> model\_SO2\_lm <- lm(SO2 ~ unit + capacity + type + province)

> summary(model\_SO2\_lm)

Call:

lm(formula = SO2 ~ unit + capacity + type + province)

Residuals:

Min 1Q Median 3Q Max

-2113.4 -127.1 -1.9 83.1 4939.4

Coefficients:

Estimate Std. Error t value Pr(>|t|)

(Intercept) -68.07944 73.40945 -0.927 0.353810

unit 51.70212 6.22011 8.312 < 2e-16 \*\*\*

capacity 0.43596 0.01484 29.376 < 2e-16 \*\*\*

typeCoal 24.94596 51.62471 0.483 0.628983

typeGas & Oil -199.45540 65.50796 -3.045 0.002352 \*\*

typeOthers 80.78566 55.67233 1.451 0.146877

provinceBeijing 116.03657 422.43639 0.275 0.783581

provinceChongqing 397.84340 89.31081 4.455 8.77e-06 \*\*\*

provinceFujian -97.08813 76.08439 -1.276 0.202051

provinceGansu 328.04329 93.18707 3.520 0.000439 \*\*\*

provinceGuangdong -26.00691 65.61803 -0.396 0.691889

provinceGuangxi 473.70696 86.65341 5.467 5.03e-08 \*\*\*

provinceGuizhou 2067.13482 96.95984 21.319 < 2e-16 \*\*\*

provinceHainan 24.96196 136.83736 0.182 0.855267

provinceHebei -94.97025 63.94531 -1.485 0.137619

provinceHeilongjiang 67.98408 65.65075 1.036 0.300514

provinceHenan -138.58553 63.28383 -2.190 0.028621 \*

provinceHubei 23.58189 71.99967 0.328 0.743296

provinceHunan 71.33389 83.25589 0.857 0.391634

provinceInner Mongol 494.50064 61.70262 8.014 1.67e-15 \*\*\*

provinceJiangsu -43.72555 58.47215 -0.748 0.454649

provinceJiangxi 197.46097 82.17667 2.403 0.016337 \*

provincejilin 132.84678 78.24475 1.698 0.089660 .

provinceLiaoning 167.56790 68.31786 2.453 0.014242 \*

provinceNingxia 259.35671 84.51710 3.069 0.002173 \*\*

provinceQinghai 67.89718 136.17516 0.499 0.618103

provinceShaanxi 15.79985 66.70048 0.237 0.812771

provinceShandong -100.22551 56.18430 -1.784 0.074563 .

provinceShanghai -103.19236 100.03729 -1.032 0.302386

provinceShanxi -16.87534 61.77582 -0.273 0.784744

provinceSichuan 132.58439 77.47102 1.711 0.087127 .

provinceTianjin -165.32141 103.04208 -1.604 0.108748

provinceXinjiang 406.82563 66.97511 6.074 1.43e-09 \*\*\*

provinceYunnan 16.84903 84.61601 0.199 0.842182

provinceZhejiang -97.27174 59.74349 -1.628 0.103615

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 417.1 on 2562 degrees of freedom

Multiple R-squared: 0.5325, Adjusted R-squared: 0.5263

F-statistic: 85.83 on 34 and 2562 DF, p-value: < 2.2e-16

> summary(model\_SO2\_lm)$coef

Estimate Std. Error t value Pr(>|t|)

(Intercept) -68.0794418 73.40944502 -0.9273935 3.538096e-01

unit 51.7021219 6.22011098 8.3120899 1.505714e-16

capacity 0.4359602 0.01484091 29.3755614 9.965911e-164

typeCoal 24.9459551 51.62471330 0.4832173 6.289827e-01

typeGas & Oil -199.4553965 65.50796258 -3.0447504 2.352425e-03

typeOthers 80.7856571 55.67232586 1.4510918 1.468767e-01

provinceBeijing 116.0365717 422.43639398 0.2746841 7.835811e-01

provinceChongqing 397.8434019 89.31080950 4.4545941 8.765872e-06

provinceFujian -97.0881315 76.08439443 -1.2760584 2.020505e-01

provinceGansu 328.0432912 93.18706939 3.5202662 4.386334e-04

provinceGuangdong -26.0069128 65.61802911 -0.3963379 6.918888e-01

provinceGuangxi 473.7069551 86.65341152 5.4666856 5.028138e-08

provinceGuizhou 2067.1348233 96.95984217 21.3194945 5.621918e-93

provinceHainan 24.9619625 136.83736088 0.1824207 8.552670e-01

provinceHebei -94.9702487 63.94531279 -1.4851792 1.376194e-01

provinceHeilongjiang 67.9840847 65.65075244 1.0355416 3.005138e-01

provinceHenan -138.5855314 63.28383138 -2.1899043 2.862106e-02

provinceHubei 23.5818881 71.99966567 0.3275277 7.432955e-01

provinceHunan 71.3338883 83.25589419 0.8568029 3.916340e-01

provinceInner Mongol 494.5006414 61.70262421 8.0142562 1.666691e-15

provinceJiangsu -43.7255514 58.47214688 -0.7478014 4.546486e-01

provinceJiangxi 197.4609708 82.17667412 2.4028835 1.633707e-02

provincejilin 132.8467771 78.24474703 1.6978364 8.966009e-02

provinceLiaoning 167.5678951 68.31786039 2.4527685 1.424238e-02

provinceNingxia 259.3567136 84.51709979 3.0686892 2.172512e-03

provinceQinghai 67.8971824 136.17515555 0.4986018 6.181027e-01

provinceShaanxi 15.7998492 66.70047661 0.2368776 8.127707e-01

provinceShandong -100.2255093 56.18430312 -1.7838703 7.456307e-02

provinceShanghai -103.1923574 100.03728669 -1.0315389 3.023855e-01

provinceShanxi -16.8753364 61.77581940 -0.2731706 7.847441e-01

provinceSichuan 132.5843924 77.47101747 1.7114064 8.712716e-02

provinceTianjin -165.3214065 103.04207860 -1.6044068 1.087477e-01

provinceXinjiang 406.8256252 66.97510596 6.0742812 1.430670e-09

provinceYunnan 16.8490339 84.61601387 0.1991235 8.421820e-01

provinceZhejiang -97.2717355 59.74349129 -1.6281562 1.036147e-01

> summary(model\_SO2\_lmer1)

Linear mixed model fit by REML ['lmerMod']

Formula: SO2 ~ unit + capacity + type + (1 | province)

REML criterion at convergence: 38782.6

Scaled residuals:

Min 1Q Median 3Q Max

-4.8792 -0.3065 -0.0072 0.1969 11.8449

Random effects:

Groups Name Variance Std.Dev.

province (Intercept) 159369 399.2

Residual 173935 417.1

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 83.37922 89.80495 0.928

unit 51.64077 6.21805 8.305

capacity 0.43731 0.01483 29.485

typeCoal 25.43077 51.56204 0.493

typeGas & Oil -201.88544 65.36518 -3.089

typeOthers 79.88978 55.62213 1.436

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.105

capacity 0.031 -0.407

typeCoal -0.538 -0.039 -0.083

typeGas&Oil -0.435 -0.025 -0.059 0.764

typeOthers -0.493 -0.062 0.018 0.877 0.700

> summary(model\_SO2\_lmer2)

Linear mixed model fit by REML ['lmerMod']

Formula: SO2 ~ unit + capacity + type + (1 + type | province)

REML criterion at convergence: 38746.9

Scaled residuals:

Min 1Q Median 3Q Max

-4.9374 -0.3062 -0.0106 0.1895 11.9034

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 0 0.0

typeCoal 171118 413.7 NaN

typeGas & Oil 20832 144.3 NaN 0.94

typeOthers 33382 182.7 NaN 0.93 0.76

Residual 171363 414.0

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) -36.88715 48.35831 -0.763

unit 53.86297 6.18194 8.713

capacity 0.43339 0.01477 29.349

typeCoal 153.00412 91.46808 1.673

typeGas & Oil -199.86520 68.55872 -2.915

typeOthers 122.83714 64.20552 1.913

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.189

capacity 0.072 -0.408

typeCoal -0.505 -0.024 -0.057

typeGas&Oil -0.673 -0.036 -0.061 0.676

typeOthers -0.715 -0.057 0.011 0.803 0.656

optimizer (nloptwrap) convergence code: 0 (OK)

boundary (singular) fit: see ?isSingular

> model\_SO2\_lmer3 <- lmer(SO2 ~ unit + capacity + type + (1+unit|province))

> summary(model\_SO2\_lmer3)

Linear mixed model fit by REML ['lmerMod']

Formula: SO2 ~ unit + capacity + type + (1 + unit | province)

REML criterion at convergence: 38393.8

Scaled residuals:

Min 1Q Median 3Q Max

-6.2526 -0.2764 -0.0261 0.1174 12.5259

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 9241 96.13

unit 23999 154.92 -0.20

Residual 148233 385.01

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) -34.66506 50.92669 -0.681

unit 96.33922 29.71688 3.242

capacity 0.41488 0.01421 29.189

typeCoal 48.29430 47.15236 1.024

typeGas & Oil -194.91991 59.90984 -3.254

typeOthers 83.05865 50.99568 1.629

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.131

capacity 0.072 -0.104

typeCoal -0.863 -0.013 -0.076

typeGas&Oil -0.682 -0.017 -0.054 0.761

typeOthers -0.790 -0.014 0.020 0.874 0.694

> summary(model\_SO2\_lmer3)$coef

Estimate Std. Error t value

(Intercept) -34.6650610 50.92669319 -0.6806855

unit 96.3392220 29.71687657 3.2419027

capacity 0.4148784 0.01421341 29.1892158

typeCoal 48.2943016 47.15235842 1.0242182

typeGas & Oil -194.9199141 59.90984192 -3.2535541

typeOthers 83.0586487 50.99568197 1.6287389

> model\_SO2\_lmer4 <- lmer(SO2 ~ unit + type + capacity + (1+capacity|province))

Warning messages:

1: In checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :

unable to evaluate scaled gradient

2: In checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :

Model failed to converge: degenerate Hessian with 1 negative eigenvalues

> summary(model\_SO2\_lmer4)

Linear mixed model fit by REML ['lmerMod']

Formula: SO2 ~ unit + type + capacity + (1 + capacity | province)

REML criterion at convergence: 38122.1

Scaled residuals:

Min 1Q Median 3Q Max

-7.7493 -0.2772 -0.0485 0.0975 11.2729

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 7.530e+04 274.4079

capacity 2.487e-01 0.4987 0.87

Residual 1.316e+05 362.7053

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 16.72405 67.61593 0.247

unit 45.00338 5.46293 8.238

typeCoal 40.81382 44.94739 0.908

typeGas & Oil -152.49863 56.88882 -2.681

typeOthers 73.89645 48.46270 1.525

capacity 0.53019 0.09371 5.658

Correlation of Fixed Effects:

(Intr) unit typeCl typG&O typOth

unit -0.123

typeCoal -0.620 -0.043

typeGas&Oil -0.499 -0.028 0.763

typeOthers -0.568 -0.063 0.875 0.700

capacity 0.636 -0.055 -0.018 -0.016 -0.001

optimizer (nloptwrap) convergence code: 0 (OK)

unable to evaluate scaled gradient

Model failed to converge: degenerate Hessian with 1 negative eigenvalues

> summary(model\_SO2\_lmer4)$coef

Estimate Std. Error t value

(Intercept) 16.7240517 67.61592628 0.2473389

unit 45.0033801 5.46292713 8.2379609

typeCoal 40.8138249 44.94739023 0.9080355

typeGas & Oil -152.4986323 56.88882069 -2.6806432

typeOthers 73.8964519 48.46269785 1.5248109

capacity 0.5301933 0.09371025 5.6577941