Housing Prices

Ridge and Lasso regressions for the prediction of the median house price:

A machine learning implementation

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**Summary** – This paper is trying to answer to the question what the best regression model is to predict the median house price. The hedonic theory is exploited and models as the Ridge and the Lasso regression are used on a cross sectional dataset of housing prices. Applying the cross-validation we estimate the parameters and then evaluate the model. Then PCA is implemented in order to improve the risk estimator. In section 1 we introduce the problem of housing prices in the U.S. and the approach used in this work. Section 2 is dedicated to the literature about regressions in predicting the price of real estates and 3rd section the theoretical notations are clarified in order to simplify the understanding of *the notions.* Our experiment is described in section 4 with consequential critical comments and evaluations.

# Introduction and description of the problem

The hedonic theory identifies the attributes as implicitly embodied in goods and their observable market prices, so extending this concept to the housing prices we can see the attributes as the house’s characteristics that are determinant for the final value. Hedonic model exploits the consumer theory and her willingness to pay depending on the utility gained from the bundle of aggregated attributes. Each attribute differently influences the price and its strength is given by the estimated coefficient.

Our work starts from a real problem of housing prices in the United States, where the economical purposes and the low mortgage rates incentive a solid and hot real estate market*.*[[1]](#footnote-1)Indeed, the U.S. is one of the most stable and secure countries for real estate investment in the recent years[[2]](#footnote-2). It is estimated that household wealth is nearly 50% invested in real estate and the owner-occupied housing rate in July 2019was about 63.5%[[3]](#footnote-3). However, the U.S. real estate market was not always as reliable as today, indeed the sudden bubble of the housing market of 2006-2007 preceding the Great Recession and its subsequent burs is clear evidence of the system weaknesses. The speculation on the housing prices and their extremely high values is due to the lack of information caused by the manipulations of major players in the real estate sector[[4]](#footnote-4). For these reasons, the task of predicting the value of a house becomes crucial, as the constructed house price model can influence the economic growth and improve the efficiency of the real estate market. An accurate prediction model is significant and helps to fill up an information gap for the prospective homeowners, policy makers and other real estate market participants, such as, mortgage lenders and insurers[[5]](#footnote-5). Modelling house prices presents some issues, for example the median value might be extremely influenced by the value of the sold properties in the area with similar characteristics[[6]](#footnote-6) or the prediction could become wrong due to exogenous factors influencing the prices. Indeed, the economic health reflects in the market according to the supply and demand law so any shock will affect the current prices. Moreover, working on a large dataset, like the one used in this work, can lead to the so-called multicollinearity of the features which tend to overfit when it comes to implement the algorithm predicting the value. The classic OLS regression has the desired property of being unbiased, but it can suffer of overfitting and have a huge variance in those cases where features are highly correlated. To pull down the variance and obtain more biased estimator a regularization technique is necessary*.* The focus of this paper is therefore on two regularization techniques, the Ridge and Lasso regression. The Ridge regression[[7]](#footnote-7) is a useful tool for improving prediction in regression tasks with highly correlated predictors[[8]](#footnote-8). Lasso regression is also used to handle high dimensional databases where the features are correlated, and this technique shrinks some of them to zero, performing a feature selection with a consequent dimension reduction. Both methods act on the coefficients by introducing a penalty on them in order to make more effort to the most informative ones, this way minimizing overfitting of the data and solving the multicollinearity problem. The impact of each attribute on the predicted price is given by the value of the coefficient, higher coefficients mean higher influence. The penalty is the tool through which we perform the regularization, also called tuning parameter, it controls the bias-variance trade-off and the selection of it is crucial. For choosing the regularization parameter in practice, cross-validation (CV) is widely used.

# Most important related works

Many works have been developed to predict the median house value with models of different complexity [see Manjula et al., 2017]. The concept of hedonic prices was developed by Rosen (1974), however the first the first implementing the hedonic model to the house sector was Lancaster (1966). Griliches (1971)[[9]](#footnote-9) provided the reading of a commodity, such as a house, as an aggregation of individual components or attributes. Timothy Oladunni & Sharad Sharma (2016) and Limsombunchai et al. (2004) have showed that the price of a property is predictable exploiting the hedonic theory, comparing the hedonic regression in comparison with other algorithms. Dubin (1998) has developed a work to predicted house prices using MLS data, even though exploiting different algorithms for the prediction, such as kriging algorithm to create an accurate spatial interpolation of house prices. Others as Xin and Khalid (2018) have used ridge and lasso regression to deal with multicollinearity of features on a time series database for predicting the housing price. Hoerl and Kennard (1970) firstly introduced the Ridge regression as biased estimator for non-orthogonal problems. The asymptotic properties of ridge have been widely studied, [see for e.g. Dobriban and Wager (2018), Dicker (2016)]. For the validation approach we refer to the cross-validation which biased estimation of the error is known (Hastie et al., 2009, p. 243), since it uses a smaller amount of data than the entire dataset.[[10]](#footnote-10) However, we can apply a bias-control, see Liu and Dobriban (2020)[[11]](#footnote-11), for example via k-fold cross validation, see Ray (2018), since there is an inverse relation between the k size and bias, if the first grows the latter goes down.

Manca letteratura di pca e lasso.

# Notation and relevant definitions -Regression

The goal of the regression is to generate a prediction such that the loss function is small for most data points , where is a predictor from the labels set , is the coefficient vector and data domain; the prediction mistakes are a function of the difference.

## Hedonic model

Following the hedonic theory, the housing price can be written as a function in the following way:

where is the vector of all the objective attributes and is the price of the element of the data matrix. In this case, the price (our target variable) is a function of:

* longitude,
* latitude,
* housingMedianAge,
* totalRooms,
* totalBedrooms,
* population,
* households,
* medianIncome,
* medianHouseValue,
* oceanProximity.

## Loss function

With loss function we denote the measure of how different the prediction of a hypothesis is from the true outcome. We use a nonnegative loss function to measure the discrepancy between the predicted label and the true label . In the regression task we define the quadratic loss that is the squared distance between and

when then otherwise If and *c* is large then also tend to be large. The mean of the squared error (MSE) will be used on in the experiment.

## Test error and training error

The split of dataset into two separate subsets is necessary in order to have some fresh data to estimate the predictive power of the algorithm. Indeed, the validation is given by the test error which is:

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The validation is done over a fitted predictor in the training set, and its power is given by the training error:

Total error is given by three elements:

* variance,
* bias,
* irreducible error.

The main idea is to derive a trade off between the bias and variance, on order to optimize them both. More complex models present high variance and low bias since they fit good the true data but generalize worst.

Bias is calculated on the training set and variance of the test set.



*Image 1: the optimal choose for trade-off [[12]](#footnote-12)*

## Empirical Risk Minimization

The empirical risk minimization is a learning algorithm which returns the best predictor given a set of predictors, that is minimizing the training errorminimizing the training error given a non-negative real-valued loss function :

## Statistical risk, Bayes optimal predictor and Bayes optimal risk

We use statistical learning to introduce the notion of expectations in estimating the loss since we need to assume the independence between the variables and the predictor we generate is based on this assumption. Let be the predictor that maps data points to labels. y . {\displaystyle y.} The **statistical** [**risk**](https://en.wikipedia.org/wiki/Risk_(statistics)) h ( x ) {\displaystyle h(x)} is then defined as the [expectation](https://en.wikipedia.org/wiki/Expected_value) of the loss function among , the distribution from where the random sample of data points and labels were drawn:

where is the predicted . We then define as **Bayes optimal predictor** as the function which minimize the overall training error , given the conditional probability among all predictors given that our data point is :

The **Bayes optimal risk** is the expectation over the loss function of the Bayes optimal predictor and following the same logic as before we have that the Bayes risk is smaller than the other risks:

Coming to our regression problem with the squared loss, the Bayes optimal predictor is:

(1)

minimizing this quantity[[13]](#footnote-13), we have

and the Bayes risk becomes the expectation of (1):

=

## Regressions – Linear, Ridge, Lasso

Ridge and Lasso regression modify the standard linear regression by introducing a positive constant as regularization parameter. Indeed, the objective function to minimize under these solutions is **RSS[[14]](#footnote-14) + penalty**, and the penalty differs for the two methods. Starting from the classical linear model we have:

let be the data domain and a row vector of . The linear predictor is a linear function , and for a we can write as follows:

where and .

The Bayes optimal risk is given by

and it is also an empirical risk minimization to is

Since we can rewrite these terms in vector notation, we have

for the vector of predictions and the vector of real labels and for .

In matrix notation we have the design matrix with features and observations that are rows of , and therefore the vector becomes . Applying the ERM we derive

The solution to the ERM is the minimization of this convex function using the Euclidian distance. To solve the problem in linear regression we can use the closed form solution or the gradient descend.

If is a non-singular matrix[[15]](#footnote-16), and the conditions of the general position holds, the solution of the ERM is the closed form:

In some cases, the linear regression performs well on the training data, having a low bias, but it gives a non-accurate estimate on different data. The reason why it occurs it is because of multicollinearity of the prediction vectors (as known as non- orthogonality)[[16]](#footnote-17) . More in general with large or small, the risk that the model can overfit[[17]](#footnote-18) the data is high. The OLS estimator therefore is unbised but have a huge variance and it is not stable. To overcome this problem, Ridge and Lasso regression help to prevent over-fitting which results from simple linear regression. We introduce a regularized parameter which adds some bias[[18]](#footnote-19) whereas pushing the variance down. This also controls the model complexity, indeed the value of has a direct relation with the complexity. This occurs to find the best trade-off between bias and variance to get to that sweet spot for having good predictive performance[[19]](#footnote-20).

The two methods work similarly but lead to different results, this happens because of the divergent formulas.

### Ridge solution

Ridge regression uses the penalty multiplied by the square of the magnitude of the coefficients, also known as L2 regularization.

The ERM functional of Ridge regression is

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for , so the solution leads the linear regression, for the coefficient tend to a zero vector and the line becomes flatter, shrinking the linear regression solution towards to zero.

To optimize the objective function, we take the gradient as before and solve for to find a suitable value

The new estimated parameter becomes

This is the so called closed-form solution and is the one measuring the stability of the procedure.

### Lasso solution

Least Absolute Shrinkage and Selection Operator, or simply Lasso, is slightly different from the previous because the penalty is multiplied by the [absolute value](https://www.statisticshowto.com/integer/#abs) of the magnitude of coefficients, also known as L1 regularization

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For

The Lasso procedure encourages simple, sparse models[[20]](#footnote-22), indeed some coefficients can become zero and be eliminated from the model, this way performing a feature selection.

The shrinkage amount is given by the value of [tuning parameter](https://www.statisticshowto.com/tuning-parameter/) . If increase, we have some parameters go straightway to zero.

Λ (lambda) provides a trade-off between balancing RSS and magnitude of coefficients.

The optimization of a non-differentiable function as Lasso solution is done by a proximal gradient descend approach.

The first step is to take the gradient descend for current vector and form a new vector :

Where is the step size and is the moment we are considering.

Then solve the proximal regularize problem for as follows:

This is a scaler minimization problem indeed we can rewrite it as:

Since we have an absolute value for we consider two cases:

**Case 1**

differentiate with respect to and solve:

therefore, since we have the non-negativity constraint over

if ,

otherwise

**Case 2**

differentiate with respect to and solve for it:

if

otherwise

The three solutions are also known as the “soft threshold” operation. There is some shrinkage going on in this three cases, w is the shank version of z where the value taken by w is the shrinkage of z.

The update rule of the algorithm is therefore

DA COMPLETARE

The common point of these two methods is that adding the regularization parameter to the cost function the algorithm is forced to pick the lowest weights, indeed the goal is to ensure a small coefficient through this regularization parameter.

The main difference is that many coefficients are exactly zeroed under lasso, which is never the case in ridge regression where there is not any elimination of coefficients.

### Cross-validation

Cross-validation (CV) is one of the techniques used to test the effectiveness of a machine learning models, it is also a re-sampling procedure used to evaluate a model if we have a limited data[[21]](#footnote-23).

In case of limited data, this approach can present a high bias, since there is a substantial loss of data in the training set, but if data is huge and our test sample and train sample has the same distribution then this approach is acceptable.

### K-fold

K-fold cross-validation is a non-parametric method for evaluating the accuracy of a predictive rule.[[22]](#footnote-24)

It ensures that every observation from the original dataset has the chance of appearing in training and test set

for model selection

Hyper-parameters whose value must be determined before the training phase can start

The computed error on the testing part of each fold is

is the dataset divided in subsets , where is the testing part.

We want to estimate the for a fixed hyper-parameter.

And the CV final error is the egress of the errors

given the choice of two predictors, it repeatedly picks the most accurate of the two. Fix a training\test set.

So for tuning the hyper-parameter

we look on where

Estimate risk on all S

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This is the algorithm[[23]](#footnote-25)

for p in 1:P:

for k in 1:K:

keep fold k as hold-out data

use the remaining folds and λ = λp to estimate β^ridge

predict hold-out data: ytest,k=Xtest,kβ^ridge

compute a sum of squared residuals: SSRk = ||y − ytest, k||2

end for k

average SSR over the folds: SSRp=1K∑k=1KSSRk

end for p

choose optimal value: λopt = argminpSSRp

Moreover the choose of k

The k value must be chosen carefully for your data sample.

A poorly chosen value for k may result in a misrepresentative idea of the skill of the model, such as a score with a high variance (that may change a lot based on the data used to fit the model), or a high bias, (such as an overestimate of the skill of the model).

Always remember, a lower value of k is more biased, and hence undesirable. On the other hand, a higher value of K is less biased, but can suffer from large variability. It is important to know that a smaller value of k always takes us towards validation set approach, whereas a higher value of k leads to LOOCV approach.

HOW TO READ BIAS VARIANCE TRADE OFF

After k-fold cross validation, we’ll get *k* different model estimation errors (e1, e2 …..ek). In an ideal scenario, these error values should sum up to zero. To return the model’s bias, we take the average of all the errors. Lower the average value, better the model.

Similarly for calculating the model variance, we take standard deviation of all the errors. A low value of standard deviation suggests our model does not vary a lot with different subsets of training data.

We should focus on achieving a balance between bias and variance. This can be done by reducing the variance and controlling bias to an extent. It’ll result in a better predictive model. This trade-off usually leads to building less complex predictive models as well.

### Principal component analysis

Principal Component Analysis is a mathematical technique, unsupervised used for dimensionality reduction. Its goal is to reduce the number of features through a combinations of the original data variables. In this way keeping most of the original information.

Let’s identify the principal components and interpret their relationship to the original variables. The linear coefficients for the PCs (sometimes called the “loadings”) are shown in the columns of the Eigenvectors table.

Unsupervised algorithms, principal component analysis (PCA)

The features are selected on the basis of variance that they cause in the output.

The feature that causes highest variance is the first principal component.

The feature that is responsible for second highest variance is considered the second principal component, and so on.

It is important to mention that principal components do not have any correlation with each other.

It can be seen that first principal component is responsible for 72.22% variance

A general rule of thumb is to take number of principal of principal components that contribute to significant variance and ignore those with diminishing variance returns. A good way is to plot the variance against principal components and ignore the principal components with diminishing values as shown in the following graph:[[24]](#footnote-26)

VIDEO

We increase the number of features in an intelligent way, because PCA keep the most informative.

This way bias is increased but we can have a more stable prediction, it increases the bias but reduces the variance.

One of the points is a linear (Ridge) predictor that we have learned.

But basically, to improve the stability we can use ridge regression as well.

Therefore, ridge regression is a soft PCA regression in fact. They both intend to solve the multi-collinearity in order to improve the model regression.

In the PCA analysis negative values of loadings of variable in the components of the PCA means the existence of an inverse correlation between the factor PCA and the variables.

The PCA algorithm trans-formed the data into some smaller and more meaningful components which were the true representation of the attributes. In other words, new variables were derived from the datasets. PC1 is the first principal component; it is the linear combination of variables with most possible variance in the datasets. The second one, PC2 covers the next variance. A new principal component is assumed to be uncorrelated with all previous components. Mathematically; ܥܲ݊௜=(ܽ௜ଵܸ ଵ)+(ܽ௜ଶܸ ଶ)+⋯+(ܽ௜௡ܸ ௡). (2) Where nP is the number of components, ܽ௜ଵ.....ܽ௜௡are the component weights and V1.....Vn the variables.

# Proof of a technical result

In this chapter we will demonstrate the accuracy of our results.

## Data pre-processing

Before performing the analysis and regression, pre-procession of data is necessary. The dataset presents features that cannot be compared in a linear Euclidian space; therefore, geometry is not working properly on this row data. Indeed, in order to learn the algorithm, we need to encode the features and raise them to a homogeneous level, so we can compare them[[25]](#footnote-27). The dataset contains 20640 observations and 10 features for each house including the median house value which is the target value that we are trying to predict. Firstly, we create the two constants of the target variable and designed matrix:

= median\_house\_value

= data frame

## Missing values

The missing values must be handled to avoid errors in the execution of the code, so they are filled with the mean value of the corresponding column.

## Categorical features

There is a categorical feature which represents the distance from the ocean, we transform the elements of the column into columns dummies and assign it to the data set[[26]](#footnote-28). Even though in hedonic model literature[[27]](#footnote-29) there is a concern about the statistical insignificance of some features such as household size, we use two approaches:

* keep all the features to have as much information as possible,
* use some unsupervised techniques to decide which feature to drop such as PCA.

## Standardization

The standardization is done by subtracting the mean and divided by the variance. In this way we have μ = 0 and σ = 1. This procedure is needed as both L1 and L2 assume that all features are centred around 0 and have unit variance. More in general this is important to those algorithms that use Euclidian distance and for PCA implementation.

## Correlation matrix

We explore the correlation matrix between the features to see graphically how they move together. The used scoring is Pearson’s coefficient and , if the value is closer to 1 there is more correlation and the sign gives the direction of this correlation.

We have enough evidence that there exists statistical relationship between the variables. Therefore, our dataset is suitable for decomposition into its principal components to increase convergence speed and eliminate collinearity by finding the core components of the datasets.

## Model tuning

Tuning is usually a trial-and-error process by which you change some hyper-parameters (for example, the number of trees in a tree-based algorithm or the value of alpha in a linear algorithm), run the algorithm on the data again, then compare its performance on your validation set in order to determine which set of hyper-parameters results in the most accurate model.

### Scoring

We use the RMS as scoring, so the ---

### Choosing the set of parameters alpha

In order to obtain a reasonable amount of information to determine a certain where is the function that minimize the training error, we use a logarithmic range .

Training size m is bigger than the in order to avoid underfitting.

As we can see the optimal value for the hyper-parameter is around 0.01, after that the squared lost increases.

## Optimization algorithm

We used optimization algorithms.

### Cross- validate risk estimate

As we see the generalized variance is smaller then in training set as this is the k-fold regression that allows to have this results.

*Large a ---------------small a*

*Hight bias low bias*

*Low varance high variance*

*Ex w hat = 0 rss*

We perform an analysis of different tuning parameters alpha and the relative mean squared error, comparing the Lasso and Ridge (Cholensky)

The best egre value is 0.2 more or less for ridge regression, then the error increases (>0.022) for values alpha > 0.2

### Ridge learning algorithm

We fit the best in order to plot the learning curve performance. Training error becomes larger when iterations are increased, and it is stable around 4.6. Test error is higher as we could always expect a better performance on the training set. As we see the overfitting disappears as we increase the training size, and the squared loss become stable. The squared cross validate risk estimate is 73814.66.

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In this plot we can visualize how the predicted value differs from the real values. The prediction is more consistent with lower prices and becomes sparser for higher values, this can be because of the outliers.

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### Lasso learning algorithm

In lasso regression this increase is smoother, and MSE is more stable for alpha in between 0.1 and 1.

This is what we could expect if there are feature highly correlated and that are not crucial for the regression.

On the other hand R2 is specular to the MSE and tells u show well the model fits the data

The coefficient magnitude is shown in this graph

Median income has a huge power in the prediction, it means that it drives the values.

### Principal Component Analysis

Cells that are highly correlated cluster together.

Differences between the 1st pc zxex are more important than the differences between the 2nd pc.

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After 5 features we do not gain more information therefore we will implement this decomposition.

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This is the result and the performance of 5 PCA decomposition. The performance is not improving compared with the ridge regression.

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Interpretation of the graph:

<https://online.stat.psu.edu/stat505/lesson/11/11.4>

|  |
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|  |

# Some critical considerations

## Outliers problem

Even if ridge egression s modelled in a way to deal with multicollinearity and outliers, it still being sensitive to outliers. In our work there were some outliers that were pushing the fit in a wrong direction.

<https://iopscience.iop.org/article/10.1088/1742-6596/890/1/012150>

<https://iopscience.iop.org/article/10.1088/1742-6596/890/1/012150/pdf>

As the model complexity increases, the models tends to fit even smaller deviations in the training data set. Though this leads to overfitting, let’s keep this issue aside for some time and come to our main objective, i.e. the impact on the magnitude of coefficients. This can be analysed by looking at the data frame created above.

It is clearly evident that the **size of coefficients increases exponentially with increase in model complexity**. I hope this gives some intuition into why putting a constraint on the magnitude of coefficients can be a good idea to reduce model complexity.

What does a large coefficient signify? It means that we’re putting a lot of emphasis on that feature, i.e. the particular feature is a good predictor for the outcome. When it becomes too large, the algorithm starts modelling intricate relations to estimate the output and ends up overfitting to the particular training data.

Lasso can set some coefficients to zero, thus performing variable selection, while ridge regression cannot.

This way Lasso performs better in terms of reducing the variance in models with many redundant features.

In contrast, Ridge regression performs better in models where many features are important.

This experiment shows that Lasso regression and PCA do not improve the risk estimate. This is because both reduce the dimension of the designed matrix. However, PCA performs better then Lasso, this is because the feature selection is done by keeping the most informative features, and Lasso regression just shrinks some coefficients to zero. In general, we can deduce that for this specific dataset the ridge regression is the most appropriate model, indeed the performance is better when all the features are considered in the prediction.

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1. Santarelli, 2020 [↑](#footnote-ref-1)
2. Source: International Investor Survey [↑](#footnote-ref-2)
3. Source: United States Census Bureau <https://www.census.gov/quickfacts/fact/table/US/HSG445218> [↑](#footnote-ref-3)
4. Oladunni, Timothy & Sharma, Sharad. (2016) [↑](#footnote-ref-4)
5. Limsombunchai et al. (2004) [↑](#footnote-ref-5)
6. the so-called Sales comparison approach [↑](#footnote-ref-6)
7. Introduced by Hoerl and Kennard (1970), [↑](#footnote-ref-7)
8. Riccardo A. Maronna [↑](#footnote-ref-8)
9. Griliches 1991 [↑](#footnote-ref-9)
10. In other words the algorithm has not enough data to train and be approximated [↑](#footnote-ref-10)
11. <https://openreview.net/pdf?id=HklRwaEKwB> [↑](#footnote-ref-11)
12. Source: researchgate.net [↑](#footnote-ref-12)
13. By taking the derivative w.r.t since is differentiable [↑](#footnote-ref-13)
14. Sum of the squared residuals used for the classical OLS. [↑](#footnote-ref-14)
15. This happens if the data points span [↑](#footnote-ref-16)
16. <https://www.math.arizona.edu/~hzhang/math574m/Read/RidgeRegressionBiasedEstimationForNonorthogonalProblems.pdf> [↑](#footnote-ref-17)
17. Overfitting: the algorithm performs very good on training data but cannot be generalized to a new bunch of data. [↑](#footnote-ref-18)
18. Bias is how well the fit correspond to the true value [↑](#footnote-ref-19)
19. See graphic 1 in this paper [↑](#footnote-ref-20)
20. <https://www.statisticshowto.com/lasso-regression/> [↑](#footnote-ref-22)
21. <https://towardsdatascience.com/why-and-how-to-cross-validate-a-model-d6424b45261f> [↑](#footnote-ref-23)
22. <https://arxiv.org/pdf/1909.11696.pdf> [↑](#footnote-ref-24)
23. <https://www.datacamp.com/community/tutorials/tutorial-ridge-lasso-elastic-net> [↑](#footnote-ref-25)
24. <https://stackabuse.com/implementing-pca-in-python-with-scikit-learn/> [↑](#footnote-ref-26)
25. For example, longitude and households are features with real numbers however they have different interpretations. [↑](#footnote-ref-27)
26. This is called hot encoder technique; we do not worry about adding extra dimensions as the dummy variable set to zero the features that do not belong to the given observation. [↑](#footnote-ref-28)
27. Features such as garden, household size, neighborhood satisfaction and schools, as demonstrated by Berna and Craig [12]. [↑](#footnote-ref-29)