**Understanding Used Car Prices: Insights from CarDekho**

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**Introduction**

**Motivation**

Nowadays, as technological advancements revolutionize industries, digital car trading platforms have emerged as vital marketplaces, transforming the automotive market and the way people buy and sell second-hand vehicles. Notably, CarDekho.com is a well-known car trading platform based in India. The primary motivation for this analysis stems from the growing importance of platforms like CarDekho.com in connecting buyers and sellers. In particular, for buyers, understanding the relationship between car traits and pricing can facilitate purchasing decisions, and help assess whether a car is priced fairly. Meanwhile, for sellers, the insights into pricing trends can help attract more potential customers while still setting competitive selling prices, determining the optimal price for their listings. Thus, this study aims to investigate a deeper understanding of these relationships by addressing the following research questions:

* What are the relationships between the selling price and continuous covariates (year, km\_driven)?
* What categorical variables are associated with the selling price, and how do these variables influence pricing?
* What regression model can effectively explain and interpret the relationships in the data?

By answering these questions, we aim to develop a statistical model that contributes to the car trading marked by offering data-driven insights.

**Dataset**

The dataset analyzed in this report contains information about second-hand cars provided by CarDekho.com (<https://www.cardekho.com/>). The dataset was published on Kaggle (<https://www.kaggle.com/datasets/nehalbirla/vehicle-dataset-from-cardekho/data>) on June 26, 2020.

The following is a description of the variables found in the dataset:

|  |  |  |
| --- | --- | --- |
| **Variables** | **Type** | **Descriptions** |
| name | categorical | the name of the car; start with brand name which is a possible factor |
| year | continuous | the year of the car when it was bought (in years) |
| selling\_price | continuous | the price of car when it was sold (in Indian Rupee (INR)) |
| km\_driven | continuous | the distance that the car is driven (in kilometers) |
| fuel | categorical | the fuel type of the car; 5 levels (CNG/Diesel/Electric/LPG/Petrol) |
| seller\_type | categorical | the type of the seller; 3 levels (Dealer, Individual, Trustmark Dealer) |
| transmission | categorical | the type of gear transmission; 2 levels (Manual, Automatic) |
| owner | categorical | the number of previous owners; 5 levels |

By setting selling\_price as our response, we have a total of 5 categorical variables and 2 continuous variables.

**Exploratory Analysis**

**Preliminary analysis:**

To answer our research question, we commenced with an exploratory data analysis (EDA). From this, we aim to understand the structure and characteristics of the dataset while identifying underlying patterns, potential outliers, and relationships among the variables.

This analysis used the following R packages: dplyr, ggplot2, tidyr, tidyverse, readr, corrplot, and patchwork.

As previously determined, the dataset contains 5 categorical and 3 numerical variables. A summary of the dataset provides a preliminary overview of the variables in the data (Appendix 1.01).

From the summary, we observe several key findings in the continuous variables:

• The variable **year** ranges from 1992 to 2020, with a median of 2014, indicating that most vehicles in the dataset are relatively recent (modern).

• The variable **selling\_price** ranges from 20,000 to 8,900,000, with a median of 350,000 and a mean of 504,127, suggesting the presence of some high-priced outliers.

• The variable **km\_driven** ranges from 1 km to 806,599 km, with a median of 60,000 km and a mean of 66,216 km, again indicating a large amount of variance in vehicle usage.

In terms of the categorical variables, we determined that fuel has 5 levels, transmission has 2 levels, owner has 5 levels, and seller type has 3 levels.

Furthermore, we identified that the brand of vehicles might also be an important factor. Therefore, we created a variable called **brand** by extracting the car manufacturers’ names from the name column in the dataset. This variable allows us to identify trends or patterns that are specific to certain manufacturers. In addition, this simplifies and reduces the redundancy in the dataset, making it more interpretable and easier to work with in the statistical analysis phase.

**Note:** No missing values were found in the data. Thus, it was not necessary to perform any additional changes to the data to handle NaN values.

**Visualizations:**

To begin, we first created histograms to visualize the data, and understand the distributions of the continuous variables.

A graph of a car

Description automatically generated

From these plots, we observe that all distributions are not symmetric. The distribution of year is left-skewed, with a sharp increase in counts around 2005 and peaks around 2017. Meanwhile, the distribution of selling price is right skewed with the majority of vehicles sold under 625,000 INR and only a small number of vehicles priced above that price. Similarly, km driven is also right skewed with most of the vehicles reaching a mileage of under 200,000 km, and a couple over 200,000 km. **This skewness can indicate outliers in higher values, something we will need to consider when performing further analysis**.

To analyze the distribution of categorical variables, we used boxplots.

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Description automatically generated with medium confidence

Intuitively, from the distribution of owners, most of the cars offered just have one owner, while the proportion decreases by approximately half for each additional owner. Additionally, we see that petrol and diesel are the most popular in terms of fuel type while manual is the most frequent in terms of transmission. Also, we seem to have more individual sellers, followed by dealers, and finally, Trustmark dealers.

**Relationships with Selling Price:**

To investigate the relationship between the continuous variables and selling price, we created scatterplots that plotted the variables against selling price. For the **Selling Price vs. Year** plot, even though we cannot observe a straight away linear regression, we can see that the overall values seem to increase as the years go by, which is intuitive since older cars always tend to have lower prices. For the **Selling Price vs. Km Driven** plot, we observe a weak negative relationship. However, the outliers with large values make it difficult to see the trend clearly.

**A screenshot of a graph

Description automatically generated**

To investigate the relationship between the categorical variables and selling price, we created boxplots that plotted the variables against selling price (Appendix 1.03).

The outliers seemed to make the interpretation of the difference between each categorical type against selling price hard. For example, there seems to be a lot of outliers for Diesel and Petrol cars, but it could be due to the size of data for each type. However, it is still discernable that cars with less previous owners, cars that operate on diesel, automatic cars, and cars sold at Trustmark dealers have higher selling prices.

To mitigate this problem with the outliers, we plotted the boxplots once again without outliers (filtering by rejecting any value outside of the 5th quantile to the 95th quantile range). The results are consistent with our previous findings when we kept outliers in the plot.

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Description automatically generated with medium confidence

Regarding the brand variable, we created a preliminary boxplot to assess the difference in selling prices among different brands

A graph with different colored squares

Description automatically generated

There is an obvious difference between the selling prices among different brands. In particular, Audi, BMW, Land Rover, Benz, and Volvo have higher selling prices. However, the number of cars is significantly different among these brands. Thus, for model construction, **we might merge brand into two levels: luxury and economical. This is determined by the median selling price of each brand.** According to the plot above, we determined 1250000 to be the threshold that divides luxury and economical brands in terms of selling price.

According to this threshold, the following brands are luxury vehicles: Audi, BMW, Isuzu, Jaguar, Jeep, Kia, Land, MG, Mercedes-Benz, and Volvo. The rest of the brands are considered economical. The box plot comparing selling price by brand level shows consistent results with luxury vehicles having a higher selling price than economical vehicles.

Finally, we created a correlation matrix to evaluate the correlation strength between each continuous variable in the dataset (Appendix 1.05).

This correlation matrix supports our hypothesis that newer cars (cars with higher year value) tend to be more expensive. This is reflected in a moderate positive correlation with selling price (+0.41), and is consistent with our previous findings, though it is not as strong as expected. The kilometers driven display a weak negative correlation with selling price (-0.19). This indicates that the fewer kilometers driven, the higher the price of the car. This aligns with the logic that a car with lower mileage is closer to being new, and therefore, more valuable. Finally, the correlation between year and kilometers driven is moderate and negative (-0.42), implying that newer cars are less likely to have high mileage since older cars have been used longer, which is intuitive as well. **However, this correlation between covariates may lead to multicollinearity which we would need to consider in the statistical analysis phase.**

**Statistical Analysis**

After gaining an initial understanding of the data, the next step was to construct a regression model to better interpret the data and quantify the relationship between the selling price and various covariates. This modeling process aims to provide actionable insights into how these factors influence second-hand car prices.

Before fitting the regression model, it was crucial to assess the predictors for any potential concerns, particularly **multicollinearity**, which could undermine the stability and interpretability of the model. Multicollinearity occurs when predictors are highly correlated with one another, potentially inflating standard errors and obscuring the true relationship between the response variable and covariates. To diagnose multicollinearity, we calculated the Variance Inflation Factor (**VIF**) for each numerical variable. The results revealed that both year (**VIF = 1.57**) and km\_driven (**VIF = 1.48**) exhibited expected correlations without crossing the critical threshold of 10, which typically signals problematic multicollinearity. These values confirmed that the numerical predictors could be confidently included in the regression model without risking redundancy or instability in parameter estimates.

With these results, we moved forward in our analysis by fitting a linear regression model using all covariates. To enhance the model, we explored the potential **interaction between the continuous covariates km\_driven and year**. Two models were compared: one with additive effects (Appendix 2.01) and another including the interaction term (Appendix 2.02). The comparison revealed that the interaction term significantly influenced the selling price (p-value = 5.44\*10-13 ), so we decided to include this interaction term in further models.

Table 1 model with km\_driven:year (full in Appendix 2.02)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Term | km\_driven : year | fuelDiesel | fuelElectric | fuelLPG | fuelPetrol |
| p-value | 5.44⋅10-13 (\*\*\*) | 1.2⋅10-5 (\*\*\*) | 0.9484 | 0.5817 | 0.6652 |

Further observations indicated that among fuel types, only **diesel cars** were significantly different from the baseline (CNG), suggesting that the remaining fuel types could potentially be **merged** into a “non\_diesel” category. For seller type, only Trustmark dealers showed significant differences compared to the baseline (dealer). Transmission type and brand level also exhibited notable effects, with significant differences in their coefficients. Regarding ownership, the “Second Owner” category was the only one to show statistical significance, which raised the possibility of merging the other ownership levels.

We then conducted diagnostic tests to evaluate whether the model met the assumptions required for linear regression. The first diagnostic test involved **plotting residuals against fitted values** (Figure 1). This revealed a distinct “fan” shape, indicating a violation of the assumption of homoscedasticity. This finding suggested the need for a transformation of the response variable. To further validate this, we generated **a Q-Q plot** (Figure 2), which showed deviations from the Q-Q line, particularly in the tails. These deviations pointed to a heavy-tailed distribution of residuals, indicating a potential violation of the normality assumption.

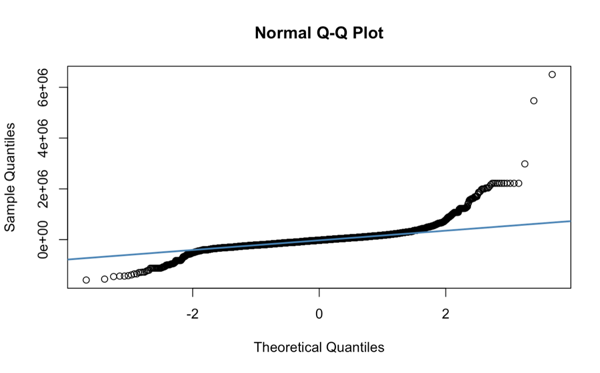


Figure 2

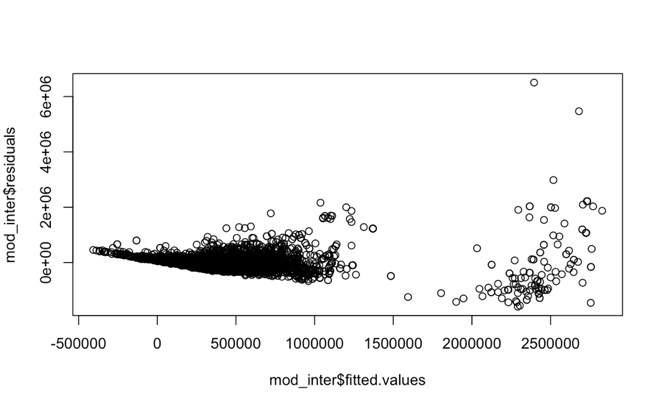


Figure 1

**Residual vs. Fitted**

Both diagnostics provided sufficient evidence that transforming the response variable was necessary. Following this, we implemented the log transformation, resulting in a new proposed model.

By running our fitted log-transformed model (Appendix 2.03), we observed significant improvements compared to the previous model. The transformation resulted in more coefficients of the owner variable becoming significant, while all coefficients of the **seller\_type** variable were now significant. For the fuel variable, only one level (diesel) showed significance, suggesting that the remaining levels could potentially be merged. Additionally, the R-squared value increased from **0.6288** to **0.7252**, indicating that the log-transformed model explained a greater proportion of the variation in the (log) selling price.

To evaluate whether the transformation improved the model’s assumptions, we revisited **diagnostic plots**. First, we examined the residuals against fitted values (Appendix 2.04). Unlike the original model, the residuals plot showed no obvious patterns, suggesting that the issue of heteroscedasticity had been mitigated. Next, we generated a Q-Q plot (Appendix 2.05) to assess the normality of residuals. While some data points still deviated from the Q-Q line, particularly in the tails, the deviations were less pronounced compared to the previous model. This indicated that the assumption of normality, though not perfectly satisfied, could now be reasonably approximated with slight heavy tails.

From the transformed model, we observed that some categories were not significant, prompting us to **merge certain levels to simplify the analysis**. We consolidated fuel types into **Diesel and Non-diesel**, based not only on their lack of significance but also to enhance interpretability. These modifications reduced the model’s complexity while retaining its explanatory power. The revised model was then re-fitted (Appendix 2.06), and the results indicated that all coefficients, except for the coefficient of Test Drive Car, were now significant. This confirmed that further variable removal through model selection was unnecessary.

One of our key research goals was to achieve an effective interpretation of the model. While the log-transformed model was a better fit than its predecessor, the presence of categorical covariates with multiple levels posed challenges in determining which interactions to include. To address this, we employed a **test-based** **backward selection** procedure. We focused on some interactions between categorical and continuous variables, and the previous added interaction between two continuous variables, specifically:

**(i) year:owner** to assess how selling price changes with the year of purchase across ownership levels.

**(ii) km\_driven:owner** to examine how kilometers driven impact selling price across ownership levels.

**(iii) year:transmission** to see whether the relationship between year and selling price differs by transmission type.

**(iv) km\_driven:transmission** to explore how kilometers driven influence selling price by transmission type.

**(v) km\_driven:year**, as the continuous interaction term, to evaluate how the combined effect of kilometers driven and year influences selling price.

Starting with a full model that included all these interactions, we iteratively removed terms with the lowest significance until all p-values were below the threshold .

|  |  |  |
| --- | --- | --- |
| Iteration | Removed Term | p-value |
| 1 | **km\_driven : transmission** | 0.665 |
| 2 | **km\_driven : year** | 0.436 |
| 3 | **year : transmission** | 0.149 |

The backward selection process resulted in a model with interactions between owner and each continuous variable (year and km\_driven). Note that we removed the interaction between continuous covariates in the second iteration. We referred to this as the **Model with Categorical Interactions** (Appendix 2.07). The final equation for this model was:

With this model finalized, we compared it to two others: the **Full Model**, which included all interactions (categorical and continuous), and the **Log-Transformed Model**, which featured only continuous interaction and merged levels in fuel. To assess model performance and select the best fit, we used Mallow’s Cp statistic, which measures how well a model balances fit and complexity. The results were as follows:

|  |  |  |
| --- | --- | --- |
| Model | Expected p+1 | Mallow’s Cp |
| Full Model | 23 | **23.00** |
| Log – Transformed | 13 | **50.56** |
| Categorical - Interactions | 20 | **19.87** |

Cp statistic is calculated relative to the Full model, so the Full model can’t be evaluated by this statistic. The **Categorical Interactions Model** emerged as the preferred choice, as its Cp closely aligned with the expected value.

To further evaluate the performance of three models, we compare their R-squared and Adjusted R-squared values. These metrics provided insight into the variance explained by each model while accounting for model complexity. The results were as follows:

|  |  |  |
| --- | --- | --- |
| Model | R-squared | Adjusted R-squared |
| Full Model | **0.728** | **0.726** |
| Log – Transformed | **0.725** | **0.724** |
| Categorical - Interactions | **0.728** | **0.736** |

The results aligned with the previous evaluation; the **Categorical Interactions Model** explains more proportion of variance in the response. While both the Full Model and the Categorical Interactions Model had similar R-squared and Adjusted R-squared values, the Categorical Interactions Model was preferred because of the principle of parsimony. The Categorical Interactions Model achieves a balance between performance and interpretability.

Confident in these results, we conducted additional diagnostics to ensure the Categorical Interactions Model adhered to linear regression assumptions. We plotted the residuals against the fitted values (Figure 3) and generated a Q-Q plot (Figure 4). Both diagnostics confirmed that the model exhibited no strong violations of homoscedasticity or normality assumptions, further validating our choice.

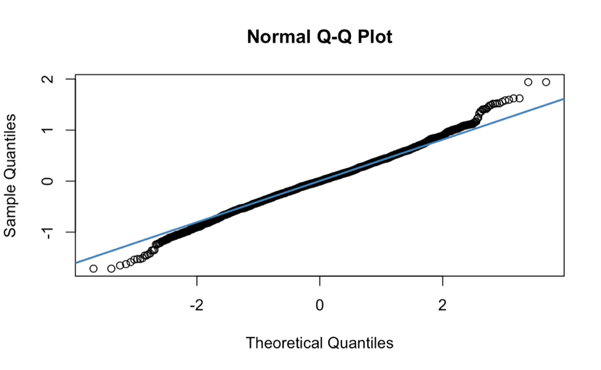


Figure 4

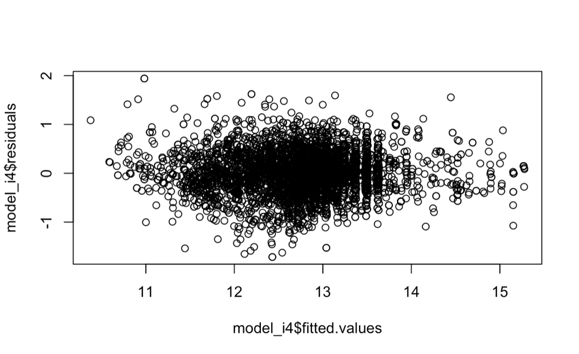


Figure 3

**Residual vs. Fitted (Categorical Interactions)**

**Discussion and Conclusion**

**Research Questions:**

Based on the Cp statistic, R-squared, Adjusted R-squared, and diagnostic evaluations, the **Categorical Interactions Model** emerged as the best fit. Compared to the full model, it is simpler and easier to interpret; compared to the model with interaction between continuous covariates, it performs better in explaining the variance in the log transformed selling price. This chosen model is what we are pursuing in the **third research question**.

**Question1 & 2:**

Based on the chosen model, we have strong evidence for the relationships between variables.

1. Fix other features, cars with one previous owner, the expected selling price decreases by a factor of (0.9999995), as the driven distance increases by 1 km.
2. Fix other features, cars with one previous owner, the expected selling price increases by a factor of (1.130093), as the car is one year newer.
3. All other features being equal, the expected selling price of cars using **diesel** is higher than that of cars using other fuels by a factor of (1.588357).
4. All other features being equal, the expected selling price of cars sold by **individual** is lower than that of cars sold by dealers by a factor of (0.8817912); the expected selling price of cars sold by **Trustmark dealer** is higher than that of cars sold by dealers by a factor of (1.474472).
5. All other features being equal, the expected selling price of **manual** cars is lower than that of automatic cars by a factor of (0.6367361).
6. All other features being equal, the expected selling price of **luxury** cars is higher than that of economical cars by a factor of (2.915379).
7. All other features being equal, except for test drive cars and cars with more than four owners, **the rates of change** of **log selling price** relative to **distance driven** are significantly different across different number of previous owners. Slope is for cars with second owner. Slope is for cars with third owner. **The rates of change** of log selling price relative to **year** are also different, specifically: 0.11079 for cars with second owner; 0.1037 for cars with third owner; 0.06759 for cars with more than four owners.

Most estimates are as expected. Less driven, newer cars tend to be expensive. As well, the prices of diesel, automatic, luxury cars tend to be higher. We found that there’s strong relationship between selling price and the type of sellers, in particular, dealers tend to sell cars at higher prices. However, some estimates of the rates of change across owners are **unexpected**. The slopes relative to **distance driven** of second owner and third owner are positive (above 7). In fact, the expected log selling price increases significantly as the distance driven increases. One possible explanation is that higher mileage with multiple previous owners may indicate the durability of used cars, resulting in the positive slope. However, further research is needed to confirm this hypothesis.

**Limitations:**

Firstly, we assume the error term of the chosen model is approximately normal. However, the Q-Q plot (figure 4) suggests a heavy tail distribution. This might violate the assumption of linear model, making conclusions less convincing. Secondly, the scope of model selection is limited by the number of interactions. Thirdly, the data set is provided online instead of via experiments, so all conclusions are restricted to the ranges of predictors. Finally, the bought price of used cars may be an underlying variable which is not contained in this data set, leading to weaker model performance.

**Conclusion:**

Based on this study, while users could trade used cars on CarDekho with their intuition most of time, the influence of prior ownership highlights the importance of carefully comparing the prices across vehicles with different ownership histories. Future research could help validate these findings and explore other contributing factors, such as purchase price, to gain deeper insights into the determinants of used car pricing.

**Appendix**

1. **Exploratory Data Analysis**
2. **Summary of Dataset**

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1. **A screenshot of a graph

   Description automatically generatedContinuous Variables vs. Selling Price**
2. **Categorical Variables vs. Selling Price**

**A group of graphs with different colored lines

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1. **Boxplot of Selling Price by Brand Level**

A graph with a blue and red rectangle

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1. **Correlation Matrix of Continuous Variables**

A diagram of a number of numbers

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1. **Statistical Analysis**
2. **Additive Regression Model with Full Covariates**

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1. **Regression Model with Full Covariates and Interaction (Year-Km\_Driven)**

**A screenshot of a computer

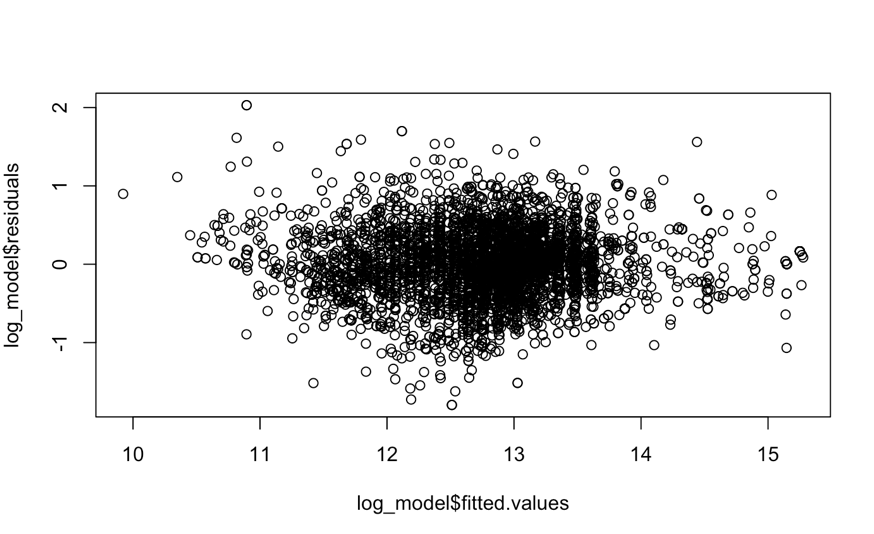
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1. **Regression Model with Log-Transformed Response**

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1. **Plot of Residuals for Log-Transformed Model**

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1. **Q-Q Plot for Log-Transformed Model**

**A graph of a normal q-q plot

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1. **Log-transformed Model with Merged Levels**

**A screenshot of a computer

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1. **Regression Model with Categorical Interactions**

**A screenshot of a computer

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