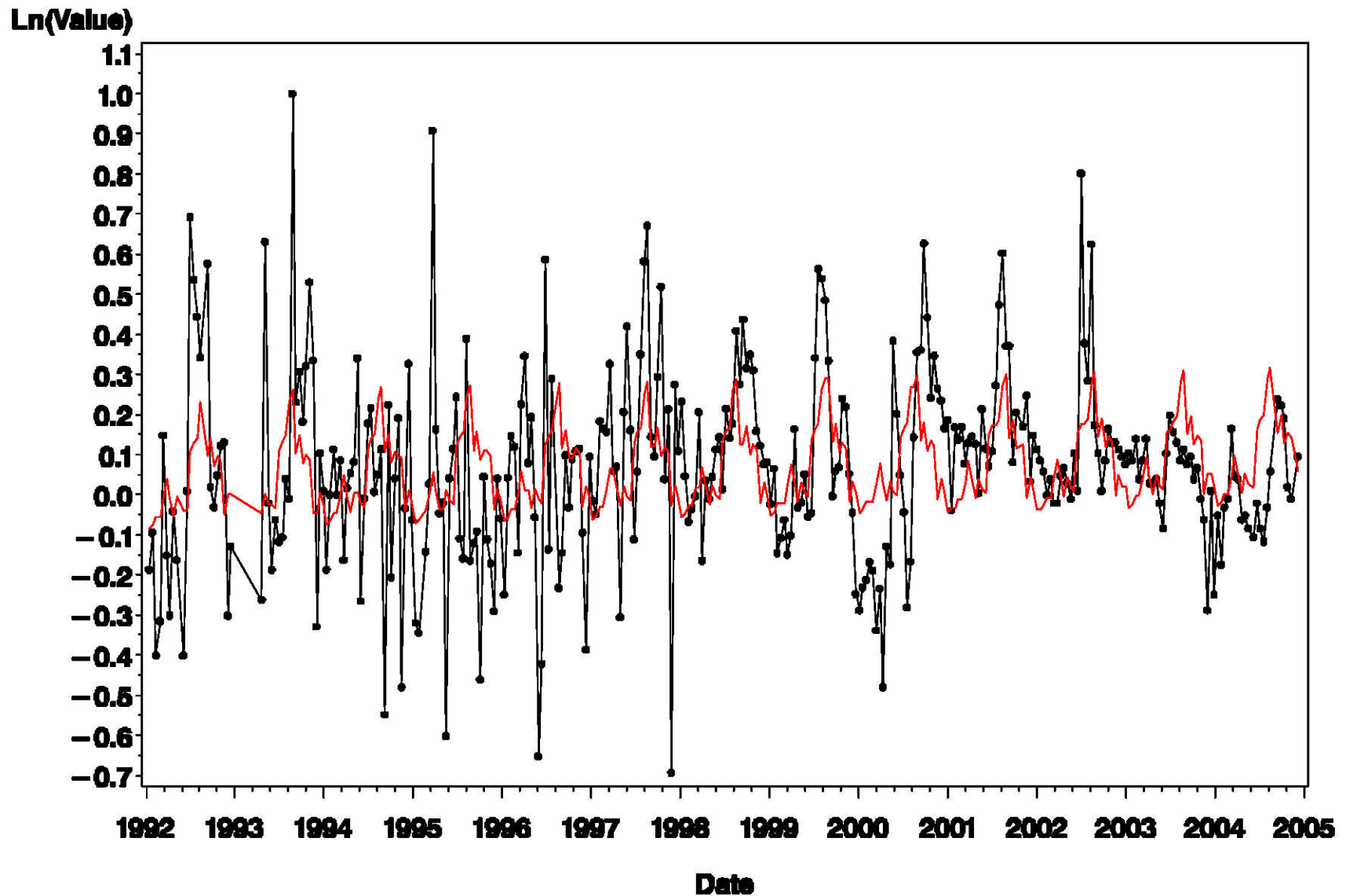


Figure A-15

Actual Data and Fitted Fixed Effects Model
Label=V_S65 TPO4

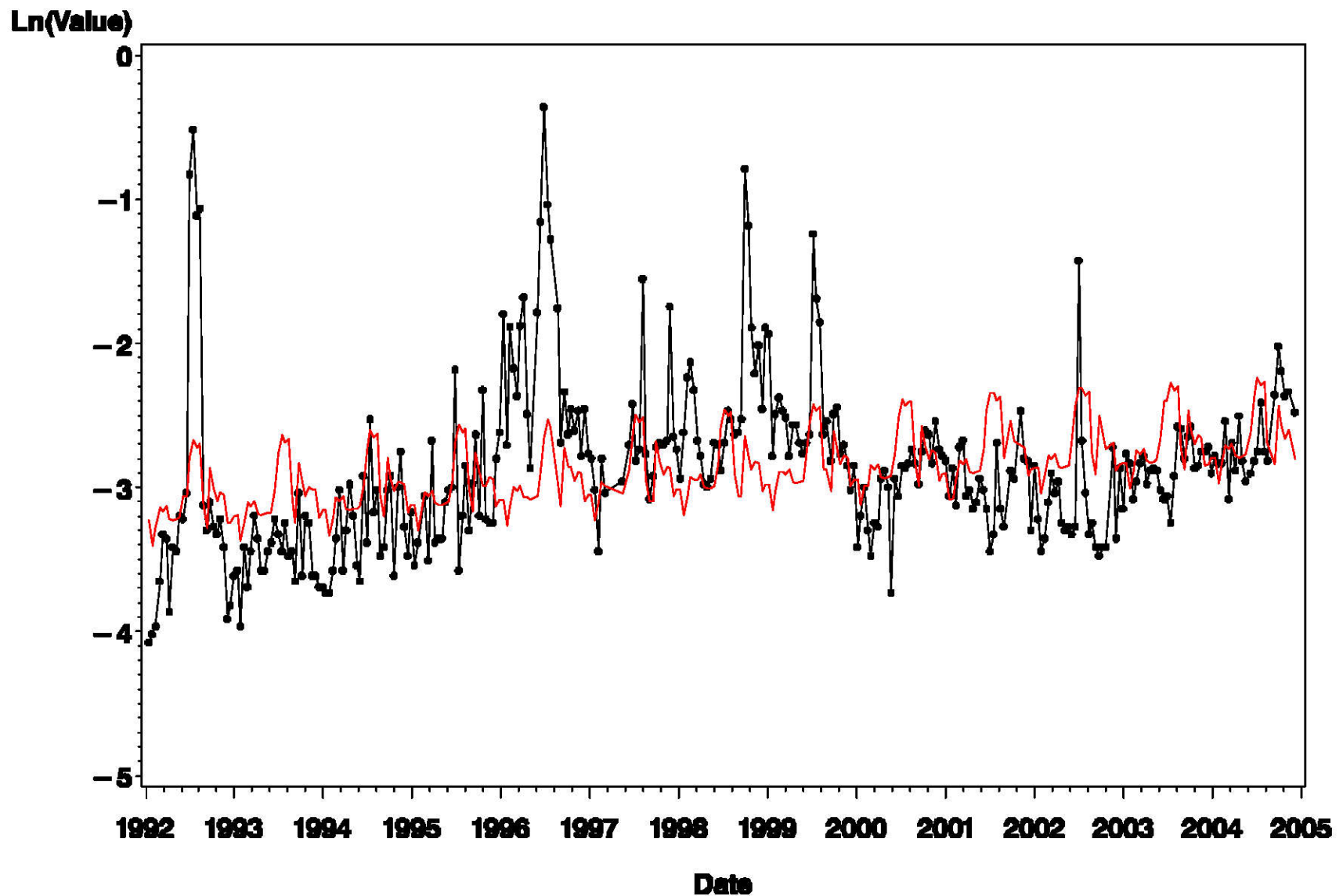
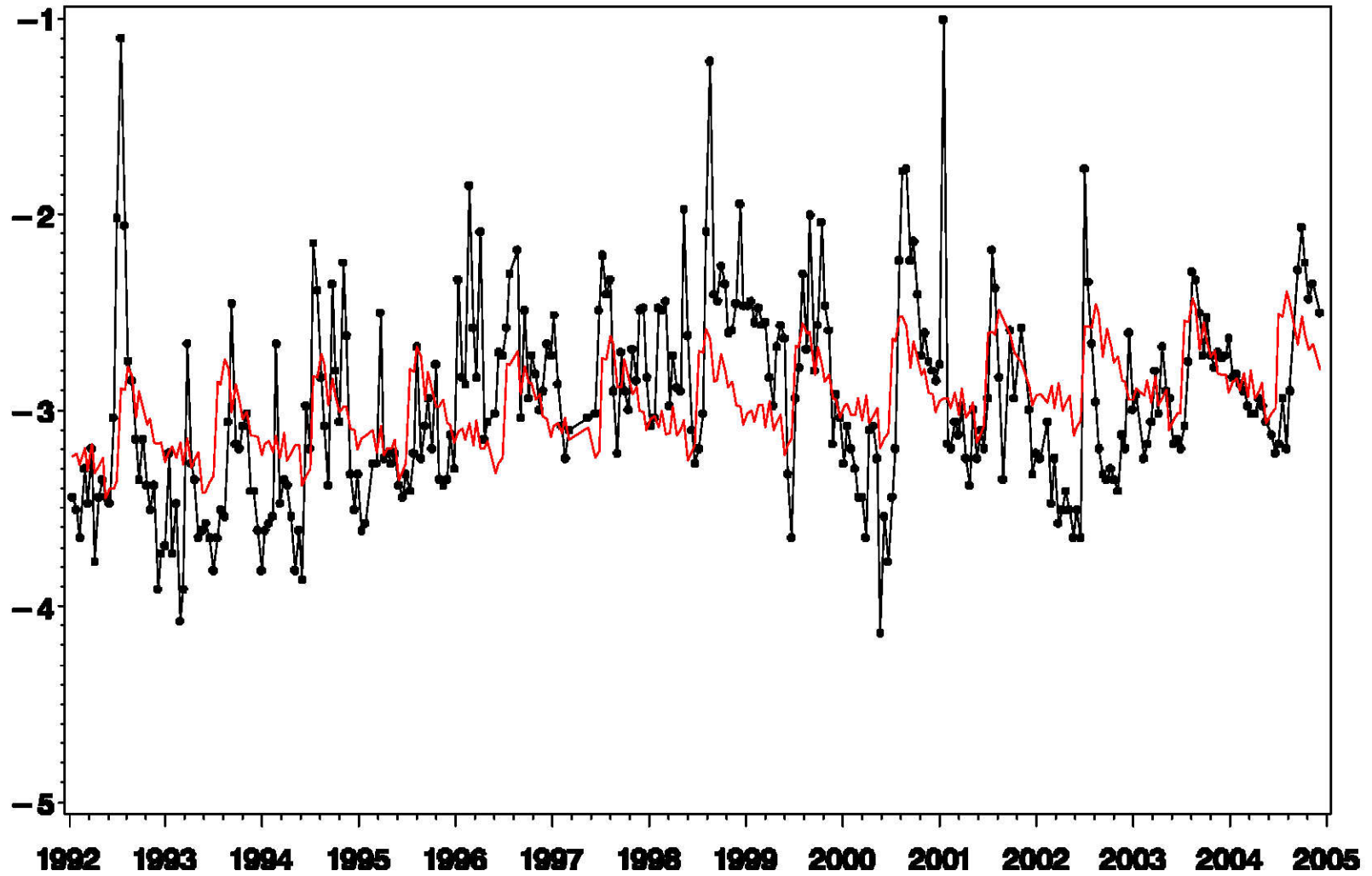


Figure A-16

Actual Data and Fitted Fixed Effects Model

Label=V_S65A TPO4

Ln(Value)



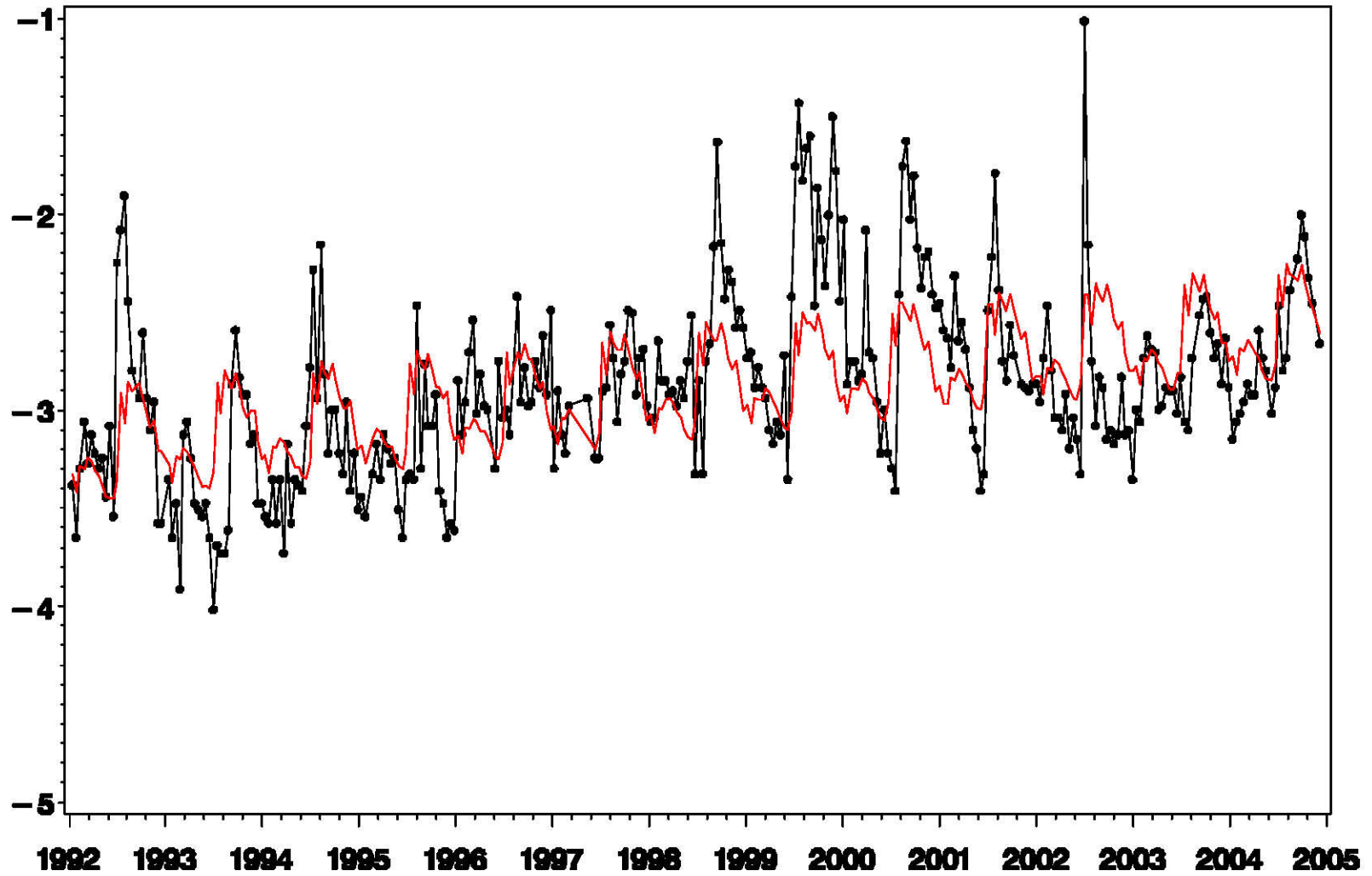
Date

Figure A-17

Actual Data and Fitted Fixed Effects Model

Label=V_S65C TPO4

Ln(Value)



Date

Figure A-18

Actual Data and Fitted Fixed Effects Model
Label=V_S65D TPO4

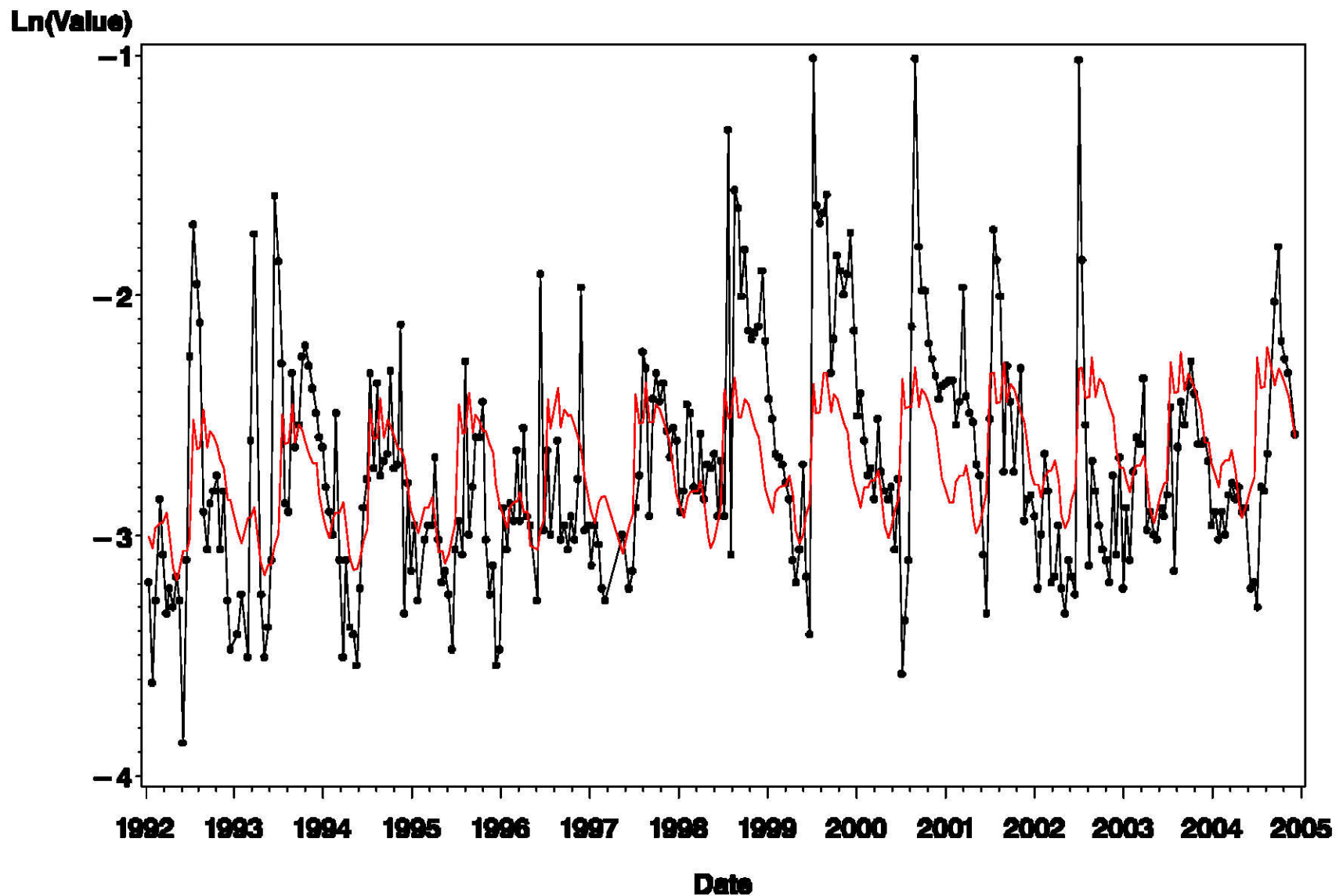


Figure A-19

Actual Data and Fitted Fixed Effects Model
Label=V_S65E TPO4

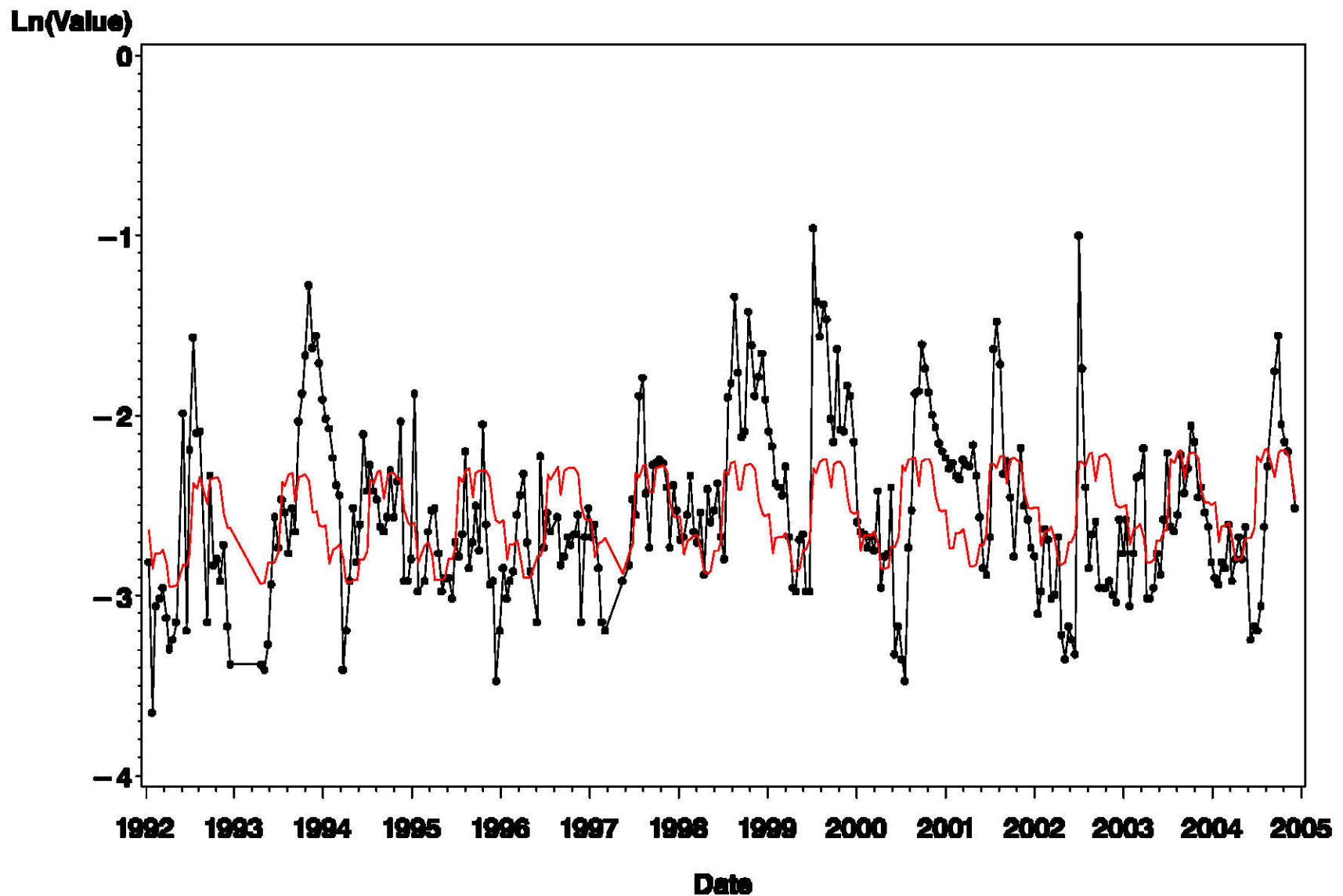


Figure A-20

Actual Data and Fitted Fixed Effects Model
Label=V_S65 CL

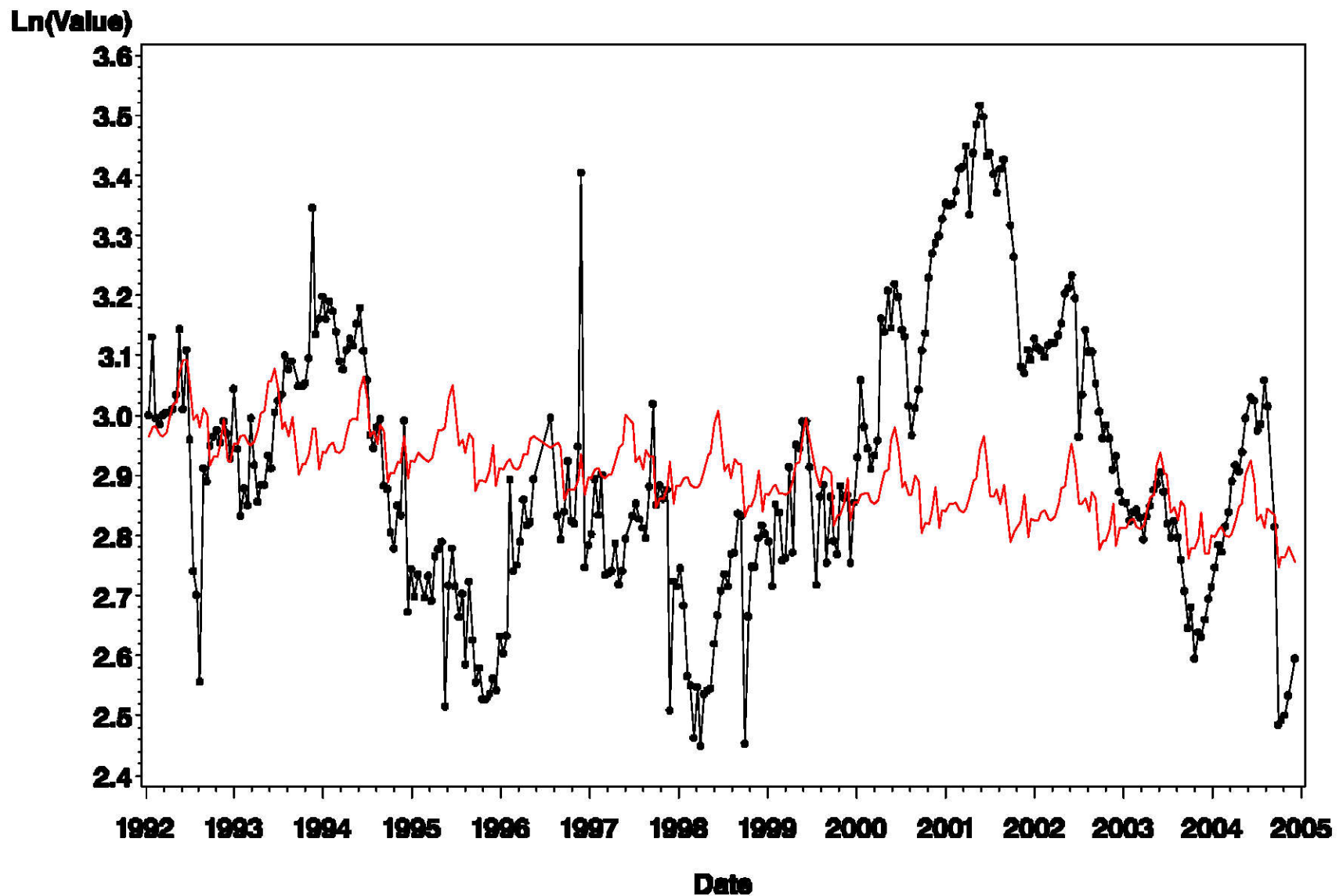


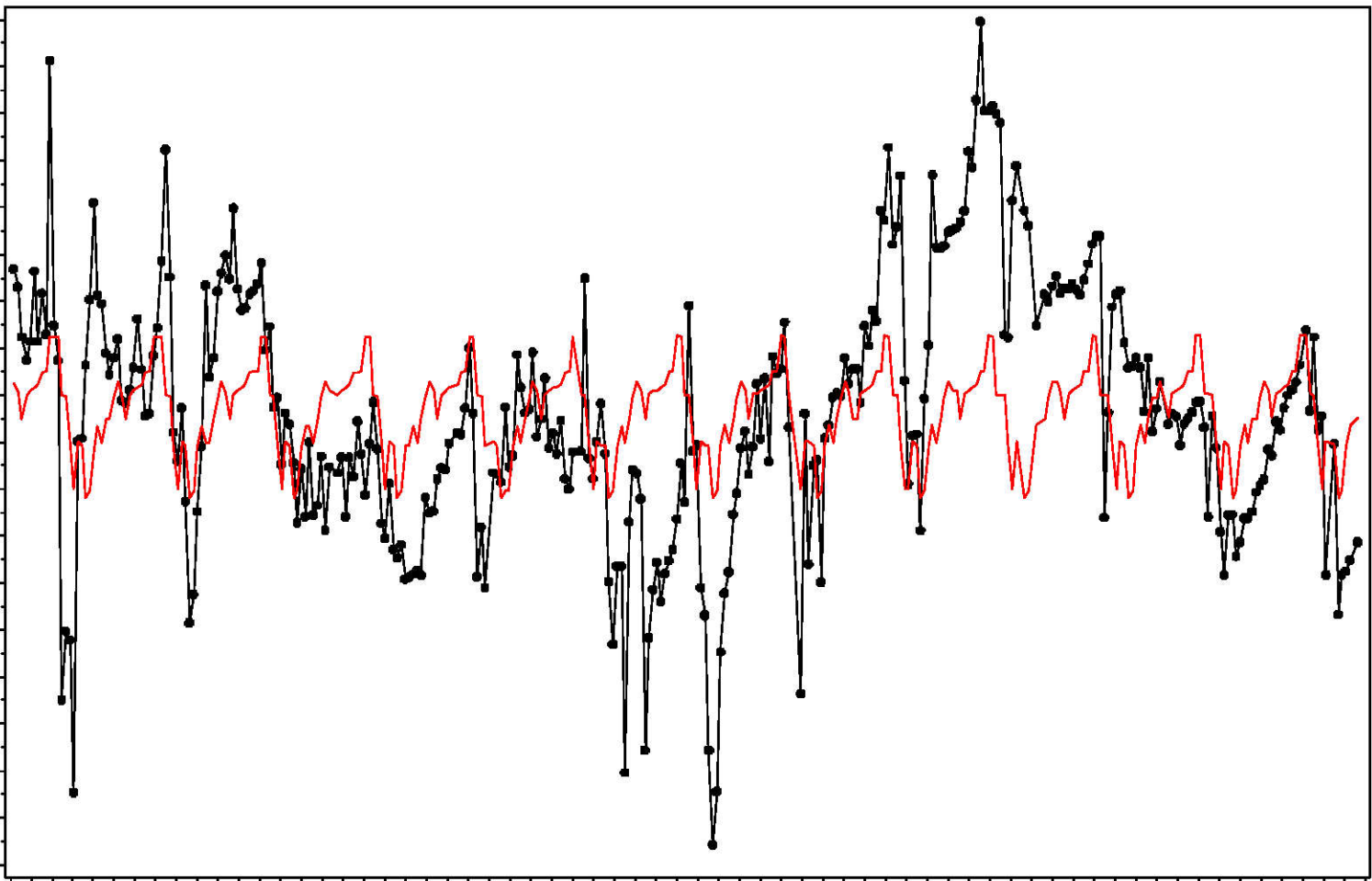
Figure A-21

Actual Data and Fitted Fixed Effects Model

Label=V_S65A CL

Ln(Value)

3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9



1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005

Date

Figure A-22

Actual Data and Fitted Fixed Effects Model
Label=V_S65C CL

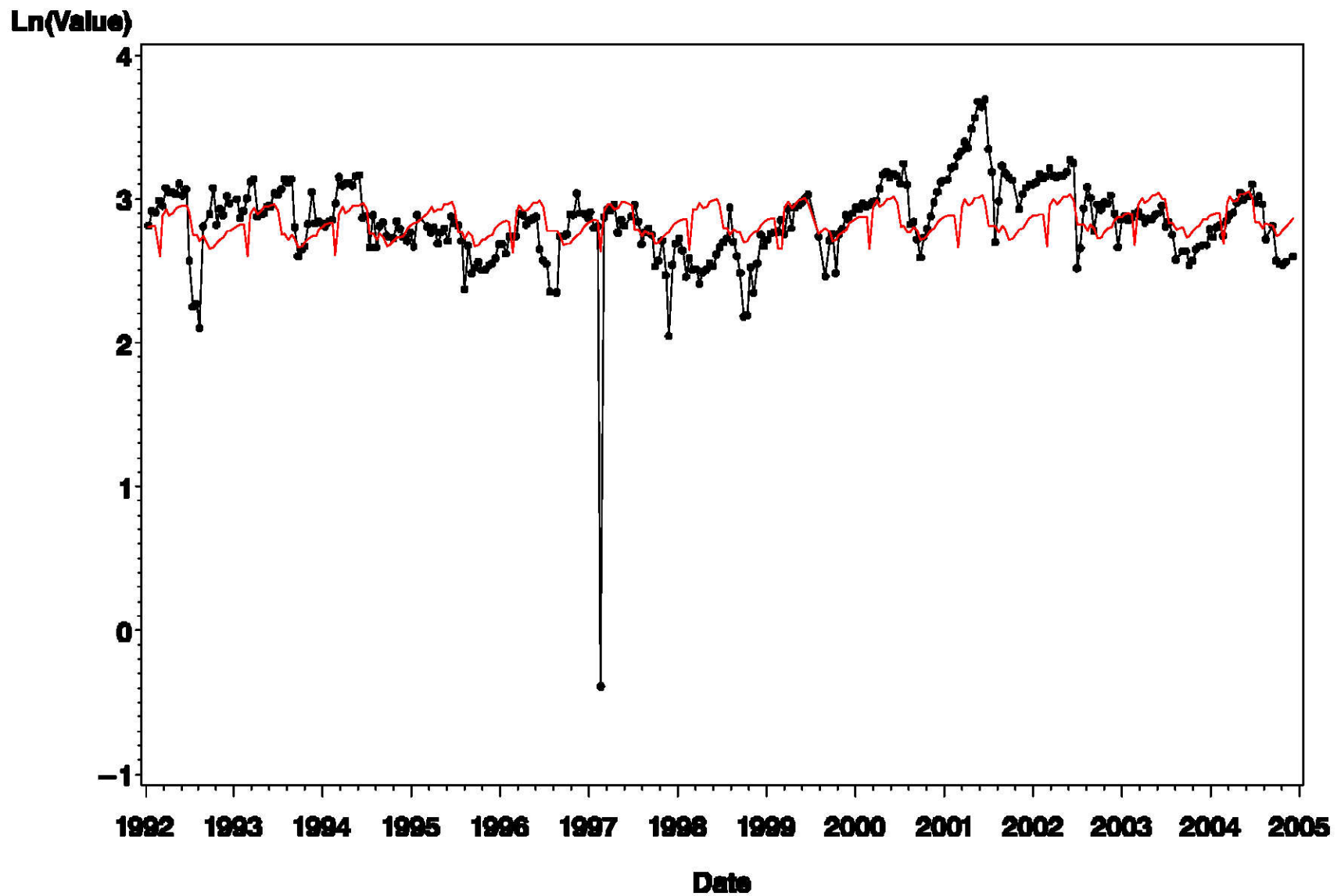
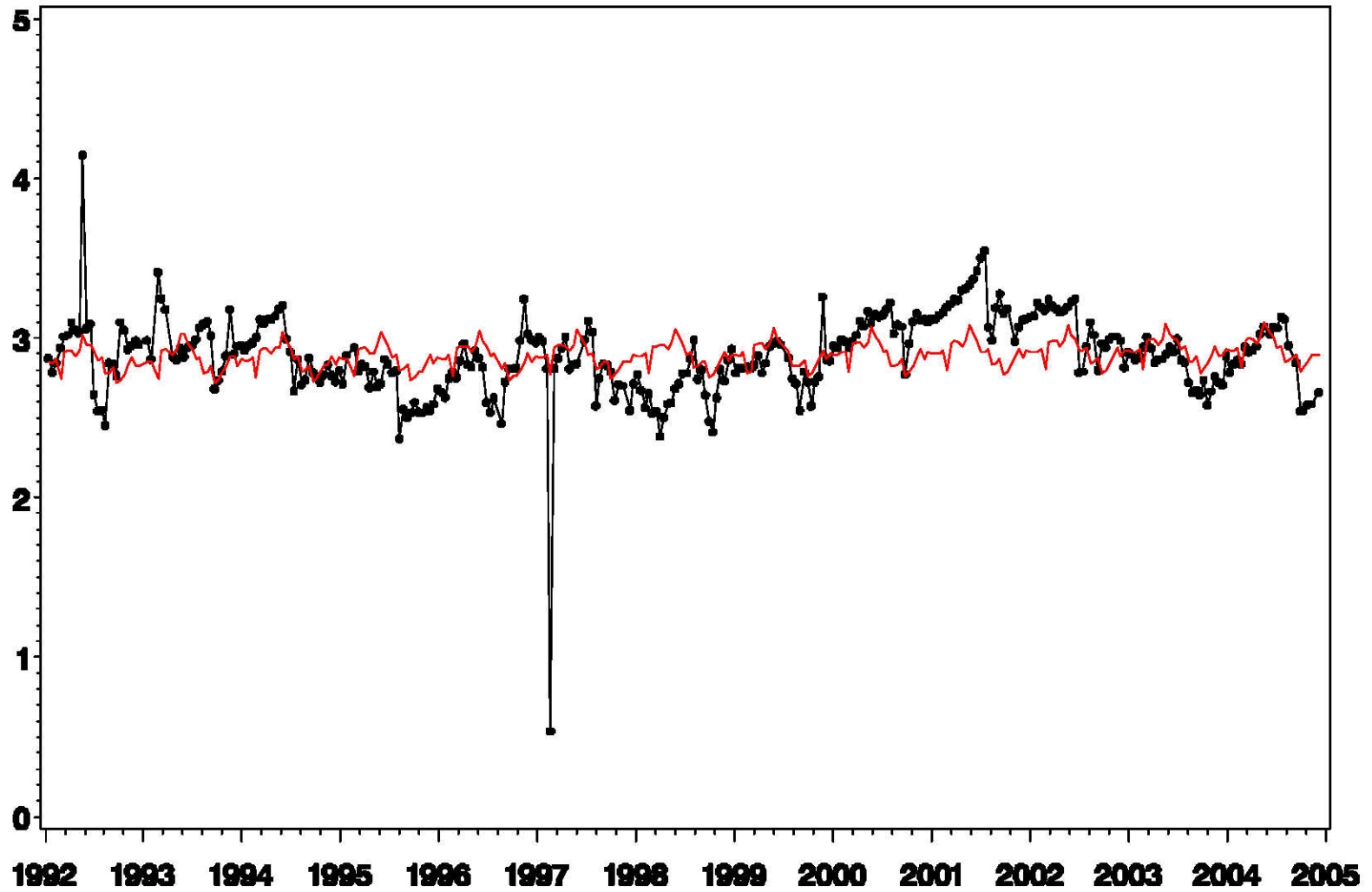


Figure A-23

Actual Data and Fitted Fixed Effects Model
Label=V_S65D CL

Ln(Value)



Date