Supplementary model inference comparisons

This document provides the labeled model-based comparisons referenced in the manuscript for its five mixed models.

The manuscript uses CR2 inference for the five mixed models. Conventional summary() output is labeled separately. All intervals are pointwise 95%; regional pairwise p values also include Holm adjustment.

Models: Regional LMM, SES interaction, forward lag, reverse lag, and NAL dispensing.

1 Regional random intercept model

N = 610 state-years; 51 jurisdictions; 2012–2023.

Age-adjusted opioid overdose deaths per 100,000 population (original units)

Dispensing is standardized using the primary 610-row reference mean and sample SD.

Manuscript inference: state-cluster CR2 and coefficient-specific Satterthwaite t intervals. Conventional lmerTest summary below uses model-based uncertainty and is a comparison.

Reference levels: region Northeast; year 2012.

Model formula

```
opioid_death_rate ~ disp_z * region + year_f + (1 | state)
```

Manuscript CR2 coefficients and 95 percent intervals

term	Estimate	SE	df	p	CI_low	CI_high
(Intercept)	15.6228	1.5506	9.0827	3.135e-06	12.1200	19.1255
disp_z	2.0991	1.6977	4.7720	0.2737	-2.3284	6.5267
regionMidwest	-10.0331	2.6765	17.4720	0.001536	-15.6685	-4.3976
regionSouth	-3.7589	2.7420	16.4124	0.1889	-9.5598	2.0419
regionWest	-10.3963	1.7715	17.3632	1.708e-05	-14.1280	-6.6646
year_f2013	0.7580	0.2250	49.0000	0.001475	0.3059	1.2101
year_f2014	2.1614	0.4139	49.6836	3.492e-06	1.3298	2.9929
year_f2015	3.5548	0.6508	49.6836	1.505e-06	2.2474	4.8622
year_f2016	6.2451	0.9778	49.6834	5.595e-08	4.2809	8.2093
year_f2017	7.4419	1.1966	49.6141	1.027e-07	5.0380	9.8459
year_f2018	6.5162	1.3704	49.2133	1.771e-05	3.7625	9.2699
year_f2019	6.8521	1.6382	46.8888	0.0001251	3.5563	10.1480
year_f2020	12.3592	1.8817	45.7654	4.148e-08	8.5710	16.1473
year_f2021	15.8149	2.1038	45.5688	1.624e-09	11.5792	20.0506
year_f2022	15.3879	2.4337	39.4621	1.758e-07	10.4671	20.3087
year_f2023	14.0270	2.8242	39.1177	1.382e-05	8.3150	19.7389
disp_z:regionMidwest	-1.9824	1.7197	11.7506	0.2719	-5.7380	1.7733
disp_z:regionSouth	1.1265	1.9856	6.4344	0.5897	-3.6537	5.9067
disp_z:regionWest	-1.8754	1.5041	6.3218	0.2567	-5.5108	1.7600

Model fit and variance components

Statistic	Value
N	610.000000
State clusters	51.000000
Variance fixed	62.759061
Variance state	52.526557
Variance residual	22.321079
R2 marginal	0.456076
R2 conditional	0.837791
ICC	0.701780

```
              AIC  3839.453889
              BIC  3932.136527
           logLik -1898.726944
```

Regional slopes and pointwise 95 percent intervals

region	Estimate	SE	df	p	CI_low	CI_high
Northeast	2.0991	1.6977	4.7720	0.2737	-2.3284	6.5267
Midwest	0.1168	1.7838	11.3006	0.9489	-3.7966	4.0302
South	3.2256	2.0383	7.4948	0.1547	-1.5303	7.9816
West	0.2238	0.8671	3.2397	0.8119	-2.4239	2.8714

Joint test of equal regional dispensing slopes

test	F_stat	df_num	df_denom	p_value
HTZ	1.50144	3	10.9428	0.268722

Six pairwise regional slope comparisons

contrast	Estimate	SE	df	p	CI_low	CI_high
Northeast - Midwest	1.9824	1.7197	11.7506	0.2719	-1.7733	5.7380
Northeast - South	-1.1265	1.9856	6.4344	0.5897	-5.9067	3.6537
Northeast - West	1.8754	1.5041	6.3218	0.2567	-1.7600	5.5108
Midwest - South	-3.1088	1.6891	10.4218	0.09431	-6.8519	0.6342
Midwest - West	-0.1070	1.4818	10.8759	0.9438	-3.3729	3.1590
South - West	3.0019	1.7041	8.8720	0.1125	-0.8616	6.8653

Holm adjusted p values across the six comparisons

contrast	p_holm
Northeast - Midwest	1.000000
Northeast - South	1.000000
Northeast - West	1.000000
Midwest - South	0.565868
Midwest - West	1.000000
South - West	0.565868

Predictor standardization

n	center	scale_sd
610	0.219369	0.3036176

Conventional model based summary comparison

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's  method
 [lmerModLmerTest]
Formula: opioid_death_rate ~ disp_z * region + year_f + (1 | state)
   Data: d

      AIC       BIC    logLik -2*log(L)  df.resid
   3839.5    3932.1   -1898.7    3797.5       589

Scaled residuals:
   Min     1Q Median     3Q    Max
-4.259 -0.555 -0.064  0.549  3.644

Random effects:
 Groups   Name        Variance Std.Dev.
 state    (Intercept) 52.5     7.25
```

```
 Residual             22.3     4.72
Number of obs: 610, groups:  state, 51

Fixed effects:
                    Estimate Std. Error      df t value Pr(>|t|)
(Intercept)           15.623      2.554  58.911    6.12  8.3e-08
disp_z                 2.099      0.637 571.513    3.29  0.00105
regionMidwest        -10.033      3.260  51.125   -3.08  0.00335
regionSouth           -3.759      3.040  50.639   -1.24  0.22203
regionWest           -10.396      3.198  50.641   -3.25  0.00205
year_f2013             0.758      0.945 558.634    0.80  0.42278
year_f2014             2.161      0.941 558.677    2.30  0.02196
year_f2015             3.555      0.941 558.680    3.78  0.00017
year_f2016             6.245      0.943 558.753    6.63  8.2e-11
year_f2017             7.442      0.949 558.994    7.85  2.2e-14
year_f2018             6.516      0.972 559.904    6.70  5.0e-11
year_f2019             6.852      1.016 561.443    6.74  3.9e-11
year_f2020            12.359      1.039 562.137   11.89  < 2e-16
year_f2021            15.815      1.082 563.312   14.62  < 2e-16
year_f2022            15.388      1.198 565.794   12.84  < 2e-16
year_f2023            14.027      1.328 567.947   10.57  < 2e-16
disp_z:regionMidwest  -1.982      0.885 563.572   -2.24  0.02548
disp_z:regionSouth     1.126      0.624 565.327    1.80  0.07164
disp_z:regionWest     -1.875      0.639 565.875   -2.94  0.00347
```

2 SES interaction model

N = 610 state-years; 51 jurisdictions; 2012–2023.

Age-adjusted opioid overdose deaths per 100,000 residents

All component, composite and dispensing z-scores use 612 potential state-years before mortality exclusions. Dispensing is prescriptions per 100 residents. The SES formula is (z education + z income - z unemployment)/3, then standardized again.

Manuscript inference: state-cluster CR2 and coefficient-specific Satterthwaite t intervals. Conventional lmerTest summary below uses model-based uncertainty and is a comparison.

Reference levels: year 2012.

Model formula

```
opioid_death_rate ~ disp_z * ses_z + year_f + (1 | state)
```

Manuscript CR2 coefficients and 95 percent intervals

term	Estimate	SE	df	p	CI_low	CI_high
(Intercept)	12.6473	1.7715	38.0526	1.583e-08	9.0612	16.2335
disp_z	1.7656	1.1338	6.9547	0.1636	-0.9189	4.4502
ses_z	3.7133	2.6459	30.5506	0.1706	-1.6862	9.1129
year_f2013	0.9387	0.2465	49.0137	0.0003911	0.4432	1.4341
year_f2014	1.8159	0.4986	49.5391	0.000646	0.8143	2.8175
year_f2015	2.4714	1.0404	48.9800	0.02148	0.3807	4.5622
year_f2016	4.3300	1.6527	46.7804	0.01182	1.0047	7.6553
year_f2017	4.6352	2.2974	42.9005	0.04991	0.0019	9.2686
year_f2018	2.8198	2.7306	39.3671	0.3081	-2.7017	8.3413
year_f2019	2.2591	3.1734	36.5250	0.4811	-4.1736	8.6918
year_f2020	7.4111	3.7619	35.6458	0.05664	-0.2210	15.0431
year_f2021	10.2456	4.2916	35.2554	0.02246	1.5355	18.9558
year_f2022	8.7844	4.8922	33.7859	0.08151	-1.1601	18.7290
year_f2023	6.4595	5.6322	33.0123	0.2597	-4.9991	17.9181
disp_z:ses_z	0.1135	0.8371	6.1511	0.8965	-1.9228	2.1498

Model fit and variance components

Statistic	Value
N	610.000000
State clusters	51.000000
Variance fixed	51.528045
Variance state	75.994606
Variance residual	23.383813
R2 marginal	0.341457
R2 conditional	0.845044
ICC	0.764699
AIC	3875.805569
BIC	3950.834371
logLik	-1920.902784

Predictor standardization

variable	reference_n	center	scale_sd
ba_z	612	3.110327e+01	6.559115e+00
inc_z	612	6.171027e+04	1.315582e+04
unemp_z	612	6.436111e+00	2.073736e+00
ses_z	612	5.054054e-16	8.083126e-01

```
   disp_z         612 2.186577e-01 3.033751e-01
```

Conventional model based summary comparison

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's  method
 [lmerModLmerTest]
Formula: opioid_death_rate ~ disp_z * ses_z + year_f + (1 | state)
   Data: d

      AIC       BIC    logLik -2*log(L)  df.resid
   3875.8    3950.8   -1920.9    3841.8       593

Scaled residuals:
   Min     1Q Median     3Q    Max
-2.737 -0.598 -0.058  0.561  4.059

Random effects:
 Groups   Name        Variance Std.Dev.
 state    (Intercept) 76.0     8.72
 Residual             23.4     4.84
Number of obs: 610, groups:  state, 51

Fixed effects:
             Estimate Std. Error      df t value Pr(>|t|)
(Intercept)    12.647      1.732 115.527    7.30  3.9e-11
disp_z          1.766      0.383 568.928    4.61  4.9e-06
ses_z           3.713      1.064 250.987    3.49  0.00057
year_f2013      0.939      0.969 555.922    0.97  0.33298
year_f2014      1.816      0.969 560.514    1.87  0.06159
year_f2015      2.471      1.022 595.772    2.42  0.01588
year_f2016      4.330      1.137 605.512    3.81  0.00016
year_f2017      4.635      1.310 548.801    3.54  0.00044
year_f2018      2.820      1.510 487.689    1.87  0.06236
year_f2019      2.259      1.696 447.337    1.33  0.18355
year_f2020      7.411      1.788 430.084    4.15  4.1e-05
year_f2021     10.246      1.945 410.717    5.27  2.2e-07
year_f2022      8.784      2.209 390.179    3.98  8.3e-05
year_f2023      6.460      2.412 388.563    2.68  0.00773
disp_z:ses_z    0.114      0.242 572.066    0.47  0.63972
```

3 Forward lag model

N = 560 state-years; 51 jurisdictions; 2013–2023.

Current-year age-adjusted opioid overdose deaths per 100,000 residents

Prior-year dispensing (prescriptions per 100 residents) is standardized over the 560 final forward-lag estimation rows; outcome remains in original mortality units.

Manuscript inference: state-cluster CR2 and coefficient-specific Satterthwaite t intervals. Conventional lmerTest summary below uses model-based uncertainty and is a comparison.

Reference levels: year 2013; region Northeast.

Model formula

```
death_t ~ disp_lag_z + year_f + region + (1 | state)
```

Manuscript CR2 coefficients and 95 percent intervals

term	Estimate	SE	df	p	CI_low	CI_high
(Intercept)	17.1723	1.4842	8.9601	1.091e-06	13.8126	20.5320
disp_lag_z	2.1390	0.9485	8.3363	0.05284	-0.0331	4.3110
year_f2014	1.4417	0.3098	49.6892	2.45e-05	0.8194	2.0640
year_f2015	2.8504	0.5374	49.6884	2.619e-06	1.7708	3.9299
year_f2016	5.7009	0.8716	49.6869	3.227e-08	3.9499	7.4519
year_f2017	6.8734	1.0398	49.6715	2.514e-08	4.7845	8.9623
year_f2018	6.0215	1.0600	49.4853	7.043e-07	3.8918	8.1512
year_f2019	6.0436	1.1861	48.2905	5.749e-06	3.6591	8.4281
year_f2020	10.8750	1.5693	45.6780	1.202e-08	7.7156	14.0344
year_f2021	14.3743	1.7939	42.8116	4.689e-10	10.7561	17.9925
year_f2022	14.1785	1.8732	39.7578	3.181e-09	10.3919	17.9652
year_f2023	12.2135	2.1402	32.6090	2.384e-06	7.8573	16.5698
regionMidwest	-10.2051	2.5506	17.4258	0.0008859	-15.5763	-4.8339
regionSouth	-3.9884	2.9792	16.4128	0.1989	-10.2912	2.3144
regionWest	-11.4657	1.7217	17.3633	3.614e-06	-15.0925	-7.8390

Model fit and variance components

Statistic	Value
N	560.000000
State clusters	51.000000
Variance fixed	60.700858
Variance state	56.420341
Variance residual	21.918350
R2 marginal	0.436573
R2 conditional	0.842359
ICC	0.720210
AIC	3524.304307
BIC	3597.879232
logLik	-1745.152153

Predictor standardization

variable	reference_n	center	scale_sd
disp_lag_z	560	0.1746741	0.2443953

Conventional model based summary comparison

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's  method
 [lmerModLmerTest]
Formula: death_t ~ disp_lag_z + year_f + region + (1 | state)
   Data: d

      AIC       BIC    logLik -2*log(L)  df.resid
   3524.3    3597.9   -1745.2    3490.3       543

Scaled residuals:
   Min     1Q Median     3Q    Max
-3.295 -0.574 -0.039  0.505  3.827

Random effects:
 Groups   Name        Variance Std.Dev.
 state    (Intercept) 56.4     7.51
 Residual             21.9     4.68
Number of obs: 560, groups:  state, 51

Fixed effects:
             Estimate Std. Error      df t value Pr(>|t|)
(Intercept)    17.172      2.635  57.988    6.52  1.9e-08
disp_lag_z      2.139      0.379 525.581    5.65  2.6e-08
year_f2014      1.442      0.932 508.719    1.55   0.1226
year_f2015      2.850      0.932 508.719    3.06   0.0023
year_f2016      5.701      0.932 508.723    6.11  1.9e-09
year_f2017      6.873      0.935 508.822    7.35  7.9e-13
year_f2018      6.022      0.943 509.139    6.38  3.9e-10
year_f2019      6.044      0.976 510.280    6.19  1.2e-09
year_f2020     10.875      1.037 512.130   10.49  < 2e-16
year_f2021     14.374      1.065 512.864   13.50  < 2e-16
year_f2022     14.179      1.123 514.223   12.62  < 2e-16
year_f2023     12.214      1.267 516.749    9.64  < 2e-16
regionMidwest -10.205      3.373  50.828   -3.03   0.0039
regionSouth    -3.988      3.151  50.679   -1.27   0.2113
regionWest    -11.466      3.314  50.679   -3.46   0.0011
```

4 Reverse lag model

N = 559 state-years; 51 jurisdictions; 2013–2023.

Current-year naloxone prescriptions per 100 residents

Prior-year age-adjusted opioid mortality (deaths per 100,000 residents) is standardized over the 559 final reverse-lag estimation rows; dispensing outcome is not standardized.

Manuscript inference: state-cluster CR2 and coefficient-specific Satterthwaite t intervals. Conventional lmerTest summary below uses model-based uncertainty and is a comparison.

Reference levels: year 2013; region Northeast.

Model formula

```
disp_t ~ death_lag_z + year_f + region + (1 | state)
```

Manuscript CR2 coefficients and 95 percent intervals

term	Estimate	SE	df	p	CI_low	CI_high
(Intercept)	0.0311	0.0382	13.7957	0.4296	-0.0510	0.1131
death_lag_z	0.0748	0.0267	17.2960	0.01203	0.0186	0.1310
year_f2014	-0.0020	0.0021	49.0003	0.3449	-0.0063	0.0023
year_f2015	-0.0039	0.0056	49.6641	0.4875	-0.0151	0.0073
year_f2016	0.0233	0.0099	49.5868	0.02343	0.0033	0.0432
year_f2017	0.0515	0.0201	49.0298	0.01335	0.0112	0.0918
year_f2018	0.1344	0.0257	48.5802	3.591e-06	0.0828	0.1861
year_f2019	0.2442	0.0344	48.5348	5.044e-09	0.1749	0.3134
year_f2020	0.2778	0.0322	48.1611	2.57e-11	0.2130	0.3426
year_f2021	0.3127	0.0486	45.2976	6.778e-08	0.2149	0.4105
year_f2022	0.4367	0.0601	42.4681	5.598e-09	0.3155	0.5578
year_f2023	0.5867	0.0832	41.9936	1.22e-08	0.4189	0.7546
regionMidwest	-0.0358	0.0477	18.6832	0.4632	-0.1358	0.0643
regionSouth	0.0270	0.0513	16.5594	0.6049	-0.0813	0.1354
regionWest	0.0764	0.0616	19.1708	0.2296	-0.0524	0.2053

Model fit and variance components

Statistic	Value
N	559.0000000
State clusters	51.0000000
Variance fixed	0.0581068
Variance state	0.0087583
Variance residual	0.0282343
R2 marginal	0.6110109
R2 conditional	0.7031072
ICC	0.2367580
AIC	-298.1491121
BIC	-224.6045710
logLik	166.0745560

Predictor standardization

variable	reference_n	center	scale_sd
death_lag_z	559	16.28623	11.46291

Conventional model based summary comparison

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's  method
 [lmerModLmerTest]
Formula: disp_t ~ death_lag_z + year_f + region + (1 | state)
   Data: d

      AIC       BIC    logLik -2*log(L)  df.resid
   -298.1    -224.6     166.1    -332.1       542

Scaled residuals:
   Min     1Q Median     3Q    Max
-2.470 -0.415 -0.001  0.338  9.950

Random effects:
 Groups   Name        Variance Std.Dev.
 state    (Intercept) 0.00876  0.0936
 Residual             0.02823  0.1680
Number of obs: 559, groups:  state, 51

Fixed effects:
               Estimate Std. Error        df t value Pr(>|t|)
(Intercept)     0.03108    0.04213  99.19260    0.74  0.46246
death_lag_z     0.07481    0.01390 295.37633    5.38  1.5e-07
year_f2014     -0.00204    0.03362 508.16343   -0.06  0.95173
year_f2015     -0.00391    0.03356 510.60001   -0.12  0.90733
year_f2016      0.02326    0.03374 514.51589    0.69  0.49091
year_f2017      0.05149    0.03437 526.61906    1.50  0.13475
year_f2018      0.13444    0.03483 534.02555    3.86  0.00013
year_f2019      0.24417    0.03469 531.81826    7.04  6.0e-12
year_f2020      0.27779    0.03497 536.00512    7.94  1.2e-14
year_f2021      0.31271    0.03760 557.61003    8.32  7.0e-16
year_f2022      0.43666    0.03994 556.70928   10.93  < 2e-16
year_f2023      0.58673    0.04024 555.70175   14.58  < 2e-16
regionMidwest  -0.03575    0.04849  55.16462   -0.74  0.46402
regionSouth     0.02703    0.04413  51.56958    0.61  0.54293
regionWest      0.07643    0.04795  55.92486    1.59  0.11660
```

5 NAL dispensing model

N = 255 state-years; 51 jurisdictions; 2012–2016.

Naloxone prescriptions per 100 residents (not standardized)

NAL_dummy is the retained binary adoption indicator (0/1); no predictor or outcome z-score is introduced in this model.

Manuscript inference: state-cluster CR2 and coefficient-specific Satterthwaite t intervals. Conventional lmerTest summary below uses model-based uncertainty and is a comparison.

Reference levels: year 2012; region Midwest.

Model formula

```
nalox_disp_rate ~ NAL_dummy + year_f + region + (1 | state)
```

Manuscript CR2 coefficients and 95 percent intervals

term	Estimate	SE	df	p	CI_low	CI_high
(Intercept)	-0.0063	0.0018	20.4618	0.001718	-0.0100	-0.0027
NAL_dummy	-0.0030	0.0025	40.9937	0.2271	-0.0080	0.0020
year_f2013	0.0007	0.0006	49.1431	0.2462	-0.0005	0.0018
year_f2014	0.0041	0.0017	45.5773	0.02379	0.0006	0.0076
year_f2015	0.0106	0.0030	40.1934	0.0008958	0.0046	0.0166
year_f2016	0.0474	0.0069	40.4220	2.557e-08	0.0335	0.0613
regionNortheast	0.0165	0.0064	18.3974	0.01889	0.0031	0.0300
regionSouth	0.0082	0.0029	24.0031	0.009747	0.0022	0.0142
regionWest	0.0066	0.0031	22.7876	0.04381	0.0002	0.0130

Model fit and variance components

Statistic	Value
N	2.55000e+02
State clusters	5.10000e+01
Variance fixed	3.21471e-04
Variance state	4.52451e-05
Variance residual	3.39238e-04
R2 marginal	4.55371e-01
R2 conditional	5.19461e-01
ICC	1.17678e-01
AIC	-1.26543e+03
BIC	-1.22648e+03
logLik	6.43715e+02

Predictor standardization

variable	reference_n	center	scale_sd
NAL_dummy and nalox_disp_rate	255	NA	NA

Conventional model based summary comparison

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's  method
 [lmerModLmerTest]
Formula: nalox_disp_rate ~ NAL_dummy + year_f + region + (1 | state)
   Data: d

      AIC       BIC    logLik -2*log(L)  df.resid
```

```
  -1265.4   -1226.5     643.7   -1287.4       244

Scaled residuals:
   Min     1Q Median     3Q    Max
-2.024 -0.339 -0.025  0.195  5.064

Random effects:
 Groups   Name        Variance Std.Dev.
 state    (Intercept) 4.52e-05 0.00673
 Residual             3.39e-04 0.01842
Number of obs: 255, groups:  state, 51

Fixed effects:
                 Estimate Std. Error        df t value Pr(>|t|)
(Intercept)     -6.31e-03   3.84e-03  1.02e+02   -1.64   0.1036
NAL_dummy       -3.02e-03   3.35e-03  2.22e+02   -0.90   0.3674
year_f2013       6.52e-04   3.71e-03  1.99e+02    0.18   0.8606
year_f2014       4.07e-03   3.88e-03  2.12e+02    1.05   0.2956
year_f2015       1.06e-02   4.31e-03  2.35e+02    2.46   0.0146
year_f2016       4.74e-02   4.49e-03  2.42e+02   10.55   <2e-16
regionNortheast  1.65e-02   4.83e-03  4.62e+01    3.42   0.0013
regionSouth      8.18e-03   4.03e-03  4.32e+01    2.03   0.0487
regionWest       6.62e-03   4.26e-03  4.27e+01    1.55   0.1276
```