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   RESEARCH METHODOLOGY

   RESULTS & DISCUSSION

   FINDINGS

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VARIABLE SELECTION IN REGRESSION MODELS

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ABSTRACT

Gaussian processes are a natural way of specifying prior distributions over functions of one or more input variables. When such a function defines the mean response in a regression model with Gaussian errors, inference can be done using matrix computations, which are feasible for datasets of up to about a thousand cases. The covariance function of the Gaussian process can be given a hierarchical prior, which allows the model to discover high-level properties of the data, such as which inputs are relevant to predicting the response. Inference for these covariance hyper parameters can be done using Markov chain sampling. Classification models can be defined using Gaussian processes for underlying latent values, which can also be sampled within the Markov chain. Gaussian processes are in my view the simplest and most obvious way of defining flexible Bayesian regression and classification models, but despite some past usage, they appear to have been rather neglected as a general-purpose technique. This may be partly due to a confusion between the properties of the function being modeled and the properties of the best predictor for this unknown function. Regression models form the core of the discipline of econometrics. Although econometricians routinely estimate a wide variety of statistical models, using many different types of data, the vast majority of these are either regression models or close relatives of them. In this chapter, we introduce the concept of a regression model, discuss several varieties of them, and introduce the estimation method that is most commonly used with regression models, namely, least squares. This estimation method is derived by using the method of moments, which is a very general principle of estimation that has many applications in econometrics.

KEYWORDS

Regression models, variable selection.

HISTORY

DEFINITION: REGRESSION MODELS

Regression models are used to predict one variable from one or more other variables. Regression models provide the scientist with a powerful tool, allowing predictions about past, present, or future events to be made with information about past or present events. The scientist employs these models either because it is less expensive in terms of time and/or money to collect the information to make the predictions than to collect the information about the event itself, or, more likely, because the event to be predicted will occur in some future time. Before describing the details of the modeling process, however, some examples of the use of regression models will be presented.

The method of investigating interactions in two-way tables by the regression analysis introduced by Yates and Cochran (1938) has been applied to data from competition diallel experiments with plant species reported by Williams (1962) and Norrington-Davies (1968). Arithmetic and logarithmic scales were used in both experiments and the relative advantages of these are briefly discussed.

Significantly high proportions of the interactions between species (row) and associates (column) effects were explained as differences between the linear regressions of individual performance on the associate values. Consequently the performance of the species in competition could largely be specified by three parameters. These were the species mean (μ), the regression coefficient (b) and the mean effect of associates (a), which respectively measured the general vigour of the species, its sensitivity to competition and its aggressiveness. These parameters jointly provided estimates of what we have termed the *general competitive abilities* of the species. *Specific competitive abilities* of particular mixtures are detected as significant deviations from the regression lines.

The parameters were used to derive formulae which provide descriptive and predictive measurements of the competitive advantage of species in particular combinations, and of the mixture performances relative to the performance of other mixtures or monocultures. The types of competition phenomena which could derive from a situation involving only general competitive abilities were shown to vary greatly and depended on the correlations between the three parameters in the experimental material.

The possible types of interactions between associated genotypes (competition, co-operation, antagonism, etc.) can be defined in terms of the general competitive ability parameters, or recognised as specific competitive abilities. It is thus suggested that the regression technique forms a useful approach to the discovery and classification of these effects among competing species.

The second experiment (Norrington-Davies, 1968) involved competition between grass species under four different treatments. Common regression lines constructed over all treatments indicated that response to competitive stress was to some extent similar to the response to other kinds of environmental stress. This raised the concept that some aspects of general competitive abilities could be determined from general response to limitation in environmental factors. The plant breeding implications of this are briefly discussed, particularly the possibility of predicting performance under competition from performance as spaced plants.

EXAMPLES AND USES OF REGRESSION MODELS

SELECTING COLLEGES

A high school student discusses plans to attend college with a guidance counselor. The student has a 2.04 grade point average out of 4.00 maximum and mediocre to poor scores on the ACT. He asks about attending Harvard. The counselor tells him he would probably not do well at that institution, predicting he would have a grade point average of 0.64 at the end of four years at Harvard. The student inquires about the necessary grade point average to graduate and when told that it is 2.25, the student decides that maybe another institution might be more appropriate in case he becomes involved in some "heavy duty partying."

When asked about the large state university, the counselor predicts that he might succeed, but chances for success are not great, with a predicted grade point average of 1.23. A regional institution is then proposed, with a predicted grade point average of 1.54. Deciding that is still not high enough to graduate, the student decides to attend a local community college, graduates with an associate's degree and makes a fortune selling real estate.

If the counselor was using a regression model to make the predictions, he or she would know that this particular student would **not** make a grade point of 0.64 at Harvard, 1.23 at the state university, and 1.54 at the regional university. These values are just "best guesses." It may be that this particular student was completely bored in high school, didn't take the standardized tests seriously, would become challenged in college and would succeed at Harvard. The selection committee at Harvard, however, when faced with a choice between a student with a predicted grade point of 3.24 and one with 0.64 would most likely make the rational decision of the most promising student.

PREGNANCY

A woman in the first trimester of pregnancy has a great deal of concern about the environmental factors surrounding her pregnancy and asks her doctor about what to impact they might have on her unborn child. The doctor makes a "point estimate" based on a regression model that the child will have an IQ of 75. It is highly unlikely that her child will have an IQ of exactly 75, as there is always error in the regression procedure. Error may be incorporated into the information given the woman in the form of an "interval estimate." For example, it would make a great deal of difference if the doctor were to say that the child had a ninety-five percent chance of having an IQ between 70 and 80 in contrast to a ninety-five percent chance of an IQ between 50 and 100. The concept of error in prediction will become an important part of the discussion of regression models.

It is also worth pointing out that regression models do not make decisions for people. Regression models are a source of information about the world. In order to use them wisely, it is important to understand how they work.

SELECTION AND PLACEMENT DURING THE WORLD WARS

Technology helped the United States and her allies to win the first and second world wars. One usually thinks of the atomic bomb, radar, bombsights, better designed aircraft, etc when this statement is made. Less well known were the contributions of psychologists and associated scientists to the development of test and prediction models used for selection and placement of men and women in the armed forces.

During these wars, the United States had thousands of men and women enlisting or being drafted into the military. These individuals differed in their ability to perform physical and intellectual tasks. The problem was one of both selection, who is drafted and who is rejected, and placement, of those selected, who will cook and who will fight. The army that takes its best and brightest men and women and places them in the front lines digging trenches is less likely to win the war than the army who places these men and women in the position of leadership.

It costs a great deal of money and time to train a person to fly an airplane. Every time one crashes, the air force has lost a plane, the time and effort to train the pilot, and not to mention, the loss of the life of a person. For this reason it was, and still is, vital that the best possible selection and prediction tools be used for personnel decisions.

MANUFACTURING WIDGETS

A new plant to manufacture widgets is being located in a nearby community. The plant personnel officer advertises the employment opportunity and the next morning has 10,000 people waiting to apply for the 1,000 available jobs. It is important to select the 1,000 people who will make the best employees because training takes time and money and firing is difficult and bad for community relations. In order to provide information to help make the correct decisions, the personnel officer employs a regression model. None of what follows will make much sense if the procedure for constructing a regression model is not understood, so the procedure will now be discussed.

PROCEDURE FOR CONSTRUCTION OF A REGRESSION MODEL

In order to construct a regression model, both the information which is going to be used to make the prediction and the information which is to be predicted must be obtained from a sample of objects or individuals. The relationship between the two pieces of information is then modeled with a linear transformation. Then in the future, only the first information is necessary, and the regression model is used to transform this information into the predicted. In other words, it is necessary to have information on both variables before the model can be constructed.

For example, the personnel officer of the widget manufacturing company might give all applicants a test and predict the number of widgets made per hour on the basis of the test score. In order to create a regression model, the personnel officer would first have to give the test to a sample of applicants and hire all of them. Later, when the number of widgets made per hour had stabilized, the personnel officer could create a prediction model to predict the widget production of future applicants. All future applicants would be given the test and hiring decisions would be based on test performance.

A notational scheme is now necessary to describe the procedure:

X_i is the variable used to predict, and is sometimes called the independent variable. In the case of the widget manufacturing example, it would be the test score.

Y_i is the observed value of the predicted variable, and is sometimes called the dependent variable. In the example, it would be the number of widgets produced per hour by that individual.

Y'_i is the predicted value of the dependent variable. In the example it would be the predicted number of widgets per hour by that individual.

The goal in the regression procedure is to create a model where the predicted and observed values of the variable to be predicted are as similar as possible. For example, in the widget manufacturing situation, it is desired that the predicted number of widgets made per hour be as similar to observed values as possible. The more similar these two values, the better the model. The next section presents a method of measuring the similarity of the predicted and observed values of the predicted variable.

REGRESSION MODELS AND VARIABLE SELECTION

The primary concern of statistics is to infer on the unknown distribution of random variables from a random sample. While this seems to be quite hopeless without any a priori information we usually attempt to make a minimum of assumptions on the underlying distribution. This knowledge is used to build a statistical model. In a next step we combine a set of observations with the theoretical model in order to investigate what is called to 'fit the model'. There are several reasons for fitting statistical models. On one hand, we want to study the relationship between variables. On the other hand, we want to make predictions for situations that are different from the observed ones. Furthermore, we want to test scientific hypotheses in order to deduce the validity of the theory.

SELECTING THE VARIABLES FOR A REGRESSION

When it comes to building a regression model, for many companies there's good news and bad news. The good news: there's plenty of independent variables from which to choose. The bad news: there's plenty of independent variables from which to choose! While it may be possible to run a regression with all possible independent variables, each one included in your model reduces your degrees of freedom and causes the model to overfit the data on which the model is built, resulting in less reliable forecasts when new data is introduced.

So how do you come up with your short list of independent variables?

Some analysts have tried plotting the dependent variable (Y) against individual independent variables (X_i) and selecting it if there's some noticeable relationship. Another tried method is to produce a correlation matrix of all the independent variables and if a large correlation between two of them is discovered, drop one from consideration (so to avoid multicollinearity). Still another approach has been to perform a multiple linear regression on all possible explanatory variables and then dropping those who t values are insignificant. These approaches are often selected because they are quick and simple, but they are not reliable for coming up with a decent regression model.

STEPWISE REGRESSION

Other approaches are a bit more complex, but more reliable. Perhaps the most common of these approaches is stepwise regression. Stepwise regression works by first identifying the independent variable with the highest correlation with the dependent variable. Once that variable is identified, a one-variable regression model is run. The residuals of that model are then obtained. Recall from previous *Forecast Friday* posts that if an important variable is omitted from a regression model, its effect on the dependent variable gets factored into the residuals. Hence, the next step in a stepwise regression is to identify the one unselected independent variable with the highest correlation with the residuals. Now you have your second independent variable, and you run a two-variable regression model. You then look at the residuals to that model and select the independent variable with the highest correlation to them, and so forth. Repeat the process until no more variables can be added into the model.

Many statistical analysis packages do stepwise regression seamlessly. Stepwise regression is not guaranteed to produce the optimal set of variables for your model.

OTHER APPROACHES

Other approaches to variable selection include best subsets regression, which involves taking various subsets of the available independent variables and running models with them, choosing the subset with the best R^2. Many statistical software packages have the capability of helping determine the various subsets to choose from. Principal components analysis of all the variables is another approach, but it is beyond the scope of this discussion.

Despite systematic techniques like stepwise regression, variable selection in regression models is as much an art as a science. Whatever variables you select for your model should have a valid rationale for being there.

REGRESSION VARIABLE SELECTION

The model-building for regression is an interactive process. Roughly speaking, it consists of four phases

1. Data collection
2. Reduction of predictor variables
3. Model refinement and selection
4. Model validation

For different purposes of the study we often have different models. E.g. if the purpose is only prediction, generally we want to include a subset of the variables in the model. But if the purpose is explanation, e.g. trying to build a descriptive model (often used for causal inference in some fields), then probably the more variables we have the better. Due to the correlations among predictor variables these two purposes, pre- diction and variable selection, often can not be satisfied simultaneously. Generally the inclusion of multiple correlated variables in the model will make the individual regression coefficients to be estimated unstably, i.e. with big variance. If we only use a small subset of variables, then the models are likely to be biased. Often we would like to achieve a balance between the variance and the bias. We can certainly say that all models are wrong, but some are useful".

MODEL SELECTION CRITERIA

Suppose we have a total P-1 predictors, and we want to select a subset of them (p-1 variables) to be included in our model. And we assume the sample size n is big enough.

QUESTIONS

1. How many different models?
2. How many different linear models?
3. How to determine the best" model?

CROSS VALIDATION (CV)

- PRES Sp is also called leave-one-out-cross-validation (LOOCV).
- Instead of LOOCV, we can consider general K-fold CV (KFCV),

where all samples are randomly divided into K groups. Each time one of the K-fold is left out (as a testing set), all the other K�1 fold (training set) are used to build a linear regression model and used to predict the left-out fold. Final prediction error is the average over the K-fold.

- Randomized CV

SEQUENTIAL SEARCH PROCEDURE

Forward stepwise regression is developed to reduce the computational efforts as compared with the all-possible-regression procedure. It is a sequential procedure, at each step adding or deleting an X variable. The criterion for adding or deleting an X variable can be stated equiv- alently in terms of error sum of squares reduction, coefficient of partial correlation, t statistic, F statistic. It works in the following way.

FORWARD STEPWISE SELECTION PROCEDURE

1. Fit a simple linear regression model for each of the P � 1 potential X variables, and choose the one with the best value of previous criteria, say Xk1 is added in the model.
2. With Xk1 in the model, we add in another one by maximizing the criterion. Xk2 is added when its value is the best and better than some (addin) threshold.
3. Drop Xk1 from the model if its value is less than some (dropout) threshold.
4. Repeat previous addin and dropout steps until no variable can be added or dropped.

Forward selection search procedure simplified the forward stepwise regression, omitting the test whether a variable once entered into the model should be dropped. Backward elimination search procedure begins with the model containing all potential X variables and considers dropping variables sequentially. A stepwise modification can be adapted that enables variables eliminated earlier to be added later. This modified procedure is called backward stepwise regression procedure.

MODEL VALIDATION

- Collect new data
- Compare with known results
- Data splitting

CONCLUSION

Regression models are powerful tools for predicting a score based on some other score. They involve a linear transformation of the predictor variable into the predicted variable. The parameters of the linear transformation are selected such that the least squares criterion is met, resulting in an "optimal" model. The model can then be used in the future to predict either exact scores, called point estimates, or intervals of scores, called interval estimates.

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