main

November 4, 2024

0.1 1) Formulate question

House prices are determined by a multitude of variables, but which one(s) have the biggest effect?

Here, we have data that can give us a clue as to what variables influence house prices, in addition to creating to a model for predicting house prices for those in other locations (e.g. New York, St. Louis, Atlanta).

0.2 2) Gather data

0.2.1 Background info:

The Boston house-price data of Harrison, D. and Rubinfeld, D.L. 'Hedonic prices and the demand for clean air', J. Environ. Economics & Management, vol.5, 81-102, 1978. Used in Belsley, Kuh & Welsch, 'Regression diagnostics …', Wiley, 1980. N.B. Various transformations are used in the table on pages 244-261 of the latter.

Variables (in order):

- **CRIM**: Per capita crime rate by town
- **ZN**: Proportion of residential land zoned for lots over 25,000 sq.ft.
- **INDUS**: Proportion of non-retail business acres per town
- **CHAS**: Charles River dummy variable (1 if tract bounds river; 0 otherwise)
- **NOX**: Nitric oxides concentration (parts per 10 million)
- **RM**: Average number of rooms per dwelling
- **AGE**: Proportion of owner-occupied units built prior to 1940
- **DIS**: Weighted distances to five Boston employment centres
- **RAD**: Index of accessibility to radial highways
- **TAX**: Full-value property-tax rate per $10,000
- **PTRATIO**: Pupil-teacher ratio by town
- **B**: 1000(Bk - 0.63)^2 where Bk is the proportion of blacks by town
- **LSTAT**: % lower status of the population
- **MEDV**: Median value of owner-occupied homes in $1000's (target variable)

	CRIM	ZN	INDUS	CHAS	NOX	RM	AGE	DIS	RAD	TAX	\
0	0.00632	18.0	2.31	0.0	0.538	6.575	65.2	4.0900	1.0	296.0	
1	0.02731	0.0	7.07	0.0	0.469	6.421	78.9	4.9671	2.0	242.0	
2	0.02729	0.0	7.07	0.0	0.469	7.185	61.1	4.9671	2.0	242.0	
3	0.03237	0.0	2.18	0.0	0.458	6.998	45.8	6.0622	3.0	222.0	
4	0.06905	0.0	2.18	0.0	0.458	7.147	54.2	6.0622	3.0	222.0	

	PTRATIO	B	LSTAT	MEDV
0	15.3	396.90	4.98	24.0
1	17.8	396.90	9.14	21.6
2	17.8	392.83	4.03	34.7
3	18.7	394.63	2.94	33.4
4	18.7	396.90	5.33	36.2

0.3 3) Clean/preprocess data

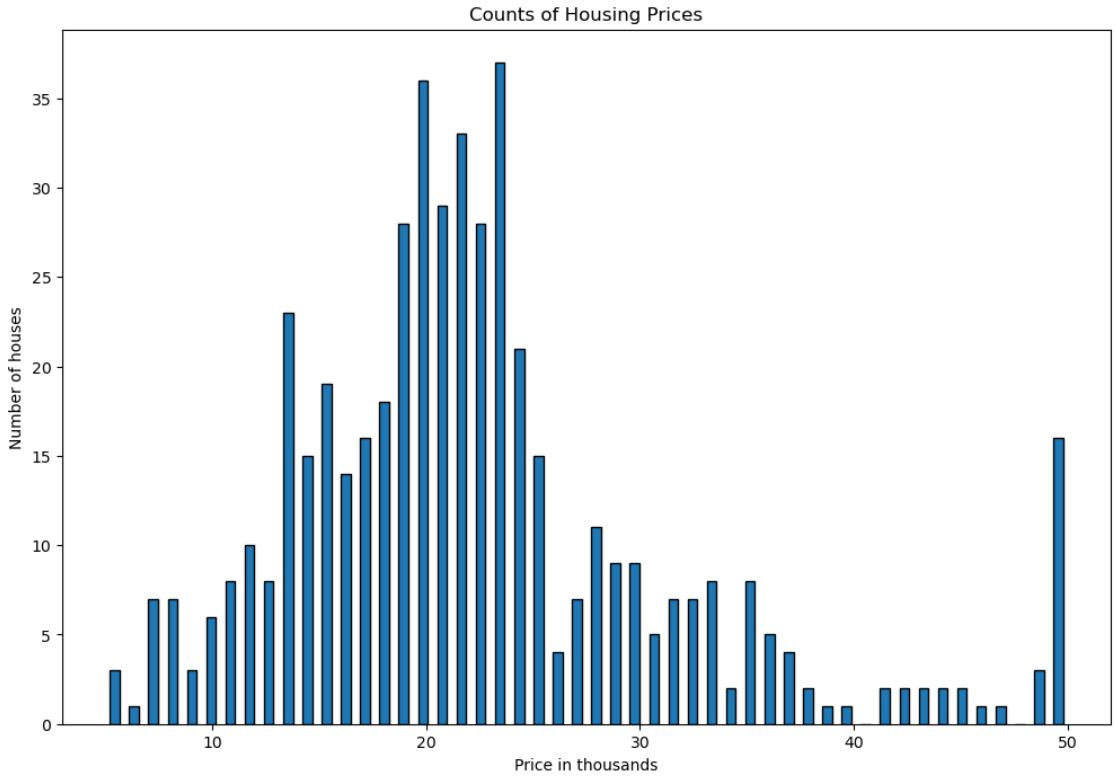
(506, 14)

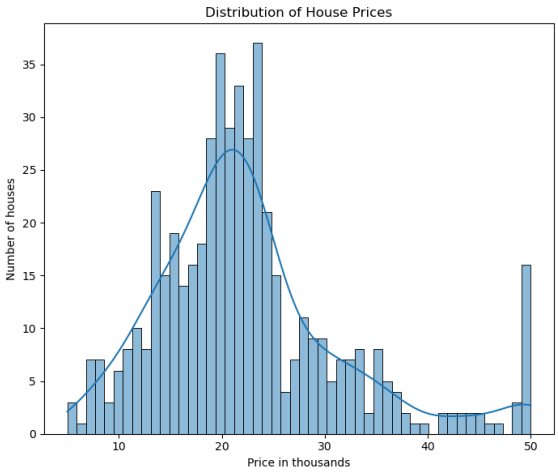
	CRIM	ZN	INDUS	CHAS	NOX	RM	\
count	506.000000	506.000000	506.000000	506.000000	506.000000	506.000000	
mean	3.613524	11.363636	11.136779	0.069170	0.554695	6.284634	
std	8.601545	23.322453	6.860353	0.253994	0.115878	0.702617	
min	0.006320	0.000000	0.460000	0.000000	0.385000	3.561000	
25%	0.082045	0.000000	5.190000	0.000000	0.449000	5.885500	
50%	0.256510	0.000000	9.690000	0.000000	0.538000	6.208500	
75%	3.677083	12.500000	18.100000	0.000000	0.624000	6.623500	
max	88.976200	100.000000	27.740000	1.000000	0.871000	8.780000	

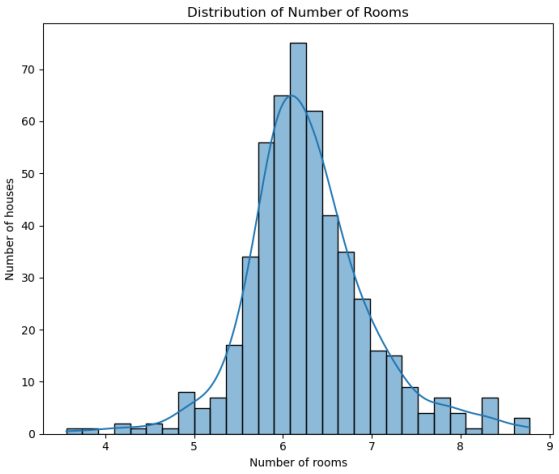
	AGE	DIS	RAD	TAX	PTRATIO	B	\
count	506.000000	506.000000	506.000000	506.000000	506.000000	506.000000	
mean	68.574901	3.795043	9.549407	408.237154	18.455534	356.674032	
std	28.148861	2.105710	8.707259	168.537116	2.164946	91.294864	
min	2.900000	1.129600	1.000000	187.000000	12.600000	0.320000	
25%	45.025000	2.100175	4.000000	279.000000	17.400000	375.377500	
50%	77.500000	3.207450	5.000000	330.000000	19.050000	391.440000	
75%	94.075000	5.188425	24.000000	666.000000	20.200000	396.225000	
max	100.000000	12.126500	24.000000	711.000000	22.000000	396.900000	

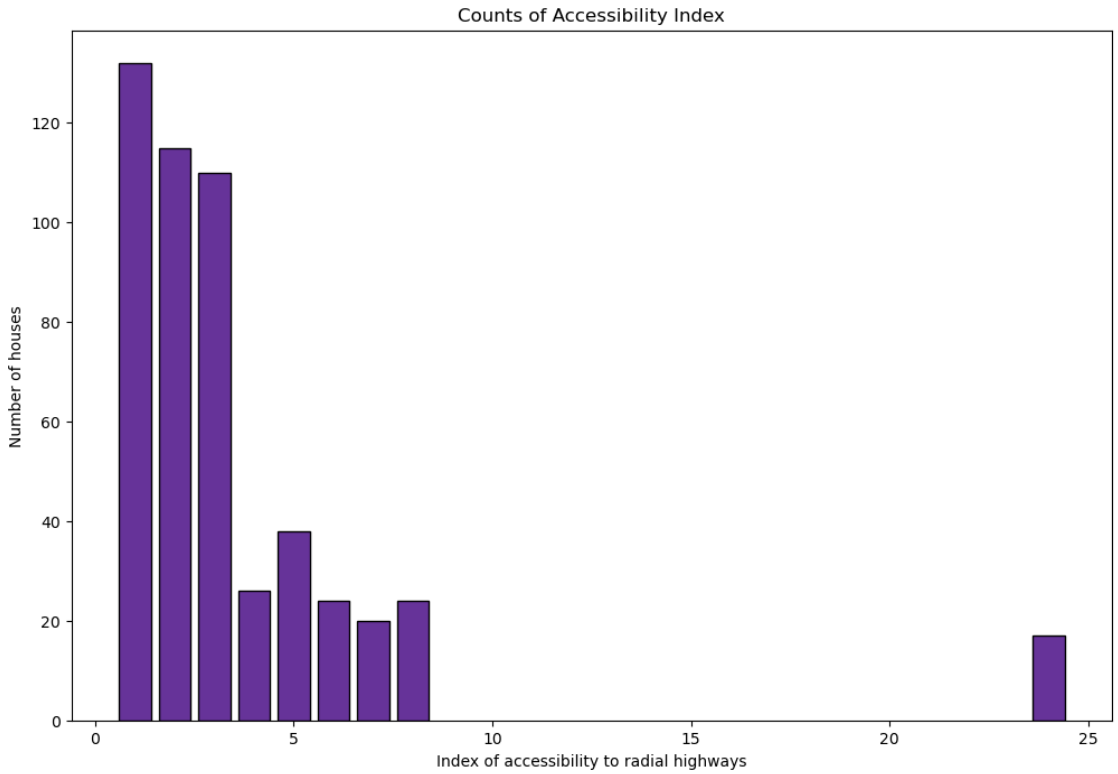
	LSTAT	MEDV
count	506.000000	506.000000
mean	12.653063	22.532806
std	7.141062	9.197104
min	1.730000	5.000000
25%	6.950000	17.025000
50%	11.360000	21.200000
75%	16.955000	25.000000
max	37.970000	50.000000

1 4) Visualize data









1.1 Descriptive Statistics

	CRIM	ZN	INDUS	CHAS	NOX	RM	\
count	506.000000	506.000000	506.000000	506.000000	506.000000	506.000000	
mean	3.613524	11.363636	11.136779	0.069170	0.554695	6.284634	
std	8.601545	23.322453	6.860353	0.253994	0.115878	0.702617	
min	0.006320	0.000000	0.460000	0.000000	0.385000	3.561000	
25%	0.082045	0.000000	5.190000	0.000000	0.449000	5.885500	
50%	0.256510	0.000000	9.690000	0.000000	0.538000	6.208500	
75%	3.677083	12.500000	18.100000	0.000000	0.624000	6.623500	
max	88.976200	100.000000	27.740000	1.000000	0.871000	8.780000	

	AGE	DIS	RAD	TAX	PTRATIO	B	\
count	506.000000	506.000000	506.000000	506.000000	506.000000	506.000000	
mean	68.574901	3.795043	9.549407	408.237154	18.455534	356.674032	
std	28.148861	2.105710	8.707259	168.537116	2.164946	91.294864	
min	2.900000	1.129600	1.000000	187.000000	12.600000	0.320000	
25%	45.025000	2.100175	4.000000	279.000000	17.400000	375.377500	
50%	77.500000	3.207450	5.000000	330.000000	19.050000	391.440000	
75%	94.075000	5.188425	24.000000	666.000000	20.200000	396.225000	
max	100.000000	12.126500	24.000000	711.000000	22.000000	396.900000	

	LSTAT	MEDV
count	506.000000	506.000000
mean	12.653063	22.532806
std	7.141062	9.197104
min	1.730000	5.000000
25%	6.950000	17.025000
50%	11.360000	21.200000
75%	16.955000	25.000000
max	37.970000	50.000000

1.2 Inferential Statistics

1.2.1 Correlation

$$\rho_{XY} = Corr(XY)$$

$$-1.0 \leq \rho_{XY} \leq +1.0$$

	CRIM	ZN	INDUS	CHAS	NOX	RM	AGE	\
CRIM	1.000000	-0.200469	0.406583	-0.055892	0.420972	-0.219247	0.352734	
ZN	-0.200469	1.000000	-0.533828	-0.042697	-0.516604	0.311991	-0.569537	
INDUS	0.406583	-0.533828	1.000000	0.062938	0.763651	-0.391676	0.644779	
CHAS	-0.055892	-0.042697	0.062938	1.000000	0.091203	0.091251	0.086518	
NOX	0.420972	-0.516604	0.763651	0.091203	1.000000	-0.302188	0.731470	
RM	-0.219247	0.311991	-0.391676	0.091251	-0.302188	1.000000	-0.240265	
AGE	0.352734	-0.569537	0.644779	0.086518	0.731470	-0.240265	1.000000	
DIS	-0.379670	0.664408	-0.708027	-0.099176	-0.769230	0.205246	-0.747881	
RAD	0.625505	-0.311948	0.595129	-0.007368	0.611441	-0.209847	0.456022	
TAX	0.582764	-0.314563	0.720760	-0.035587	0.668023	-0.292048	0.506456	
PTRATIO	0.289946	-0.391679	0.383248	-0.121515	0.188933	-0.355501	0.261515	
B	-0.385064	0.175520	-0.356977	0.048788	-0.380051	0.128069	-0.273534	
LSTAT	0.455621	-0.412995	0.603800	-0.053929	0.590879	-0.613808	0.602339	
MEDV	-0.388305	0.360445	-0.483725	0.175260	-0.427321	0.695360	-0.376955	

	DIS	RAD	TAX	PTRATIO	B	LSTAT	MEDV
CRIM	-0.379670	0.625505	0.582764	0.289946	-0.385064	0.455621	-0.388305
ZN	0.664408	-0.311948	-0.314563	-0.391679	0.175520	-0.412995	0.360445
INDUS	-0.708027	0.595129	0.720760	0.383248	-0.356977	0.603800	-0.483725
CHAS	-0.099176	-0.007368	-0.035587	-0.121515	0.048788	-0.053929	0.175260
NOX	-0.769230	0.611441	0.668023	0.188933	-0.380051	0.590879	-0.427321
RM	0.205246	-0.209847	-0.292048	-0.355501	0.128069	-0.613808	0.695360
AGE	-0.747881	0.456022	0.506456	0.261515	-0.273534	0.602339	-0.376955
DIS	1.000000	-0.494588	-0.534432	-0.232471	0.291512	-0.496996	0.249929
RAD	-0.494588	1.000000	0.910228	0.464741	-0.444413	0.488676	-0.381626

```
TAX     -0.534432  0.910228  1.000000  0.460853 -0.441808  0.543993 -0.468536
PTRATIO -0.232471  0.464741  0.460853  1.000000 -0.177383  0.374044 -0.507787
B        0.291512 -0.444413 -0.441808 -0.177383  1.000000 -0.366087  0.333461
LSTAT   -0.496996  0.488676  0.543993  0.374044 -0.366087  1.000000 -0.737663
MEDV     0.249929 -0.381626 -0.468536 -0.507787  0.333461 -0.737663  1.000000
```

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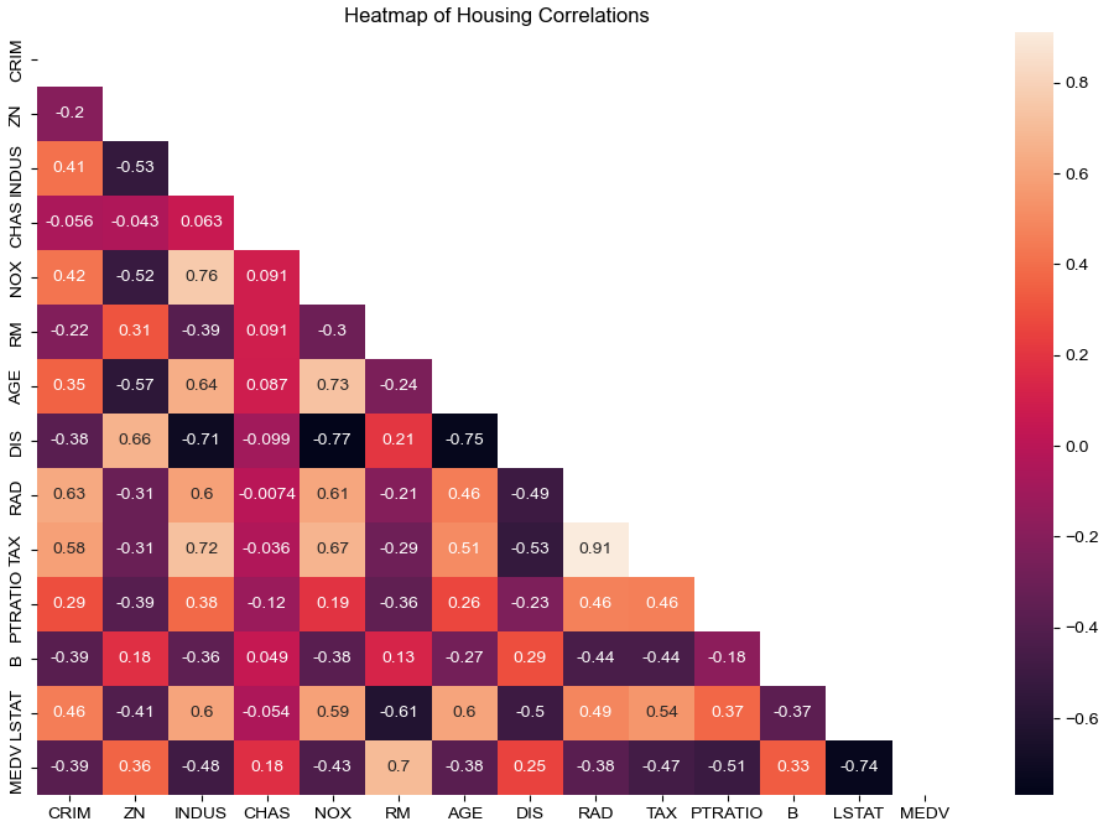
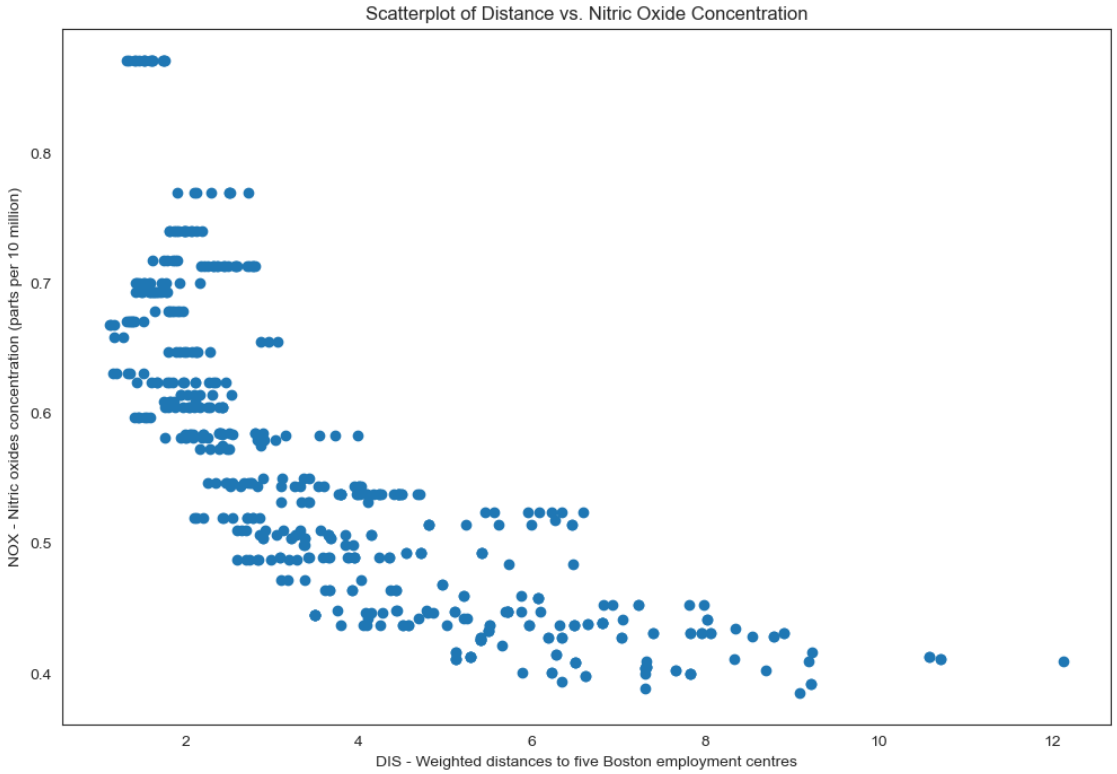
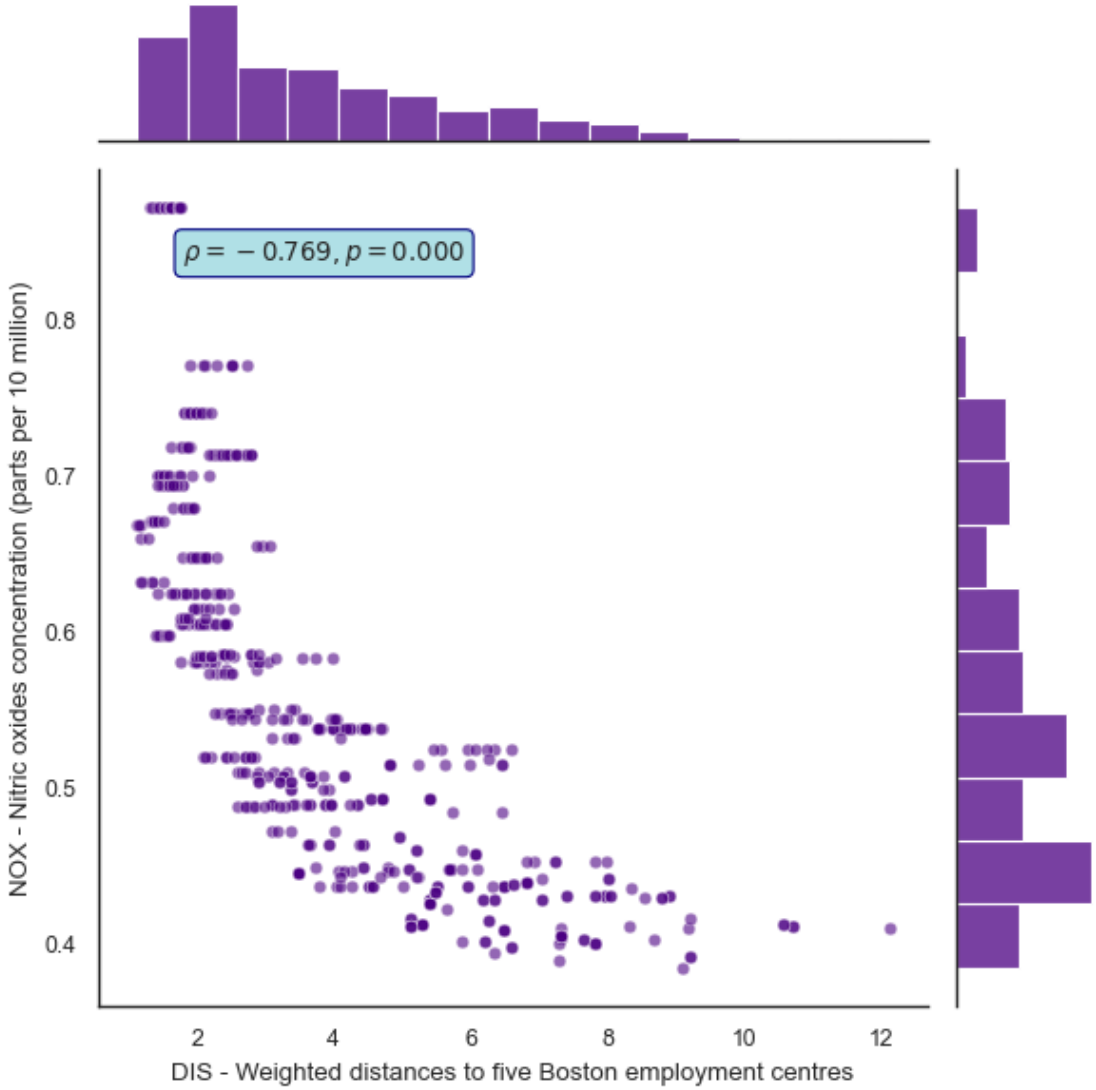
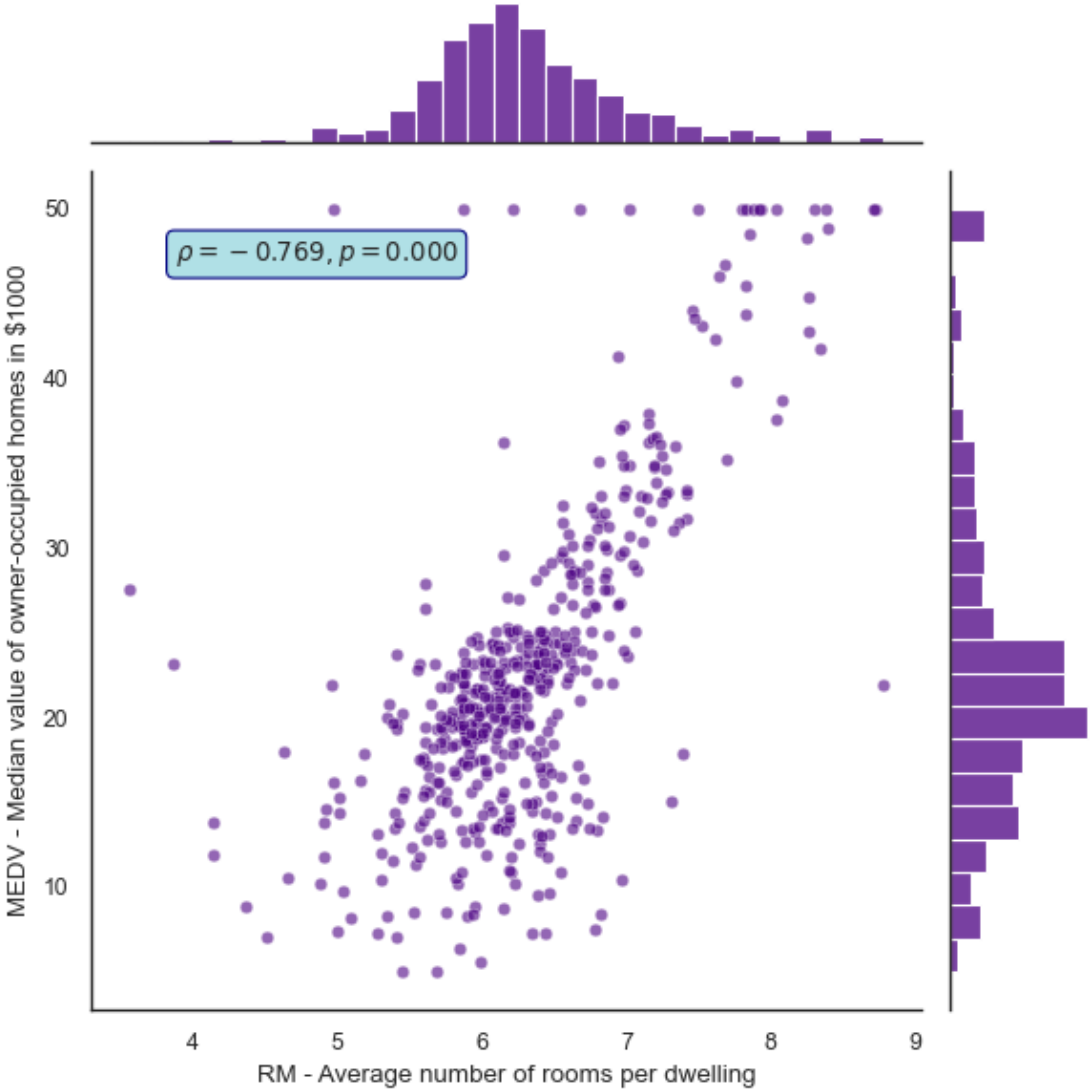
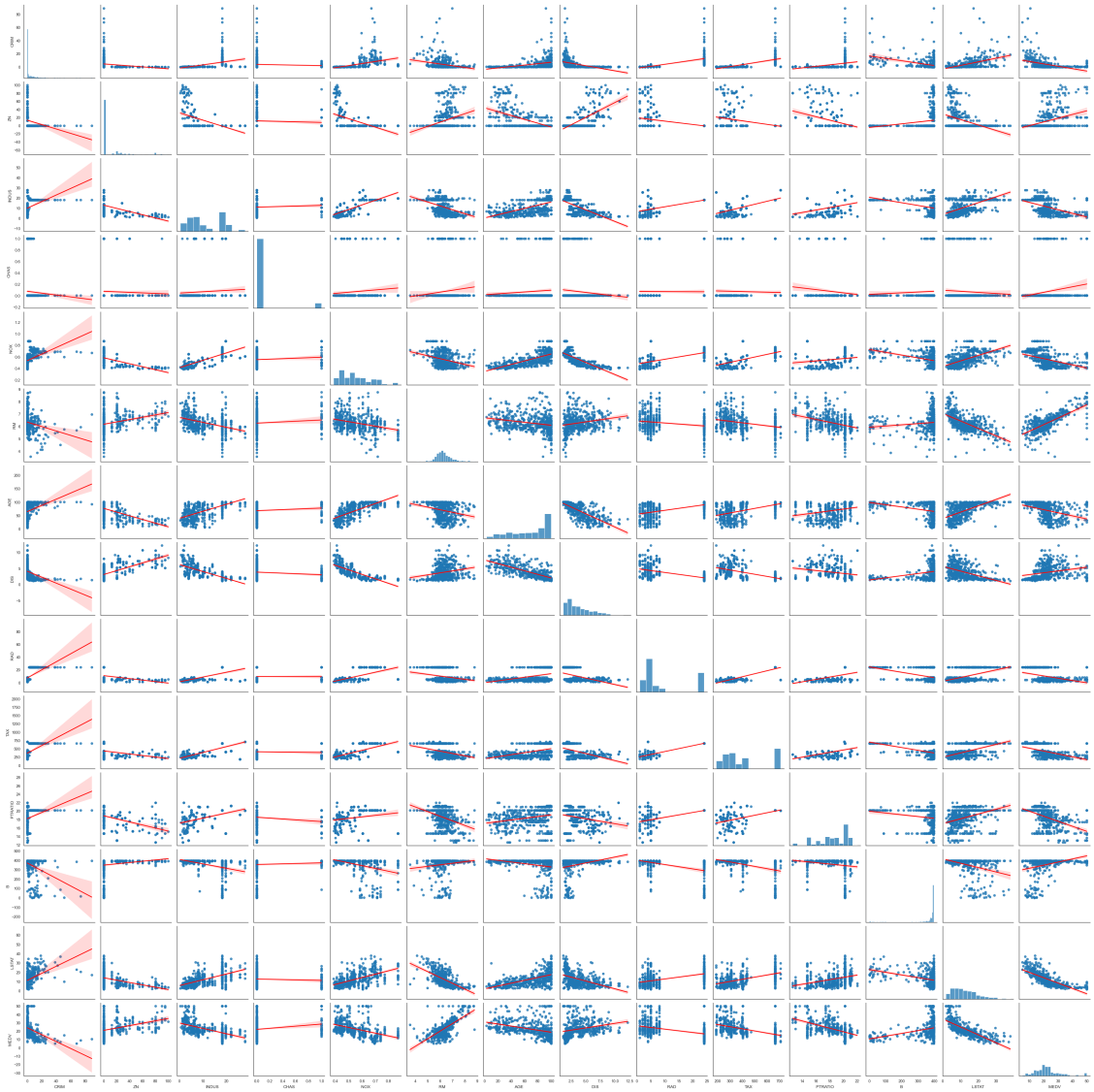



Scatterplot of Distance vs. Nitric Oxide Concentration
NOX - Nitric oxides concentration (parts per 10 million)
0.8
0.7
0.6
0.5
0.4
2
4
6
8
10
12
DIS - Weighted distances to five Boston employment centres


$\rho = -0.769, p = 0.000$
NOX - Nitric oxides concentration (parts per 10 million)
0.8
0.7
0.6
0.5
0.4
2
4
6
8
10
12
DIS - Weighted distances to five Boston employment centres


$\rho = -0.769, p = 0.000$
MEDV - Median value of owner-occupied homes in $1000
RM - Average number of rooms per dwelling
50
40
30
20
10
4
5
6
7
8
9



```
CPU times: user 52.7 s, sys: 721 ms, total: 53.4 s
Wall time: 56.8 s
```

1.3 5) Train & build algorithm: Multiple Regression

1.3.1 Training & testing sets

1.3.2 Training Results

```
R-squared:  0.750121534530608
         Coefficients
CRIM         -0.128181
ZN            0.063198
INDUS        -0.007576
CHAS          1.974515
```

```
NOX        -16.271989
RM           3.108456
AGE          0.016292
DIS         -1.483014
RAD          0.303988
TAX         -0.012082
PTRATIO     -0.820306
B            0.011419
LSTAT       -0.581626
Intercept:  36.53305138282434
```

```
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 13.32233024 22.40099547 24.18543936 31.58822487 33.13516905  6.5126739
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  8.94474091 20.22604989 14.63275313 36.27993935 19.64984827  1.08767142
 18.66415262 35.82218783 34.09308555 18.76537952 35.19869636  8.27271481
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 16.28431195 12.02178999 12.319154   25.86776284 16.1331981  30.5438815
 37.36066103 24.13473736 18.30792779 39.35764324 20.5206877  16.7709602
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 20.70719308 25.47953329 19.67485932 34.58480536  3.62264799 37.63427821
 23.08044691 11.12352083 20.78751336 11.71352368 22.76714085 25.0269165
 13.45932025 15.88345795 32.51022857 24.84599397 19.89193201 19.16746008
 22.40634226 28.57061195]
50     19.7
367    23.1
34     13.5
78     21.2
172    23.1
       …
320    23.8
15     19.9
484    20.6
125    21.4
265    22.8
Name: MEDV, Length: 404, dtype: float64
```
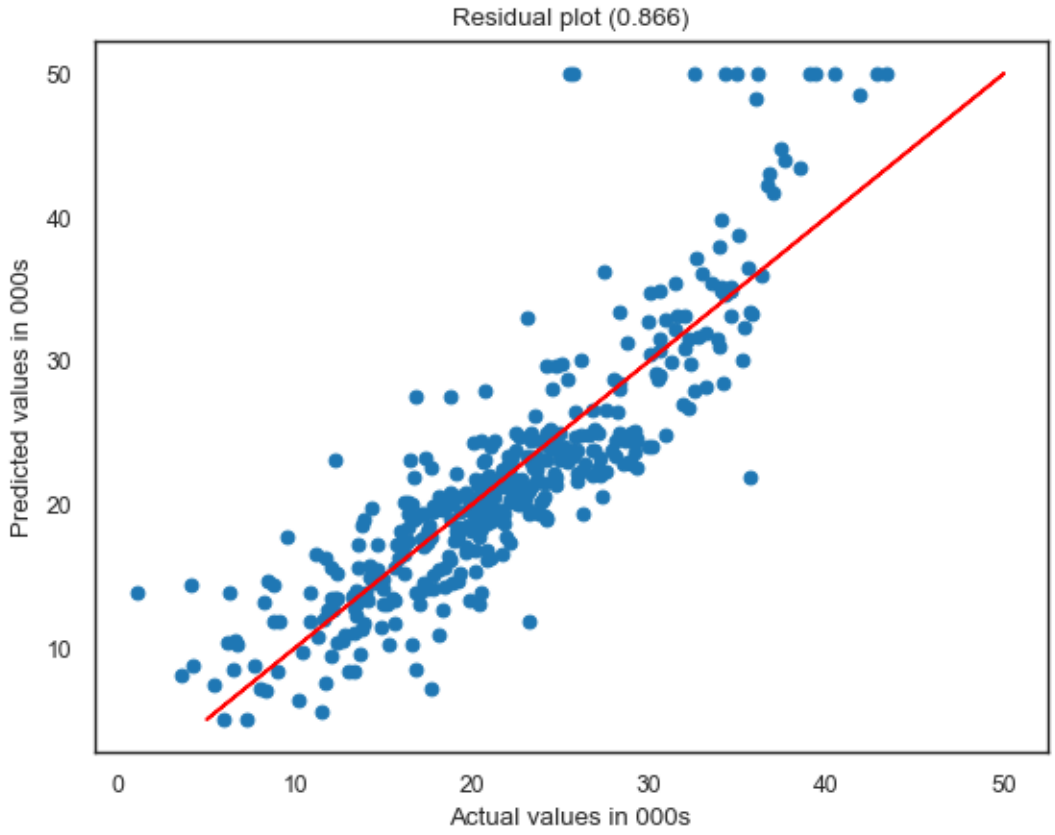

1.3.3 Regression: Actual values vs. predicted



1.3.4 Assessing the model (e.g. coefficient p-Values)

OLS Regression Results

Dep. Variable:	MEDV	R-squared:	0.750
Model:	OLS	Adj. R-squared:	0.742
Method:	Least Squares	F-statistic:	90.06
Date:	Mon, 04 Nov 2024	Prob (F-statistic):	1.12e-108
Time:	11:19:50	Log-Likelihood:	-1170.5
No. Observations:	404	AIC:	2369.
Df Residuals:	390	BIC:	2425.
Df Model:	13		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	36.5331	5.428	6.730	0.000	25.861	47.205
CRIM	-0.1282	0.032	-4.005	0.000	-0.191	-0.065
ZN	0.0632	0.014	4.420	0.000	0.035	0.091

```
INDUS         -0.0076      0.063     -0.119      0.905      -0.132       0.117
CHAS           1.9745      0.924      2.138      0.033       0.159       3.790
NOX          -16.2720      3.965     -4.104      0.000     -24.067      -8.477
RM             3.1085      0.449      6.926      0.000       2.226       3.991
AGE            0.0163      0.015      1.123      0.262      -0.012       0.045
DIS           -1.4830      0.214     -6.920      0.000      -1.904      -1.062
RAD            0.3040      0.067      4.514      0.000       0.172       0.436
TAX           -0.0121      0.004     -3.208      0.001      -0.019      -0.005
PTRATIO       -0.8203      0.141     -5.826      0.000      -1.097      -0.543
B              0.0114      0.003      4.239      0.000       0.006       0.017
LSTAT         -0.5816      0.053    -11.016      0.000      -0.685      -0.478
==============================================================================
Omnibus:                      141.305   Durbin-Watson:                   2.125
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              651.065
Skew:                           1.454   Prob(JB):                    4.20e-142
Kurtosis:                       8.497   Cond. No.                     1.54e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
[2] The condition number is large, 1.54e+04. This might indicate that there are
strong multicollinearity or other numerical problems.
50     -1.329586
367    10.881555
34     -0.247853
78      0.464848
172    -0.312624
         …
320    -1.045994
15      0.008068
484     1.432540
125    -1.006342
265    -5.770612
Length: 404, dtype: float64
19.921197403247984
19.230858879373056
```

1.3.5 A. Checking that there's a linear relationship

1.3.6 B. Showing that the residuals are independent using the Durbin-Watson statistic

```
2.124548455902406
```

Because the Durbin-Watson test returns a value between 1.5 and 2.5, autocorrelation is likely not a cause for concern.

Therefore, the residuals are independent.

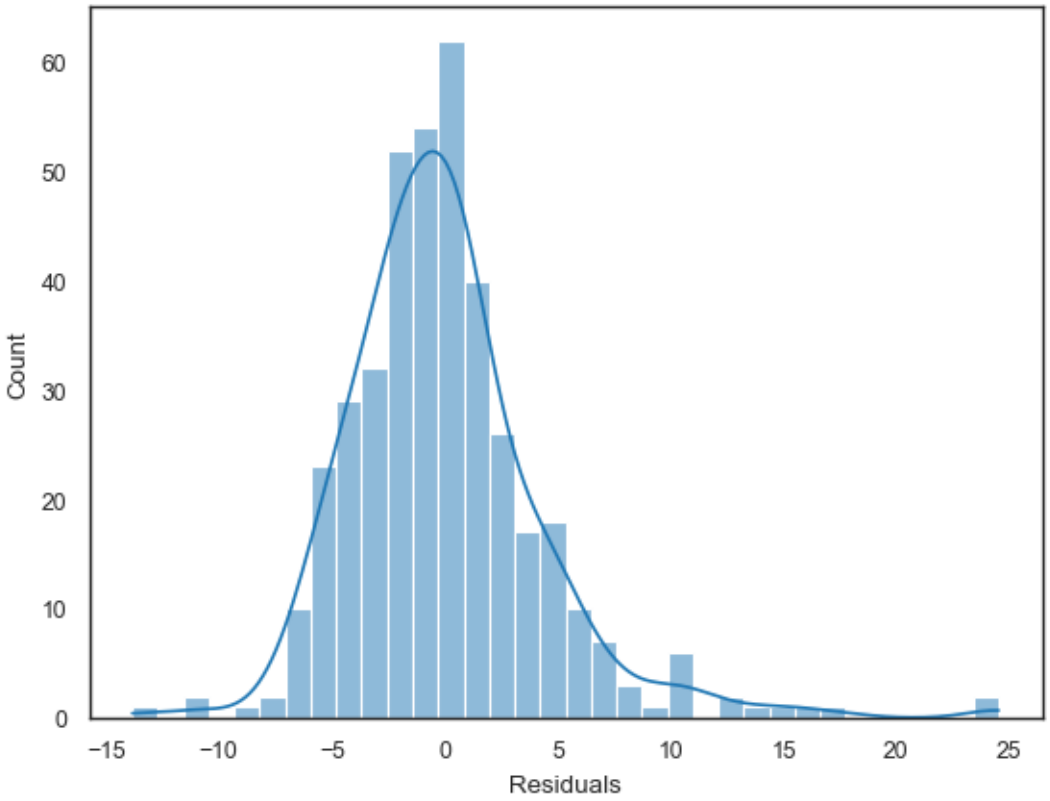
1.3.7 C. Showing that the residuals display homoscedasticity (i.e. constant variance) using the Breusch-Pagan Test

```
Lagrange multiplier statistic    6.254941e+01
p-value                          1.830725e-08
f-value                          5.495618e+00
f p-value                        3.498179e-09
dtype: float64
```

Since the p-value is less than our significance less (0.05), our regression is homoscedastic.

Source: https://www.statology.org/breusch-pagan-test/

1.3.8 D. Showing that the residuals display normality



1.3.9 E. Checking for multicollinearity using the variance influence factor (VIF)

```
CRIM       597.55
ZN           1.71
INDUS        2.33
CHAS         3.94
NOX          1.08
RM           4.41
AGE          1.84
DIS          3.33
RAD          4.22
TAX          7.31
PTRATIO      8.51
B            1.84
LSTAT        1.34
dtype: float64
```

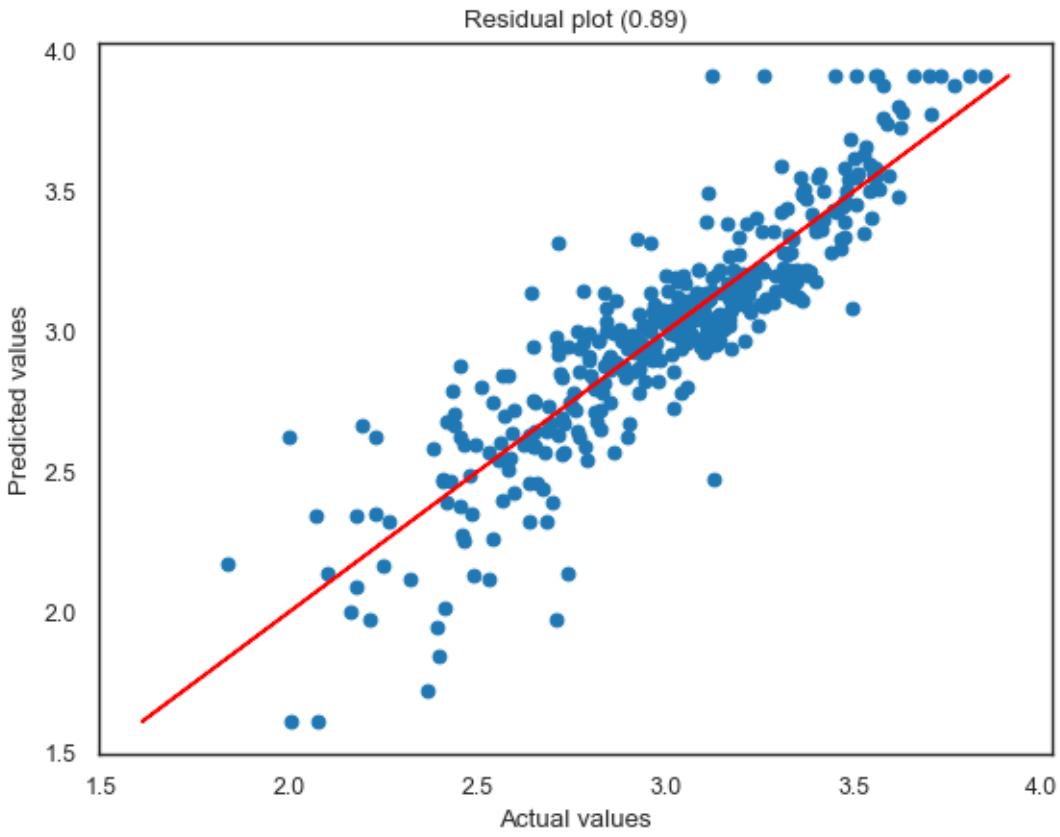
The cutoff for multicollinearity is 10, and none of the features meet that cutoff.

Therefore, we can say that there is no multicollinearity.

1.4 Transforming Regression with Log Prices

```
R-squared: 0.7918657661852815
         Coefficients
CRIM        -0.010702
ZN           0.001461
CHAS         0.086449
NOX         -0.616448
RM           0.076133
DIS         -0.052692
RAD          0.013743
TAX         -0.000590
PTRATIO     -0.033481
B            0.000518
LSTAT       -0.030271
Intercept: 4.03592171504836
```

1.4.1 Regression: Actual values vs. predicted



1.4.2 Assessing the model (e.g. coefficient p-Values)

OLS Regression Results

Dep. Variable:	MEDV	R-squared:	0.792
Model:	OLS	Adj. R-squared:	0.786
Method:	Least Squares	F-statistic:	135.6
Date:	Mon, 04 Nov 2024	Prob (F-statistic):	3.68e-126
Time:	11:19:51	Log-Likelihood:	110.76
No. Observations:	404	AIC:	-197.5
Df Residuals:	392	BIC:	-149.5
Df Model:	11		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	4.0359	0.226	17.819	0.000	3.591	4.481
CRIM	-0.0107	0.001	-8.002	0.000	-0.013	-0.008
ZN	0.0015	0.001	2.465	0.014	0.000	0.003
CHAS	0.0864	0.038	2.251	0.025	0.011	0.162
NOX	-0.6164	0.155	-3.990	0.000	-0.920	-0.313
RM	0.0761	0.018	4.155	0.000	0.040	0.112
DIS	-0.0527	0.008	-6.376	0.000	-0.069	-0.036
RAD	0.0137	0.003	5.060	0.000	0.008	0.019
TAX	-0.0006	0.000	-4.098	0.000	-0.001	-0.000
PTRATIO	-0.0335	0.006	-5.770	0.000	-0.045	-0.022
B	0.0005	0.000	4.611	0.000	0.000	0.001
LSTAT	-0.0303	0.002	-14.706	0.000	-0.034	-0.026

Omnibus:	30.564	Durbin-Watson:	2.072
Prob(Omnibus):	0.000	Jarque-Bera (JB):	117.705
Skew:	0.117	Prob(JB):	2.76e-26
Kurtosis:	5.634	Cond. No.	1.50e+04

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 1.5e+04. This might indicate that there are strong multicollinearity or other numerical problems.

```
50    -0.056143
367    0.498215
34    -0.033868
78     0.043520
172    0.033242
         …
320   -0.041251
15    -0.033156
```

```
484    0.074891
125    0.008542
265   -0.214594
Length: 404, dtype: float64
0.03487337082354599
```

1.4.3 A. Checking that there's a linear relationship

1.4.4 B. Showing that the residuals are independent using the Durbin-Watson statistic

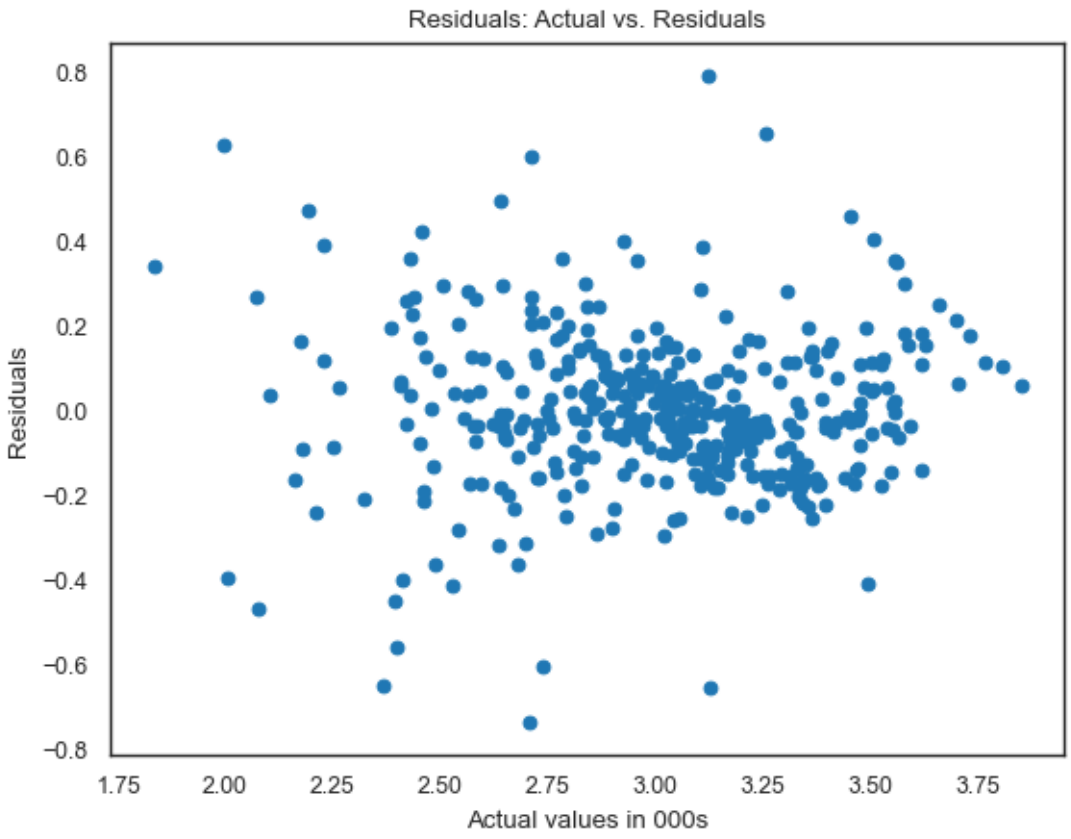
```
2.0716128816841124
```

Because the Durbin-Watson test returns a value between 1.5 and 2.5, autocorrelation is likely not a cause for concern.

Therefore, the residuals are independent.

1.4.5 C. Showing that the residuals display homoscedasticity (i.e. constant variance) using the Breusch-Pagan Test

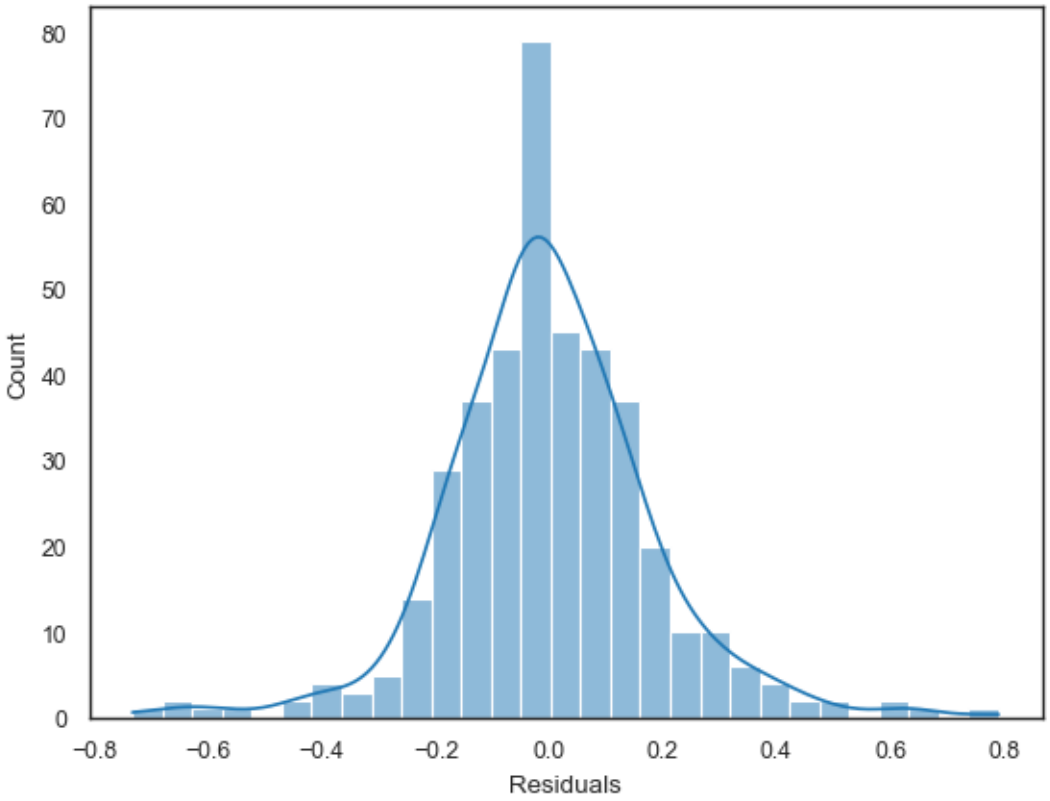
```
Lagrange multiplier statistic    5.792609e+01
p-value                          2.245454e-08
f-value                          5.964839e+00
f p-value                        5.194101e-09
dtype: float64
```



Since the p-value is less than our significance less (0.05), our regression is homoscedastic.

Source: https://www.statology.org/breusch-pagan-test/

1.4.6 D. Showing that the residuals display normality



1.4.7 E. Checking for multicollinearity using the variance influence factor (VIF)

```
CRIM       594.28
ZN           1.71
CHAS         2.29
NOX          1.07
RM           3.83
DIS          1.75
RAD          3.59
TAX          6.79
PTRATIO      7.11
B            1.79
LSTAT        1.33
dtype: float64
```

The cutoff for multicollinearity is 10, and none of the features meet that cutoff.

Therefore, we can say that there is no multicollinearity.

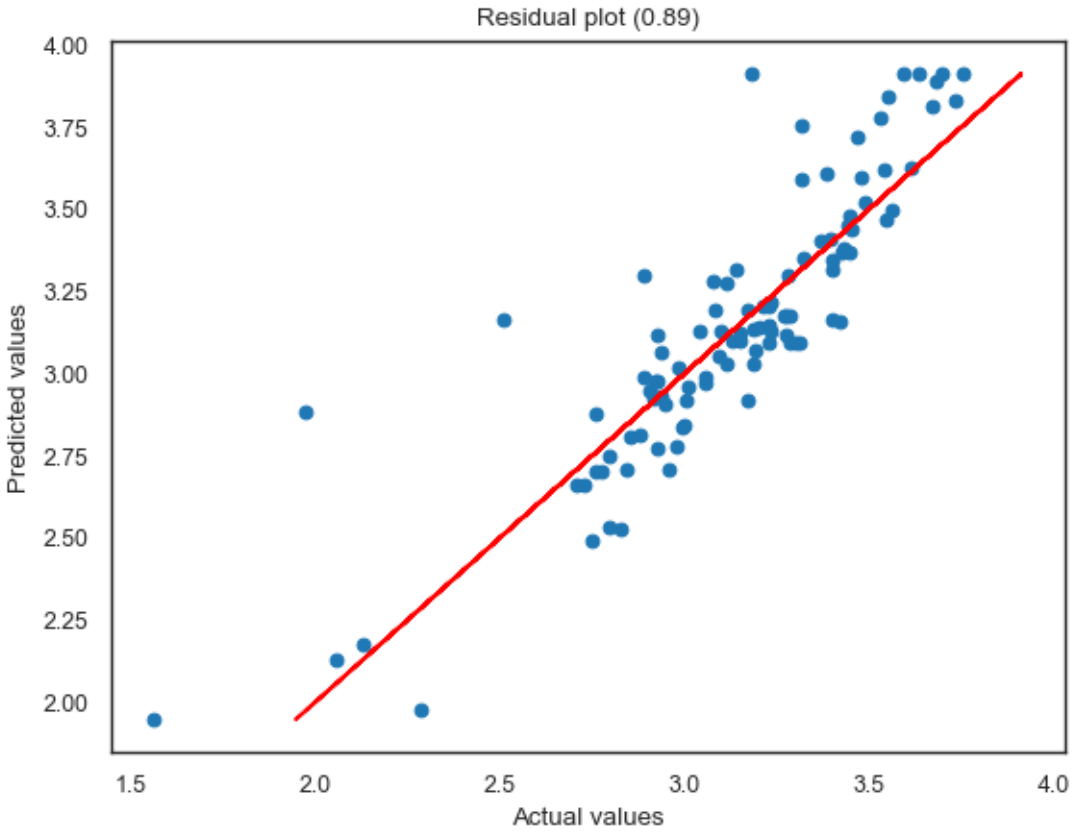
1.4.8 Test Results

```
R-squared: 0.7490934185196063
         Coefficients
CRIM        -0.010702
ZN           0.001461
CHAS         0.086449
NOX         -0.616448
RM           0.076133
DIS         -0.052692
RAD          0.013743
TAX         -0.000590
PTRATIO     -0.033481
B            0.000518
LSTAT       -0.030271
Intercept: 4.03592171504836
```

1.4.9 How well does the training set fit the test set? Do new data points (i.e. test set) have similar coefficients, MSE, R-Squared, etc. as the training set?

Metric	Training	Testing
R^2…	0.7919	0.7491
MSE…	407.3670	0.0419
RMSE…	20.1833	0.2046

1.4.10 Regression: Actual values vs. predicted



OLS Regression Results

Dep. Variable:	MEDV	R-squared:	0.802
Model:	OLS	Adj. R-squared:	0.777
Method:	Least Squares	F-statistic:	33.08
Date:	Mon, 04 Nov 2024	Prob (F-statistic):	6.22e-27
Time:	11:19:53	Log-Likelihood:	29.106
No. Observations:	102	AIC:	-34.21
Df Residuals:	90	BIC:	-2.712
Df Model:	11		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	4.3113	0.473	9.122	0.000	3.372	5.250
CRIM	-0.0071	0.005	-1.318	0.191	-0.018	0.004
ZN	-0.0007	0.001	-0.516	0.607	-0.003	0.002
CHAS	0.1604	0.073	2.193	0.031	0.015	0.306
NOX	-1.1155	0.358	-3.115	0.002	-1.827	-0.404

```
RM             0.1501      0.037      4.053      0.000       0.077       0.224
DIS           -0.0474      0.017     -2.849      0.005      -0.080      -0.014
RAD            0.0095      0.007      1.374      0.173      -0.004       0.023
TAX           -0.0003      0.000     -0.853      0.396      -0.001       0.000
PTRATIO       -0.0471      0.011     -4.195      0.000      -0.069      -0.025
B             -0.0004      0.000     -1.283      0.203      -0.001       0.000
LSTAT         -0.0250      0.005     -4.862      0.000      -0.035      -0.015
==============================================================================
Omnibus:                       28.336   Durbin-Watson:                   1.993
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               50.440
Skew:                           1.156   Prob(JB):                     1.11e-11
Kurtosis:                       5.554   Cond. No.                     1.44e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
[2] The condition number is large, 1.44e+04. This might indicate that there are
strong multicollinearity or other numerical problems.
305    0.018684
193   -0.002554
65    -0.166738
349    0.195032
151    0.166675
         …
208    0.020968
174   -0.132241
108   -0.060968
242   -0.068103
102   -0.283282
Length: 102, dtype: float64
Mean absolute error: 0.03749988129807514
```

1.4.11 A. Checking that there's a linear relationship

1.4.12 B. Showing that the residuals are independent using the Durbin-Watson statistic

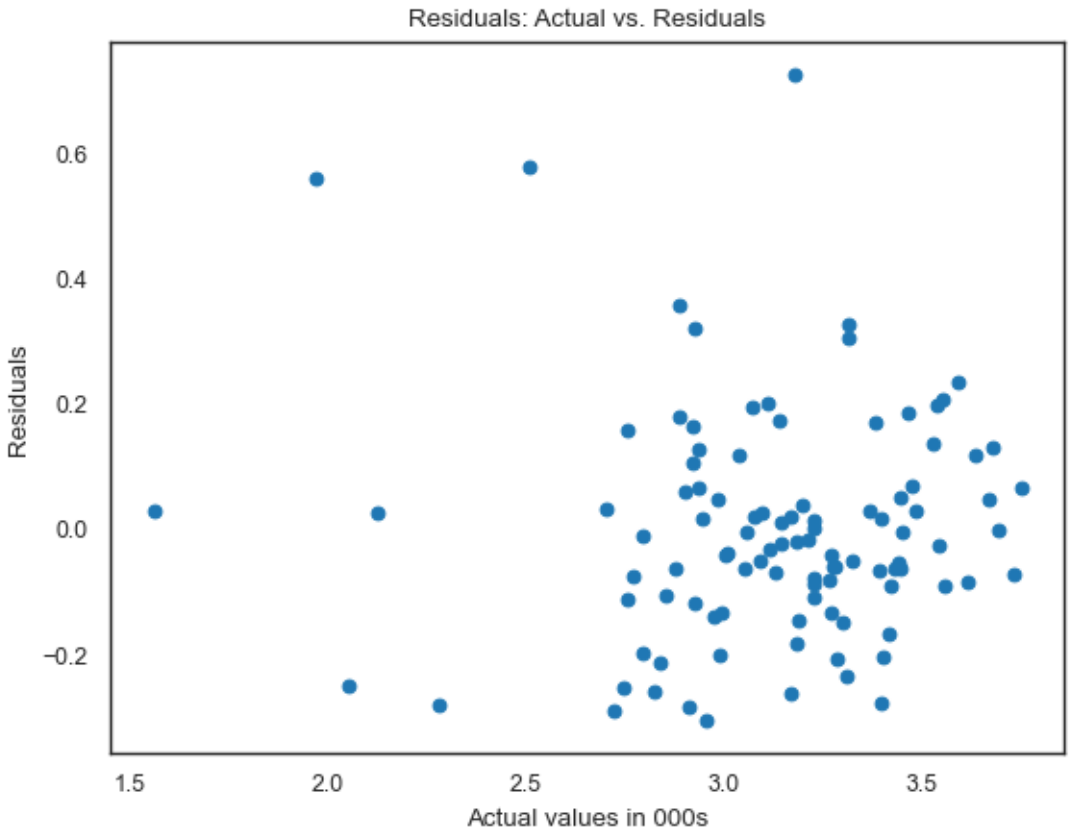
```
1.9925897546011744
```

Because the Durbin-Watson test returns a value between 1.5 and 2.5, autocorrelation is likely not a cause for concern.

Therefore, the residuals are independent.

1.4.13 C. Showing that the residuals display homoscedasticity (i.e. constant variance) using the Breusch-Pagan Test

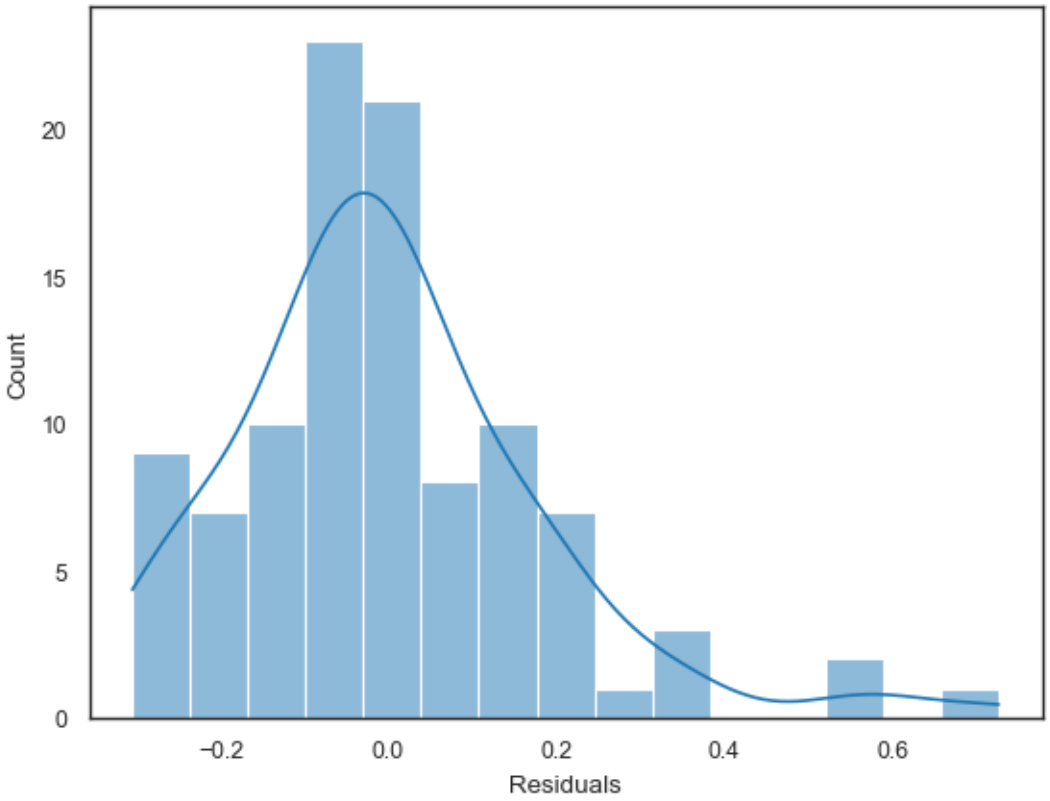
```
Lagrange multiplier statistic    23.792137
p-value                           0.013639
f-value                           2.489046
f p-value                         0.008936
dtype: float64
```



Since the p-value is less than our significance less (0.05), our regression is homoscedastic.

Source: https://www.statology.org/breusch-pagan-test/

1.4.14 D. Showing that the residuals display normality



1.4.15 E. Checking for multicollinearity using the variance influence factor (VIF)

```
CRIM       607.66
ZN           2.97
CHAS         2.23
NOX          1.05
RM           3.97
DIS          2.31
RAD          2.99
TAX          7.50
PTRATIO      8.29
B            1.68
LSTAT        1.63
dtype: float64
```

The cutoff for multicollinearity is 10, and none of the features meet that cutoff.

Therefore, we can say that there is no multicollinearity.

1.5 6) Evaluation: How well does the model do?

```
The prediction interval is 34999.98140857814 <= 35000 <= 35000.01859142186
```