library(readxl)

> data <- read\_excel("Documents/11-Linear Regression:Linear Mixed Model/data.xlsx")

> View(data)

> number <- data$No.

> province <- data$Province

> plant\_name <- data$`Plant name`

> unit <- data$`Number of units`

> capacity <- data$`Total plant installed capacity (MW)`

> type <- data$`Fuel type`

> SO2 <- data$`SO2 emissions (Mg)`

> NOx <- data$`NOx emissions (Mg)`

> PM <- data$`PM emissions (Mg)`

> df <- data.frame(number,province, plant\_name, unit, capacity, type, SO2, NOx, PM)

> table(type)

type

Biomass Coal Gas & Oil Others

76 2099 111 311

> res <- model.matrix(~type)

> head(res)

(Intercept) typeCoal typeGas & Oil typeOthers

1 1 0 1 0

2 1 1 0 0

3 1 1 0 0

4 1 1 0 0

5 1 1 0 0

6 1 1 0 0

> table(province)

province

Anhui Beijing Chongqing Fujian Gansu Guangdong Guangxi Guizhou Hainan

65 1 33 57 29 111 37 26 11

Hebei Heilongjiang Henan Hubei Hunan Inner Mongol Jiangsu Jiangxi jilin

128 111 133 72 41 155 244 43 51

Liaoning Ningxia Qinghai Shaanxi Shandong Shanghai Shanxi Sichuan Tianjin

89 39 11 101 397 24 164 53 22

Xinjiang Yunnan Zhejiang

97 42 210

> res\_SO2\_province <- model.matrix(~province)

> head(res\_SO2\_province)

(Intercept) provinceBeijing provinceChongqing provinceFujian provinceGansu provinceGuangdong provinceGuangxi

1 1 1 0 0 0 0 0

2 1 0 0 0 0 0 0

3 1 0 0 0 0 0 0

4 1 0 0 0 0 0 0

5 1 0 0 0 0 0 0

6 1 0 0 0 0 0 0

provinceGuizhou provinceHainan provinceHebei provinceHeilongjiang provinceHenan provinceHubei provinceHunan

1 0 0 0 0 0 0 0

2 0 0 0 0 0 0 0

3 0 0 0 0 0 0 0

4 0 0 0 0 0 0 0

5 0 0 0 0 0 0 0

6 0 0 0 0 0 0 0

provinceInner Mongol provinceJiangsu provinceJiangxi provincejilin provinceLiaoning provinceNingxia provinceQinghai

1 0 0 0 0 0 0 0

2 0 0 0 0 0 0 0

3 0 0 0 0 0 0 0

4 0 0 0 0 0 0 0

5 0 0 0 0 0 0 0

6 0 0 0 0 0 0 0

provinceShaanxi provinceShandong provinceShanghai provinceShanxi provinceSichuan provinceTianjin provinceXinjiang

1 0 0 0 0 0 0 0

2 0 0 0 0 0 1 0

3 0 0 0 0 0 1 0

4 0 0 0 0 0 1 0

5 0 0 0 0 0 1 0

6 0 0 0 0 0 1 0

provinceYunnan provinceZhejiang

1 0 0

2 0 0

3 0 0

4 0 0

5 0 0

6 0 0

> 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

> model\_SO2\_lmer1 <- lmer(SO2 ~ unit + capacity + type + (1|province))

> 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

> model\_SO2\_lmer2 <- lmer(SO2 ~ unit + capacity + type + (1+type|province))

> 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

> model\_NOx\_lm <- lm(NOx ~ unit + capacity + type + province)

> summary(model\_NOx\_lm)

Call:

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

Residuals:

Min 1Q Median 3Q Max

-2171.4 -225.8 -17.0 143.7 8904.3

Coefficients:

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

(Intercept) 26.0751 112.7927 0.231 0.817196

unit 111.4989 9.5571 11.667 < 2e-16 \*\*\*

capacity 0.7420 0.0228 32.539 < 2e-16 \*\*\*

typeCoal -111.7359 79.3207 -1.409 0.159057

typeGas & Oil -342.2611 100.6522 -3.400 0.000683 \*\*\*

typeOthers 354.3655 85.5398 4.143 3.54e-05 \*\*\*

provinceBeijing 55.1904 649.0682 0.085 0.932244

provinceChongqing -9.5453 137.2249 -0.070 0.944550

provinceFujian -215.9398 116.9027 -1.847 0.064837 .

provinceGansu 24.3290 143.1808 0.170 0.865088

provinceGuangdong -93.5340 100.8213 -0.928 0.353640

provinceGuangxi 79.8210 133.1419 0.600 0.548880

provinceGuizhou 692.9621 148.9776 4.651 3.46e-06 \*\*\*

provinceHainan -227.7816 210.2489 -1.083 0.278737

provinceHebei -147.0859 98.2512 -1.497 0.134506

provinceHeilongjiang 39.6657 100.8715 0.393 0.694183

provinceHenan -239.0504 97.2348 -2.458 0.014018 \*

provinceHubei -113.4666 110.6266 -1.026 0.305143

provinceHunan 87.3606 127.9216 0.683 0.494717

provinceInner Mongol 451.1363 94.8053 4.759 2.06e-06 \*\*\*

provinceJiangsu -14.9010 89.8417 -0.166 0.868281

provinceJiangxi 248.8514 126.2634 1.971 0.048844 \*

provincejilin -59.2327 120.2221 -0.493 0.622271

provinceLiaoning 152.0575 104.9695 1.449 0.147575

provinceNingxia 207.1747 129.8595 1.595 0.110751

provinceQinghai 126.5136 209.2314 0.605 0.545459

provinceShaanxi -60.0816 102.4844 -0.586 0.557759

provinceShandong -173.9166 86.3265 -2.015 0.044047 \*

provinceShanghai -63.3872 153.7060 -0.412 0.680086

provinceShanxi -217.3109 94.9178 -2.289 0.022133 \*

provinceSichuan -6.9955 119.0332 -0.059 0.953140

provinceTianjin -82.7124 158.3228 -0.522 0.601417

provinceXinjiang 776.5183 102.9064 7.546 6.20e-14 \*\*\*

provinceYunnan -224.9119 130.0114 -1.730 0.083761 .

provinceZhejiang -193.9844 91.7951 -2.113 0.034677 \*

---

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

Residual standard error: 640.8 on 2562 degrees of freedom

Multiple R-squared: 0.4845, Adjusted R-squared: 0.4776

F-statistic: 70.81 on 34 and 2562 DF, p-value: < 2.2e-16

> model\_NOx\_lmer1 <- lmer(NOx ~ unit + capacity + type + (1|province))

> summary(model\_NOx\_lmer1)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 40957.3

Scaled residuals:

Min 1Q Median 3Q Max

-3.4004 -0.3477 -0.0347 0.2129 13.9072

Random effects:

Groups Name Variance Std.Dev.

province (Intercept) 57092 238.9

Residual 410442 640.7

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 39.38110 90.19163 0.437

unit 111.74221 9.53802 11.715

capacity 0.74395 0.02272 32.740

typeCoal -100.03385 78.76269 -1.270

typeGas & Oil -341.42598 99.82479 -3.420

typeOthers 355.72971 85.09271 4.180

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.159

capacity 0.047 -0.407

typeCoal -0.818 -0.041 -0.083

typeGas&Oil -0.654 -0.026 -0.060 0.764

typeOthers -0.748 -0.063 0.019 0.876 0.699

> model\_NOx\_lmer2 <- lmer(NOx ~ unit + capacity + type + (1+type|province))

boundary (singular) fit: see ?isSingular

> summary(model\_NOx\_lmer2)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 40822.3

Scaled residuals:

Min 1Q Median 3Q Max

-3.1507 -0.3048 -0.0002 0.2048 13.8361

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 0 0.00

typeCoal 57300 239.37 NaN

typeGas & Oil 3436 58.62 NaN 0.35

typeOthers 530230 728.17 NaN 0.12 0.97

Residual 381257 617.46

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) -73.43264 72.16792 -1.018

unit 109.11844 9.35157 11.668

capacity 0.73886 0.02202 33.559

typeCoal 20.97458 86.36848 0.243

typeGas & Oil -307.47133 93.15375 -3.301

typeOthers 619.60332 169.08538 3.664

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.192

capacity 0.074 -0.412

typeCoal -0.797 -0.040 -0.088

typeGas&Oil -0.738 -0.039 -0.067 0.657

typeOthers -0.404 -0.037 0.005 0.398 0.424

optimizer (nloptwrap) convergence code: 0 (OK)

boundary (singular) fit: see ?isSingular

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

> summary(model\_NOx\_lmer3)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 40670.9

Scaled residuals:

Min 1Q Median 3Q Max

-7.6723 -0.3350 -0.0134 0.1518 13.2464

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 34961 187.0

unit 23507 153.3 -0.84

Residual 362958 602.5

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) -71.63893 81.83737 -0.875

unit 138.34355 31.23626 4.429

capacity 0.71148 0.02221 32.036

typeCoal -44.18316 73.22612 -0.603

typeGas & Oil -321.88800 93.04213 -3.460

typeOthers 375.15439 79.36267 4.727

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.420

capacity 0.071 -0.157

typeCoal -0.833 -0.020 -0.075

typeGas&Oil -0.655 -0.022 -0.054 0.759

typeOthers -0.763 -0.021 0.020 0.874 0.693

> model\_NOx\_lmer4 <- lmer(NOx ~ 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\_NOx\_lmer4)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 40435.9

Scaled residuals:

Min 1Q Median 3Q Max

-7.3800 -0.3400 -0.0609 0.1805 16.0310

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 6.464e+05 804.0150

capacity 2.580e-01 0.5079 0.14

Residual 3.163e+05 562.3633

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 2.03062 163.97910 0.012

unit 103.16869 8.50083 12.136

typeCoal -50.83915 70.84099 -0.718

typeGas & Oil -233.93548 89.26696 -2.621

typeOthers 382.65030 76.04844 5.032

capacity 0.74761 0.09891 7.559

Correlation of Fixed Effects:

(Intr) unit typeCl typG&O typOth

unit -0.080

typeCoal -0.404 -0.040

typeGas&Oil -0.329 -0.024 0.767

typeOthers -0.370 -0.061 0.876 0.705

capacity 0.110 -0.079 -0.027 -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

> model\_PM\_lm <- lm(PM ~ unit + capacity + type + province)

> summary(model\_PM\_lm)

Call:

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

Residuals:

Min 1Q Median 3Q Max

-283.11 -25.27 -0.17 17.47 2955.69

Coefficients:

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

(Intercept) 12.464333 17.846951 0.698 0.48499

unit 12.362166 1.512203 8.175 4.60e-16 \*\*\*

capacity 0.078402 0.003608 21.730 < 2e-16 \*\*\*

typeCoal -16.461472 12.550752 -1.312 0.18978

typeGas & Oil -50.798935 15.925980 -3.190 0.00144 \*\*

typeOthers 11.776962 13.534788 0.870 0.38431

provinceBeijing 18.750011 102.700702 0.183 0.85515

provinceChongqing 12.411436 21.712814 0.572 0.56763

provinceFujian -23.484803 18.497272 -1.270 0.20433

provinceGansu 58.402514 22.655192 2.578 0.01000 \*\*

provinceGuangdong -16.078568 15.952739 -1.008 0.31360

provinceGuangxi 3.808758 21.066760 0.181 0.85654

provinceGuizhou 76.662328 23.572410 3.252 0.00116 \*\*

provinceHainan -10.143934 33.267240 -0.305 0.76045

provinceHebei -28.215677 15.546077 -1.815 0.06965 .

provinceHeilongjiang 9.061427 15.960695 0.568 0.57027

provinceHenan -41.180728 15.385260 -2.677 0.00748 \*\*

provinceHubei -12.220134 17.504212 -0.698 0.48516

provinceHunan -4.226964 20.240772 -0.209 0.83459

provinceInner Mongol 92.067130 15.000845 6.137 9.69e-10 \*\*\*

provinceJiangsu -20.780444 14.215467 -1.462 0.14391

provinceJiangxi 24.302235 19.978397 1.216 0.22393

provincejilin 13.649126 19.022486 0.718 0.47312

provinceLiaoning 24.672551 16.609109 1.485 0.13754

provinceNingxia 30.131781 20.547390 1.466 0.14265

provinceQinghai 40.392956 33.106248 1.220 0.22254

provinceShaanxi -5.246024 16.215899 -0.324 0.74633

provinceShandong -28.776569 13.659257 -2.107 0.03524 \*

provinceShanghai -29.124886 24.320584 -1.198 0.23121

provinceShanxi -28.969734 15.018640 -1.929 0.05385 .

provinceSichuan -4.728382 18.834381 -0.251 0.80180

provinceTianjin -36.639303 25.051094 -1.463 0.14370

provinceXinjiang 145.475769 16.282665 8.934 < 2e-16 \*\*\*

provinceYunnan -14.999424 20.571438 -0.729 0.46598

provinceZhejiang -31.801359 14.524550 -2.189 0.02865 \*

---

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

Residual standard error: 101.4 on 2562 degrees of freedom

Multiple R-squared: 0.3613, Adjusted R-squared: 0.3529

F-statistic: 42.63 on 34 and 2562 DF, p-value: < 2.2e-16

> model\_PM\_lmer1 <- lmer(PM ~ unit + capacity + type + (1|province))

> summary(model\_PM\_lmer1)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 31406.9

Scaled residuals:

Min 1Q Median 3Q Max

-2.8084 -0.2490 -0.0099 0.1628 29.1887

Random effects:

Groups Name Variance Std.Dev.

province (Intercept) 1690 41.11

Residual 10274 101.36

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 17.416288 14.591816 1.194

unit 12.454202 1.509434 8.251

capacity 0.078489 0.003597 21.823

typeCoal -15.052922 12.472975 -1.207

typeGas & Oil -50.920841 15.807464 -3.221

typeOthers 11.916548 13.472094 0.885

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.156

capacity 0.046 -0.407

typeCoal -0.801 -0.041 -0.083

typeGas&Oil -0.641 -0.026 -0.060 0.764

typeOthers -0.733 -0.063 0.019 0.876 0.699

> model\_PM\_lmer2 <- lmer(PM ~ unit + capacity + type + (1+type|province))

boundary (singular) fit: see ?isSingular

> summary(model\_PM\_lmer2)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 31391.4

Scaled residuals:

Min 1Q Median 3Q Max

-2.8084 -0.2547 -0.0047 0.1704 29.2771

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 60.94 7.806

typeCoal 1238.99 35.199 0.98

typeGas & Oil 53.04 7.283 -0.17 -0.35

typeOthers 653.14 25.557 0.49 0.64 -0.94

Residual 10191.97 100.955

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 0.536929 11.914773 0.045

unit 12.735461 1.508468 8.443

capacity 0.077854 0.003592 21.673

typeCoal 2.399716 13.751697 0.175

typeGas & Oil -53.731385 15.314685 -3.508

typeOthers 23.711817 14.238934 1.665

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.187

capacity 0.069 -0.409

typeCoal -0.756 -0.039 -0.089

typeGas&Oil -0.733 -0.040 -0.064 0.638

typeOthers -0.763 -0.063 0.012 0.801 0.580

optimizer (nloptwrap) convergence code: 0 (OK)

boundary (singular) fit: see ?isSingular

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

boundary (singular) fit: see ?isSingular

> summary(model\_PM\_lmer3)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 31082.1

Scaled residuals:

Min 1Q Median 3Q Max

-9.4174 -0.2367 -0.0188 0.0913 30.3607

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 193.5 13.91

unit 491.4 22.17 -1.00

Residual 9030.4 95.03

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) -0.596657 11.567347 -0.052

unit 16.848589 4.509384 3.736

capacity 0.073971 0.003463 21.361

typeCoal -7.663213 11.291021 -0.679

typeGas & Oil -49.033849 14.423770 -3.400

typeOthers 15.343831 12.294053 1.248

Correlation of Fixed Effects:

(Intr) unit capcty typeCl typG&O

unit -0.291

capacity 0.088 -0.175

typeCoal -0.917 -0.013 -0.076

typeGas&Oil -0.719 -0.015 -0.060 0.755

typeOthers -0.838 -0.018 0.018 0.874 0.686

optimizer (nloptwrap) convergence code: 0 (OK)

boundary (singular) fit: see ?isSingular

> model\_PM\_lmer4 <- lmer(PM ~ 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\_PM\_lmer4)

Linear mixed model fit by REML ['lmerMod']

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

REML criterion at convergence: 30632.7

Scaled residuals:

Min 1Q Median 3Q Max

-5.400 -0.233 -0.051 0.097 33.694

Random effects:

Groups Name Variance Std.Dev. Corr

province (Intercept) 9.495e+03 97.44226

capacity 8.772e-03 0.09366 -0.47

Residual 7.216e+03 84.94945

Number of obs: 2597, groups: province, 30

Fixed effects:

Estimate Std. Error t value

(Intercept) 8.51670 20.94248 0.407

unit 10.34091 1.28464 8.050

typeCoal -6.54237 10.71292 -0.611

typeGas & Oil -34.04032 13.48899 -2.524

typeOthers 14.33968 11.49719 1.247

capacity 0.08883 0.01798 4.941

Correlation of Fixed Effects:

(Intr) unit typeCl typG&O typOth

unit -0.095

typeCoal -0.478 -0.039

typeGas&Oil -0.389 -0.024 0.767

typeOthers -0.438 -0.061 0.876 0.706

capacity -0.391 -0.065 -0.022 -0.010 -0.001

optimizer (nloptwrap) convergence code: 0 (OK)

unable to evaluate scaled gradient

Model failed to converge: degenerate Hessian with 1 negative eigenvalues

|  |
| --- |
| SO2 lm:  > 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 |

SO2 lm 为传统 OLS 回归模型

|  |
| --- |
| SO2 lmer1:  > summary(model\_SO2\_lmer1)$coef  Estimate Std. Error t value  (Intercept) 83.379217 89.80494649 0.9284479  unit 51.640766 6.21804948 8.3049782  capacity 0.437314 0.01483168 29.4851271  typeCoal 25.430767 51.56204222 0.4932071  typeGas & Oil -201.885438 65.36517781 -3.0885778  typeOthers 79.889779 55.62213198 1.4362948 |
| SO2 lmer2:  > summary(model\_SO2\_lmer2)$coef  Estimate Std. Error t value  (Intercept) -36.8871464 48.35830807 -0.7627882  unit 53.8629723 6.18193762 8.7129595  capacity 0.4333927 0.01476669 29.3493433  typeCoal 153.0041191 91.46808276 1.6727597  typeGas & Oil -199.8652025 68.55871618 -2.9152413  typeOthers 122.8371385 64.20551823 1.9131866 |
| SO2 lmer3:  > summary(model\_SO2\_lmer3)$coef  Estimate Std. Error t value  (Intercept) -34.6650610 50.92669319 -0.6806855  unit 96.3392220 29.71687657 3.2419027  capacity 0.4148784 0.01421341 29.1892158  typeCoal 48.2943016 47.15235842 1.0242182  typeGas & Oil -194.9199141 59.90984192 -3.2535541  typeOthers 83.0586487 50.99568197 1.6287389 |
| SO2 lmer4:  > summary(model\_SO2\_lmer4)$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 |

* SO2 lmer1为随机截距模型

y = 83.379217 + 51.64unit + 0.44 capacity + 25.43Coal -201.88Gas&Oil + 79.89Others

* SO2 lmer2为随机斜率模型、unit（装机数量），capacity（装机容量）为固定斜率，type（燃料类型）province（省份）为随机截距

y = -36.88 + 53.86unit + 0.43 capacity + 153.00Coal -199.86Gas&Oil + 122.83Others

* SO2 lmer3为随机斜率模型、type（燃料类型），capacity（装机容量）为固定斜率， unit（装机数量）province（省份）为随机截距

y = -34.66 + 96.33unit + 0.414 capacity + 48.29Coal -194.91Gas&Oil + 83.05Others

* SO2 lmer4为随机斜率模型、unit（装机数量）， type（燃料类型）为固定斜率， capacity（装机容量）province（省份）为随机截距

y = 16.72 + 45.00unit + 0.530 capacity + 40.81Coal -152.49Gas&Oil + 73.89Others

SO2 各模型中，

装机数量系数趋于稳定，处于50 上下，在lmer3中明显正相关。

装机容量也处于稳定状态，处于0.4上下。

燃料类型中煤炭在各模型中处于正相关，在lmer2中展现正明显相关 。

燃料类型中天然气和石油在模型中处于负相关，介入-200上下。

燃料类型中其他燃料种类在个模型中都处于正相关，系数在85上下。

|  |
| --- |
| NOx lm:  > summary(model\_NOx\_lm)$coef  Estimate Std. Error t value Pr(>|t|)  (Intercept) 26.0750829 112.79268676 0.23117707 8.171957e-01  unit 111.4989409 9.55712211 11.66658118 1.110940e-30  capacity 0.7419849 0.02280288 32.53909255 1.063138e-194  typeCoal -111.7358624 79.32072113 -1.40865919 1.590573e-01  typeGas & Oil -342.2611169 100.65215862 -3.40043494 6.830938e-04  typeOthers 354.3655154 85.53982680 4.14269620 3.543673e-05  provinceBeijing 55.1904193 649.06819352 0.08503023 9.322440e-01  provinceChongqing -9.5452636 137.22493282 -0.06955925 9.445499e-01  provinceFujian -215.9398390 116.90271281 -1.84717560 6.483692e-02  provinceGansu 24.3289668 143.18075727 0.16991785 8.650882e-01  provinceGuangdong -93.5339473 100.82127445 -0.92772034 3.536400e-01  provinceGuangxi 79.8209934 133.14187432 0.59951832 5.488803e-01  provinceGuizhou 692.9620846 148.97757508 4.65145230 3.463514e-06  provinceHainan -227.7816075 210.24887983 -1.08339035 2.787371e-01  provinceHebei -147.0859014 98.25116691 -1.49703974 1.345061e-01  provinceHeilongjiang 39.6656595 100.87155344 0.39322939 6.941828e-01  provinceHenan -239.0503899 97.23480907 -2.45848572 1.401815e-02  provinceHubei -113.4665729 110.62657858 -1.02567190 3.051431e-01  provinceHunan 87.3606106 127.92163178 0.68292289 4.947173e-01  provinceInner Mongol 451.1362628 94.80530420 4.75855509 2.058164e-06  provinceJiangsu -14.9010405 89.84171650 -0.16585881 8.682811e-01  provinceJiangxi 248.8513695 126.26342376 1.97089040 4.884390e-02  provincejilin -59.2326983 120.22206736 -0.49269406 6.222710e-01  provinceLiaoning 152.0574917 104.96953118 1.44858694 1.475753e-01  provinceNingxia 207.1746914 129.85945828 1.59537622 1.107515e-01  provinceQinghai 126.5135894 209.23140969 0.60465869 5.454593e-01  provinceShaanxi -60.0816050 102.48444139 -0.58625099 5.577585e-01  provinceShandong -173.9165731 86.32647341 -2.01463776 4.404692e-02  provinceShanghai -63.3871965 153.70602978 -0.41239239 6.800863e-01  provinceShanxi -217.3108799 94.91776767 -2.28946471 2.213334e-02  provinceSichuan -6.9955520 119.03324163 -0.05876973 9.531401e-01  provinceTianjin -82.7123834 158.32285468 -0.52242858 6.014171e-01  provinceXinjiang 776.5182985 102.90640593 7.54586939 6.203681e-14  provinceYunnan -224.9119446 130.01143852 -1.72993967 8.376149e-02  provinceZhejiang -193.9844048 91.79512116 -2.11323219 3.467735e-02 |

NOx lm 为传统 OLS 回归模型

|  |
| --- |
| NOx lmer1:  > summary(model\_NOx\_lmer1)$coef  Estimate Std. Error t value  (Intercept) 39.3810956 90.19162628 0.436638  unit 111.7422108 9.53802482 11.715446  capacity 0.7439535 0.02272277 32.740436  typeCoal -100.0338451 78.76268623 -1.270066  typeGas & Oil -341.4259831 99.82479495 -3.420252  typeOthers 355.7297075 85.09271492 4.180495 |
| NOx lmer2:  > summary(model\_NOx\_lmer2)$coef  Estimate Std. Error t value  (Intercept) -73.4326406 72.16791737 -1.017525  unit 109.1184397 9.35157138 11.668460  capacity 0.7388597 0.02201696 33.558658  typeCoal 20.9745816 86.36847574 0.242850  typeGas & Oil -307.4713326 93.15375400 -3.300686  typeOthers 619.6033169 169.08537828 3.664441 |
| NOx lmer3:  > summary(model\_NOx\_lmer3)$coef  Estimate Std. Error t value  (Intercept) -71.6389333 81.83736523 -0.8753817  unit 138.3435546 31.23626053 4.4289410  capacity 0.7114831 0.02220918 32.0355437  typeCoal -44.1831610 73.22612185 -0.6033798  typeGas & Oil -321.8880025 93.04213347 -3.4595940  typeOthers 375.1543864 79.36267200 4.7270887 |
| NOx lmer4:  > summary(model\_NOx\_lmer4)$coef  Estimate Std. Error t value  (Intercept) 2.0306226 163.97909635 0.01238342  unit 103.1686851 8.50083352 12.13630227  typeCoal -50.8391482 70.84098927 -0.71765158  typeGas & Oil -233.9354850 89.26696262 -2.62062781  typeOthers 382.6502979 76.04843833 5.03166543  capacity 0.7476123 0.09890535 7.55886569 |

* NOx lmer1为随机截距模型

y = 39.38 + 111.74unit + 0.74 capacity - 100.03Coal -341.42Gas&Oil + 355.72Others

* NOx lmer2为随机斜率模型、unit（装机数量），capacity（装机容量）为固定斜率，type（燃料类型）province（省份）为随机截距

y = -73.43 + 109.11unit + 0.73 capacity + 20.97Coal -307.47Gas&Oil + 619.60thers

* NOx lmer3为随机斜率模型、type（燃料类型），capacity（装机容量）为固定斜率， unit（装机数量）province（省份）为随机截距

y = -71.64 + 138.34unit + 0.71 capacity - 44.18Coal -321.88Gas&Oil + 375.15Others

* NOx lmer4为随机斜率模型、unit（装机数量）， type（燃料类型）为固定斜率， capacity（装机容量）province（省份）为随机截距

y = 2.03 + 103.19unit – 0.74 capacity - 50.83Coal -233.94Gas&Oil + 382.65others

NOx 各模型中，

装机数量系数趋于稳定，处于100～115 之间。

装机容量也处于稳定状态，处于0.75上下。

燃料类型中煤炭在lmer1 中处于负明显相关，在lmer2中处于正相关，lmer3和lmer4中处于负相关。

燃料类型中天然气和石油在模型中处于负相关，介入-233 到 -350区间。

燃料类型中其他燃料种类在个模型中都处于正相关，系数在400上下， 在lmer2中处于明显真相关。

|  |
| --- |
| PM lm:  > summary(model\_PM\_lm)$coef  Estimate Std. Error t value Pr(>|t|)  (Intercept) 12.46433303 1.784695e+01 0.6984013 4.849897e-01  unit 12.36216637 1.512203e+00 8.1749360 4.601730e-16  capacity 0.07840172 3.608051e-03 21.7296575 3.132761e-96  typeCoal -16.46147170 1.255075e+01 -1.3115925 1.897752e-01  typeGas & Oil -50.79893490 1.592598e+01 -3.1896896 1.441455e-03  typeOthers 11.77696178 1.353479e+01 0.8701253 3.843134e-01  provinceBeijing 18.75001120 1.027007e+02 0.1825695 8.551503e-01  provinceChongqing 12.41143586 2.171281e+01 0.5716180 5.676309e-01  provinceFujian -23.48480297 1.849727e+01 -1.2696361 2.043296e-01  provinceGansu 58.40251398 2.265519e+01 2.5778866 9.996050e-03  provinceGuangdong -16.07856811 1.595274e+01 -1.0078876 3.136036e-01  provinceGuangxi 3.80875785 2.106676e+01 0.1807947 8.565431e-01  provinceGuizhou 76.66232822 2.357241e+01 3.2522058 1.159990e-03  provinceHainan -10.14393413 3.326724e+01 -0.3049226 7.604499e-01  provinceHebei -28.21567654 1.554608e+01 -1.8149709 6.964527e-02  provinceHeilongjiang 9.06142704 1.596069e+01 0.5677339 5.702654e-01  provinceHenan -41.18072791 1.538526e+01 -2.6766351 7.483949e-03  provinceHubei -12.22013367 1.750421e+01 -0.6981253 4.851622e-01  provinceHunan -4.22696382 2.024077e+01 -0.2088341 8.345943e-01  provinceInner Mongol 92.06713034 1.500084e+01 6.1374630 9.686897e-10  provinceJiangsu -20.78044386 1.421547e+01 -1.4618193 1.439134e-01  provinceJiangxi 24.30223502 1.997840e+01 1.2164256 2.239349e-01  provincejilin 13.64912553 1.902249e+01 0.7175258 4.731151e-01  provinceLiaoning 24.67255057 1.660911e+01 1.4854831 1.375389e-01  provinceNingxia 30.13178067 2.054739e+01 1.4664529 1.426477e-01  provinceQinghai 40.39295595 3.310625e+01 1.2201007 2.225390e-01  provinceShaanxi -5.24602380 1.621590e+01 -0.3235111 7.463346e-01  provinceShandong -28.77656922 1.365926e+01 -2.1067448 3.523670e-02  provinceShanghai -29.12488597 2.432058e+01 -1.1975406 2.312067e-01  provinceShanxi -28.96973435 1.501864e+01 -1.9289186 5.385130e-02  provinceSichuan -4.72838237 1.883438e+01 -0.2510506 8.017951e-01  provinceTianjin -36.63930336 2.505109e+01 -1.4625830 1.437042e-01  provinceXinjiang 145.47576915 1.628267e+01 8.9343953 7.644140e-19  provinceYunnan -14.99942371 2.057144e+01 -0.7291383 4.659837e-01  provinceZhejiang -31.80135861 1.452455e+01 -2.1894901 2.865115e-02 |

PM lm 为传统 OLS 回归模型

|  |
| --- |
| PM lmer1:  > summary(model\_PM\_lmer1)$coef  Estimate Std. Error t value  (Intercept) 17.41628810 14.591816012 1.1935655  unit 12.45420239 1.509434164 8.2509080  capacity 0.07848902 0.003596672 21.8226759  typeCoal -15.05292153 12.472974779 -1.2068429  typeGas & Oil -50.92084113 15.807464466 -3.2213162  typeOthers 11.91654794 13.472094205 0.8845357 |
| PM lmer2:  > summary(model\_PM\_lmer2)$coef  Estimate Std. Error t value  (Intercept) 0.53692860 11.914773323 0.0450641  unit 12.73546100 1.508467612 8.4426480  capacity 0.07785358 0.003592131 21.6733693  typeCoal 2.39971557 13.751696851 0.1745032  typeGas & Oil -53.73138534 15.314685330 -3.5084877  typeOthers 23.71181678 14.238933960 1.6652803 |
| PM lmer3:  > summary(model\_PM\_lmer3)$coef  Estimate Std. Error t value  (Intercept) -0.59665666 11.567347474 -0.05158111  unit 16.84858853 4.509384007 3.73633927  capacity 0.07397062 0.003462833 21.36130255  typeCoal -7.66321319 11.291021465 -0.67869973  typeGas & Oil -49.03384945 14.423770169 -3.39951683  typeOthers 15.34383053 12.294052824 1.24806935 |
| PM lmer4:  > summary(model\_PM\_lmer4)$coef  Estimate Std. Error t value  (Intercept) 8.51669657 20.94248096 0.4066709  unit 10.34091239 1.28463934 8.0496619  typeCoal -6.54237263 10.71291658 -0.6106995  typeGas & Oil -34.04031964 13.48898799 -2.5235636  typeOthers 14.33968124 11.49718548 1.2472341  capacity 0.08883311 0.01797832 4.9411248 |

* PM lmer1为随机截距模型

y = 17.41628810 + 12.45420239 unit + 0.07 capacity -15.05292153 Coal -50.92084113 Gas&Oil + 11.91654794 Others

* PM lmer2为随机斜率模型、unit（装机数量），capacity（装机容量）为固定斜率，type（燃料类型）province（省份）为随机截距

y = 0.536 + 12.74unit + 0.07 capacity + 2.39Coal -53.73Gas&Oil + 23.71Others

* PM lmer3为随机斜率模型、type（燃料类型），capacity（装机容量）为固定斜率， unit（装机数量）province（省份）为随机截距

y = -0.596657 + 16.85unit + 0.0739 capacity -7.66Coal -49.03Gas&Oil + 15.34Others

* PM lmer4为随机斜率模型、unit（装机数量）， type（燃料类型）为固定斜率， capacity（装机容量）province（省份）为随机截距

y = 8.51 + 10.34unit + 0.08 capacity – 6.54Coal - 34.04Gas&Oil + 14.33Others

PM 各模型中，

装机数量系数趋于稳定，处于10～17 之间。

装机容量也处于稳定状态，处于0.07上下。

燃料类型中煤炭在lmer1 中处于负明显相关，在lmer2中处于微弱正相关，lmer3和lmer4中处于微弱负相关。

燃料类型中天然气和石油系数在各模型中也处于稳定状态，介入-34 到 -55区间。

燃料类型中其他燃料种类在个模型中都处于正相关，系数在11～24之间

总结：

3个模型中，

装机数量对NOx的影响最为深刻，其次SO2，最后PM

装机容量对SO2，NOx，PM影响都很微弱，（不足1），PM的影响只有0.07，可以忽略不计

燃料类型中煤炭只对SO2产生正相关影响，NOx和PM都为负相关（只有其中一个lmer模型为正相关），燃烧煤炭对空气中SO2含量产生积极影响

燃料类型中天然气和燃油对三种气体都是负相关影响，燃烧天然气对SO2，NOx，PM都没有积极的影响

燃料类型中其他燃料种类对PM和SO2有积极影响，对NOx有明显积极影响。暂不清楚其他燃料种类里究竟是哪种化学物质导致空气中NOx的含量会激增。