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Modelling the Income Elasticity of Demand of Different Beverages Among CBC Hefei No.1 Secondary School Students in the Context of Covid-19

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Abstract

This paper aims to analyze the influence of the Covid-19 pandemic on consumer behavior of high school students as a social group with no independent regular income. As the sources for data collection, we obtained the empirical sales data set of two beverage categories at an on-campus provision store run by students, representing inferior and luxury goods, respectively. We then took the periodic trends at times of the Covid-19 pandemic outbreak, transformed data basis into graphical representation,d and manipulated the data set with a mathematical modeling technique to approximate of students' choice in a relatively precise manner. From which we draw the conclusion based on our mathematical model and found its approximation to the demand elasticity curve of inferior vs. luxury goods from an economic perspective. The seamless integration of mathematical approach and behavioral economic analysis could produce a more concise pattern of consumers' choice during this special time of the epidemic.

Keywords: mathematical modelling, income elasticity of demand, Covid-19 pandemic

1. Introduction

1.1 Background

Interdisciplinary applications of mathematics in quantitative aspects of behavioral economics have never been more significant now. Statistical analysis plays an undeniably crucial role in summarizing business patterns from immense day-to-day operation data.

As a credible data source for first-hand statistics, we collect sales data from an on-campus provision store in my high school on a quotidian basis. Representing the conjoint effort of dedicated volunteers and student unions, we aim to offer a convenient selection of refreshing beverage options for students during recess time.

Starting from 2019, multiple waves of Covid outbreaks struck the global economy heavily, where a significant decline in the service industry has been observed in massive small enterprises. As a coincidence much worth discussing, the choice of our consumers shifted simultaneously and drastically towards cheaper products.

1.2 Economic Concepts

To analyze the reasons behind such phenomenon, we need to understand the uniqueness of high- school students as a social group with no stable source of income on their own, which served as a pre-requisite for their reliance on household earnings coming from the various economic sector, particularly the severely damaged small and medium-sized enterprises.

Purchasing options of students with no independent income could reflect the financial capacity of their households in times of general economic downturn, and factoring that consideration into mathematical models could yield meaningful results concerning studying consumer behavioral patterns when an epidemic crisis arises.

As the inevitable consequences of regional Coronavirus outbreak and following lockdowns, household disposable income has been continuously decreasing, further impacting purchasing power of students since they are completely reliant on family financial support for any daily expenses. To that end, we need to introduce the economic concept of YED, namely income elasticity of demand.

1.3 Income Elasticity of Demand (YED)

Income elasticity of demand (YED) measures the responsiveness of consumers' demand for a particular good to a change in income. YED is calculated as the ratio of the percentage change in quantity demanded for a good to the percentage change in the consumers' income.

$$YED = \frac{\%\ \text{change in quantity demanded}}{\%\ \text{change in income}}$$

The value ranges of the YED value indicate different categories of goods, respectively.

Inferior goods: a negative YED value is associated with inferior goods; an increase in income will lead to a fall in quantity demanded.

Normal goods: a positive YED value is associated with normal goods; an increase in income will lead to a rise in quantity demanded.

Necessity goods: a positive YED value smaller than one represents necessity good with income inelastic demand, where a percentage increase in income produces a lower percentage increase in purchase.

Luxury goods: a positive YED value larger than one represents luxury good with income elastic demand, which means a percentage increase in income results in a higher percentage increase in quantity demanded.

2. Data Collection

From the aforementioned statistical source, namely the on-campus provision store purely run by students, we actively built a sales database every week, which serves as a foundation for business analytics targeting student preferences, to improve customer experience through diversifying product selection on the shelf.

As we observe the behavior of two categories of products available in the on-campus provision store in terms of price distinction, we set the standard line at CNY3 and presumed the products under the line CNY3 represents inferior goods while more expensive type above the line represents necessity goods. However, later we found out that the sales volume curve of relatively more costly products has a ratio larger than one and therefore represents luxury goods.

Considering the fact that school holidays are designed differently from the regular schedule (i.e. the summer and winter vacation), it's ineffective to organize our data by normal calendar week due to the many unavoidable vacancies. Especially when the Covid-19 epidemic brings more unexpected temporary lockdowns, which forcibly turned massive on-campus schooldays into study-from-home time.

To maintain the consistency of our graphical analytics, we only take school weeks where students are required to be physically present on campus for all five days a week and denote them "effective school week(s)".

Furthermore, we number the aforementioned effective school weeks from 1 to n, which excludes school holidays and interim halts due to sudden Covid outbreaks in the region. Sales volume data for in-store purchases are gathered and summarized weekly for a total of 51 weeks as demonstrated below.

Table 1. (Relative) luxury and inferior goods sales table

Week(x)	Luxury	Inferior	Week(x)	Luxury	Inferior	Week(x)	Luxury	Inferior
1	725	223	18	207	339	35	139	403
2	651	232	19	213	340	36	157	413
3	602	245	20	195	353	37	138	425
4	541	267	21	184	342	38	112	438
5	491	283	22	174	347	39	126	453
6	438	274	23	166	341	40	154	470
7	412	298	24	163	356	41	139	489
8	391	302	25	192	362	42	106	512

9	372	313	26	184	358	43	115	527
10	346	295	27	176	356	44	109	548
11	343	314	28	153	360	45	130	604
12	329	312	29	145	364	46	122	637
13	322	327	30	167	368	47	134	661
14	297	354	31	132	343	48	128	726
15	285	367	32	146	379	49	130	743
16	264	334	33	118	386	50	119	756
17	231	358	34	142	394	51	105	777

To gain a better graphical representation of data trends, we transform our dataset into sales volume curves respectively for a clear visual image.

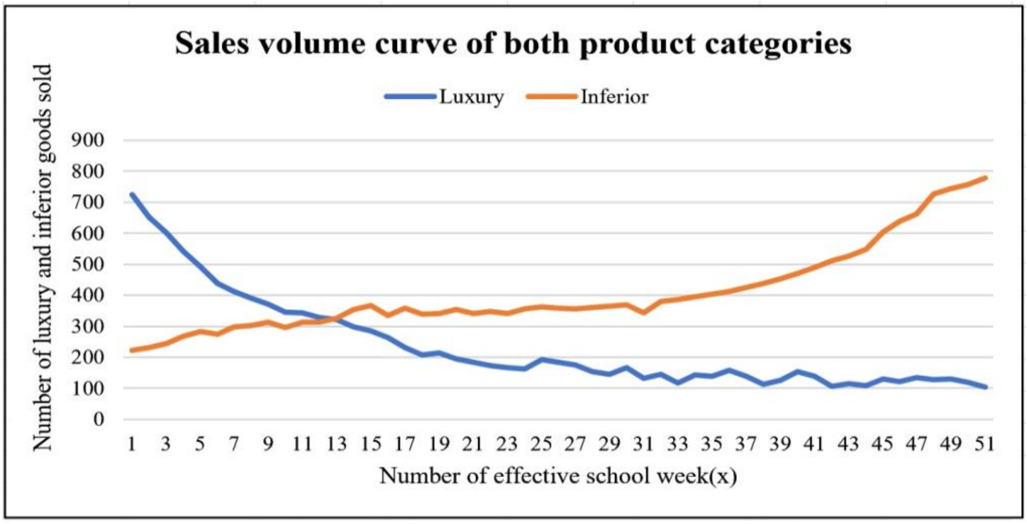

Figure 1. Line graph of both sales volume curve based on luxury and inferior goods

3. Modelling and Mathematical Manipulation

To achieve comprehensible data visualization, sales volume curves of luxury and inferior goods are analyzed separately. Five different types of mathematical models are presumed to approximate the general data pattern of both product categories by plotting trend lines within volume curve images respectively.

As a standard of evaluating which model fits both sales volume curves the best, we use the coefficient of determination R^2, which indicates how much variation of a dependent variable is explained by the independent variable(s) in a regression model.

R^2 values range from 0 to 1 and are commonly stated as percentages from 0% to 100%. An R^2 of 100% means that all movements of our products are completely explained by movements in our model. Therefore, comparisons of R^2 values will help us ascertain which one out of five mathematical models could represent consumer choice in the most precise manner possible.

In this paper, R^2 values are shown correct to four decimal places.

3.1 Linear Model

Model form: $f(x) = kx + b$.

Result function after substitution and calculation: y = -8.7176x + 463.13 Coefficient of determination: $R^2 = 0.7247$.

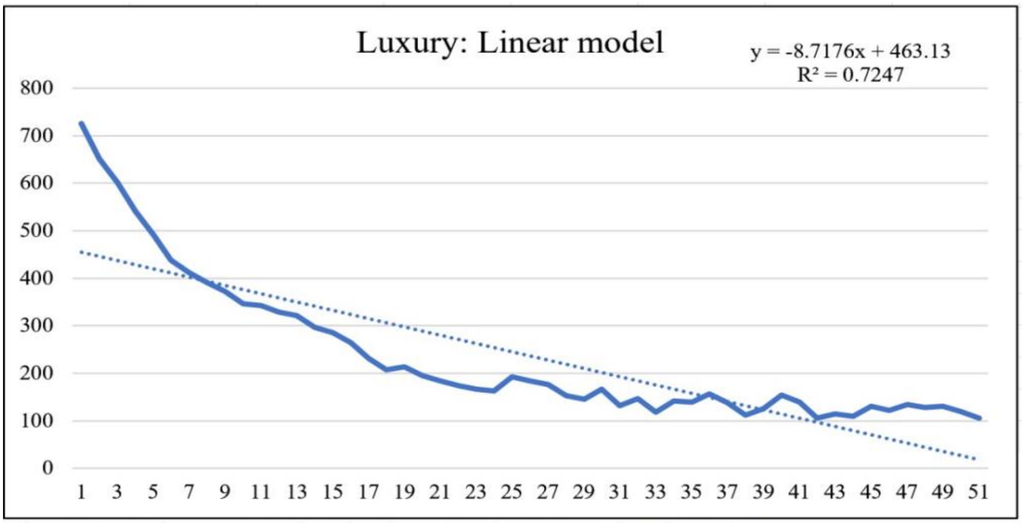

Figure 2. Linear approximation based on luxury goods sales volume

Result function after substitution and calculation: y = 8.2282x + 193.28

Coefficient of determination: $R^2 = 0.7811$

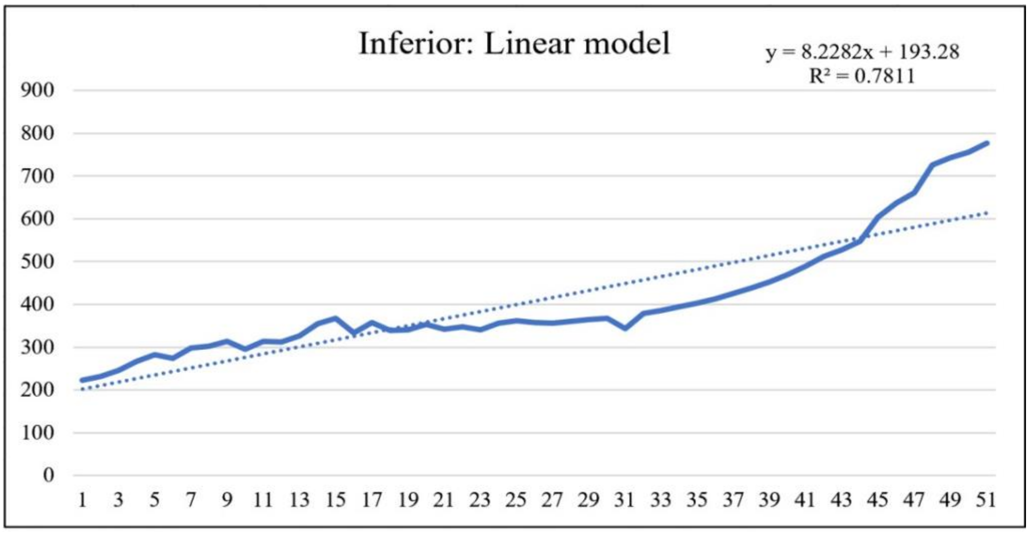

Figure 3. Linear approximation based on inferior goods sales volume

3.2 Exponential Model

Model form: $f(x) = a + be^{cx}$

Results after substitution and calculation: $y = 482.41e^{-0.03x}$

Coefficient of determination: $R^2 = 0.8786$

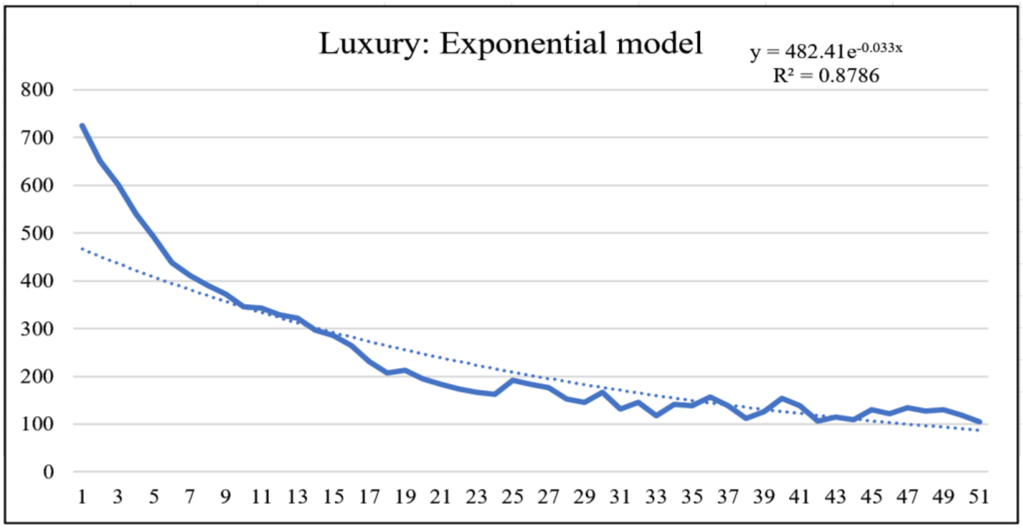

Figure 4. Exponential approximation based on luxury goods sales volume

Result function after substitution and calculation: $y = 236.43e^{0.0191x}$

Coefficient of determination: $R^2 = 0.8545$

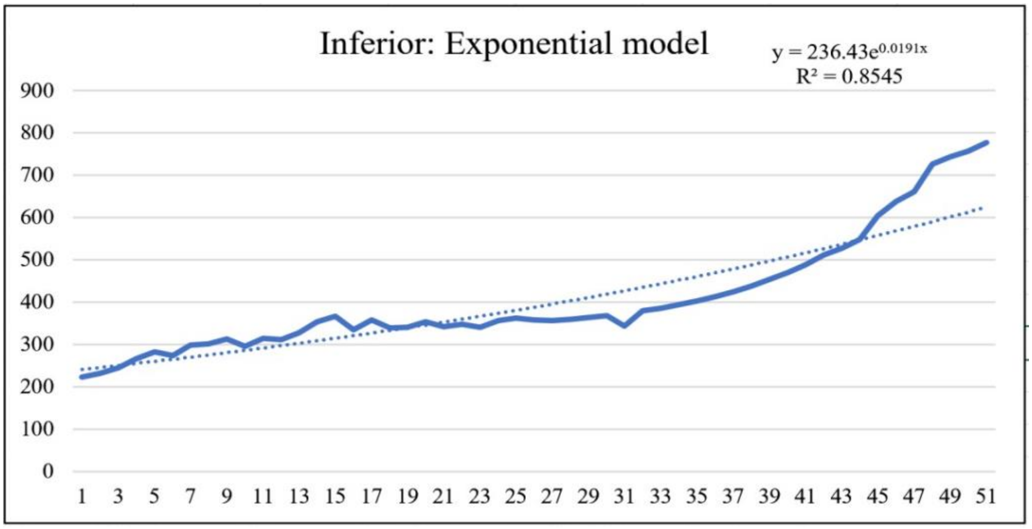

Figure 5. Exponential approximation based on inferior goods sales volume

3.3 Logarithmic Model

Model form: $f(x) = a + b\ln{(x)}$

Result function after substitution and calculation: $y = -168.4\ln(x) + 739.69$

Coefficient of determination: $R^2 = 0.9702$

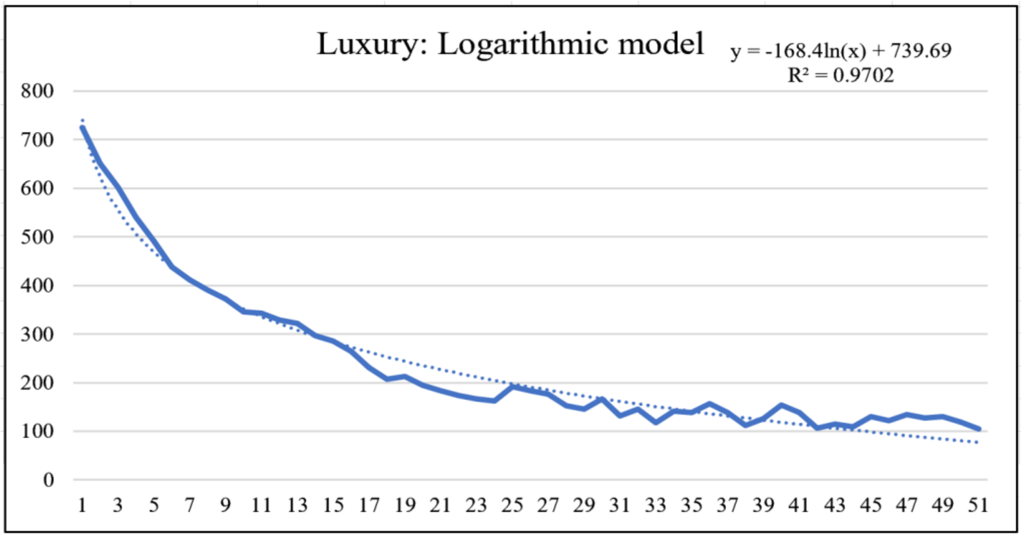

Figure 6. Logarithmic approximation based on luxury goods sales volume

Result function after substitution and calculation: y = 112.88ln(x) + 69.87

Coefficient of determination: $R^2 = 0.5275$

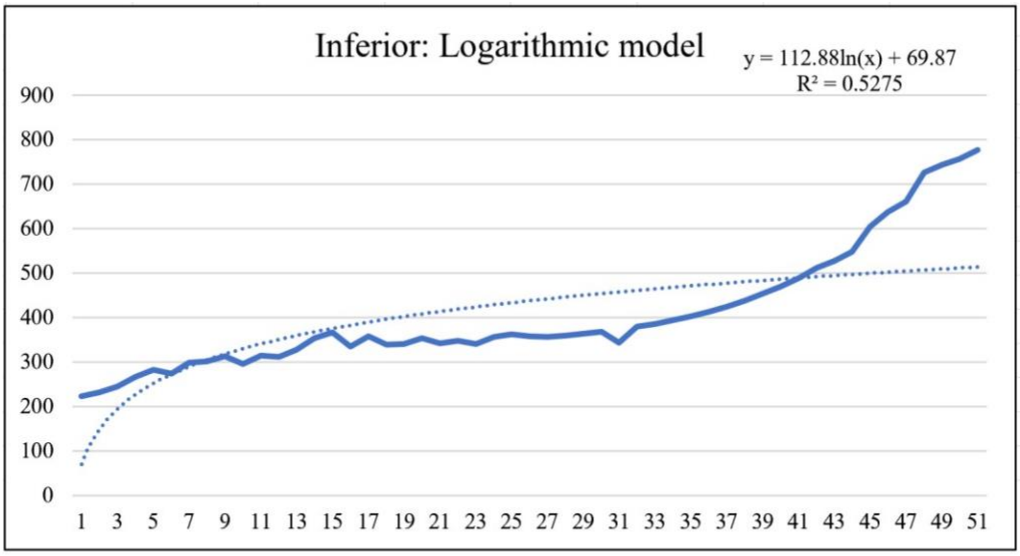

Figure 7. Logarithmic approximation based on inferior goods sales volume

3.4 Power Model

Model form: $f(x) = ax^b$

Result function after substitution and calculation: $y = 1148.8x^{-0.582}$

Coefficient of determination: $R^2 = 0.8794$

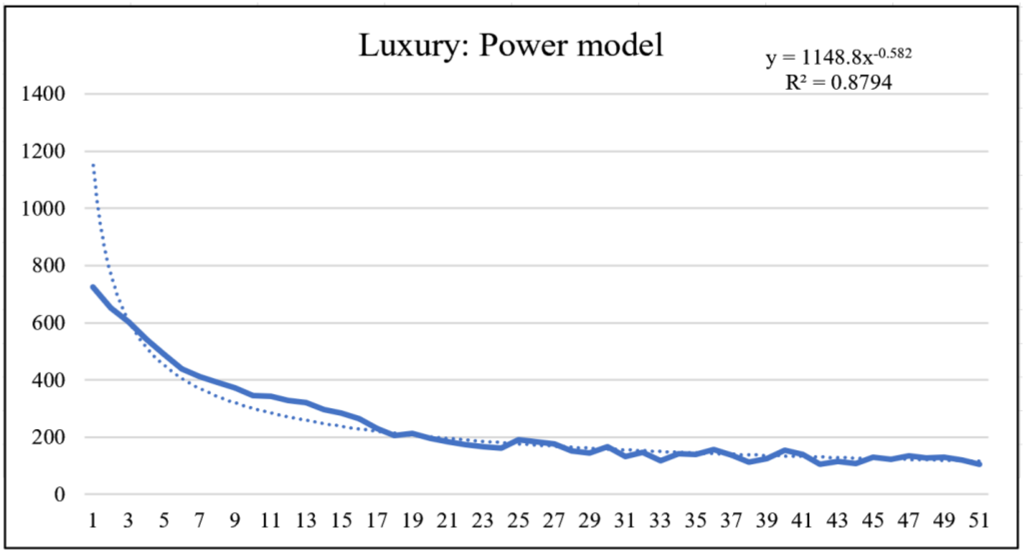

Figure 8. Power approximation based on luxury goods sales volume

Result function after substitution and calculation: $y = 167.42x^{0.2813}$

Coefficient of determination: $R^2 = 0.6196$

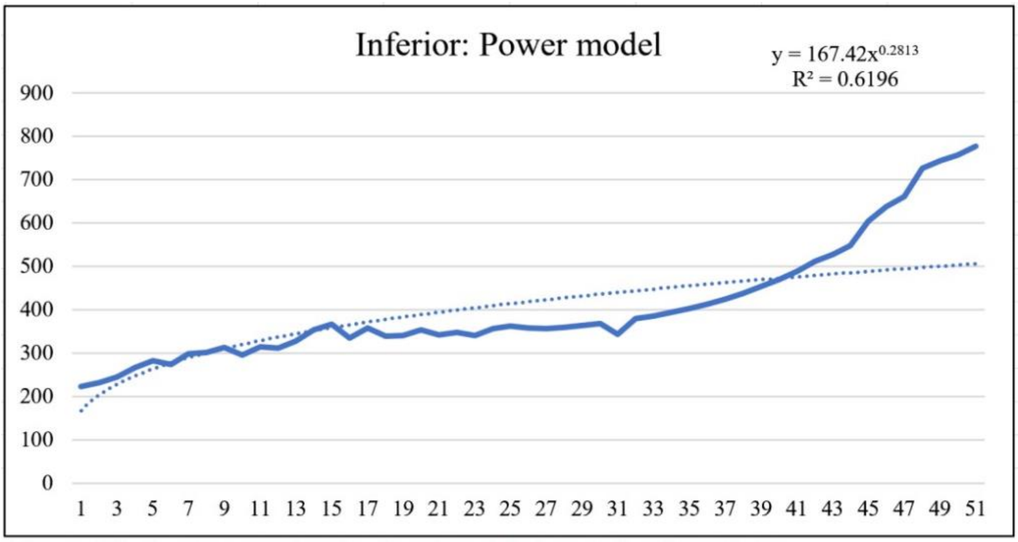

Figure 9. Power approximation based on inferior goods sales volume

3.5 Polynomial Model

Model form (deg=2): $f(x) = ax^2 + bx + c$

Result function after substitution and calculation: $y = 0.3678x^2 - 27.843x + 632.07$

Coefficient of determination: $R^2 = 0.9481$

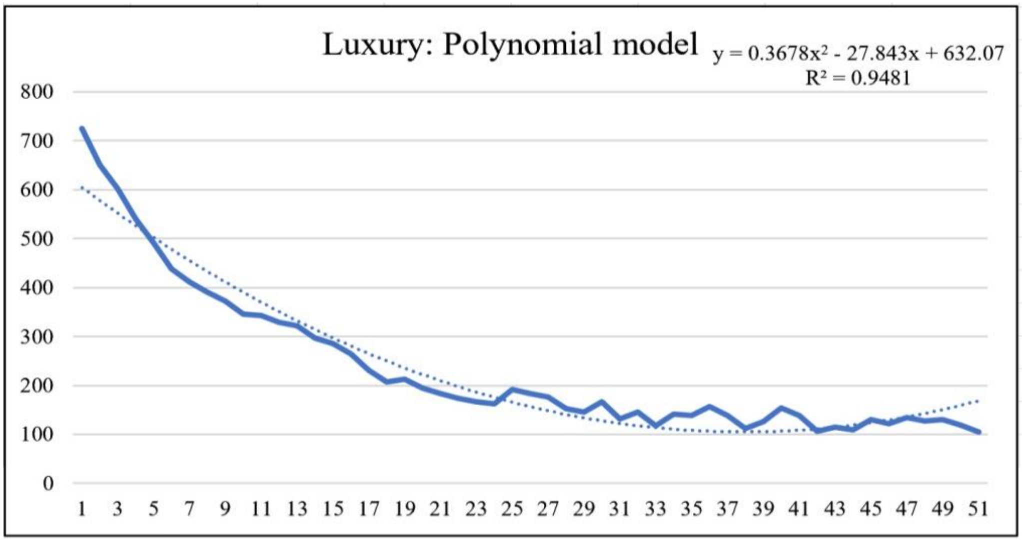

Figure 10. Polynomial approximation based on luxury goods sales volume

Result function after substitution and calculation: $y = 0.2551x^2 - 5.0363x + 310.45$

Coefficient of determination: $R^2 = 0.9112$

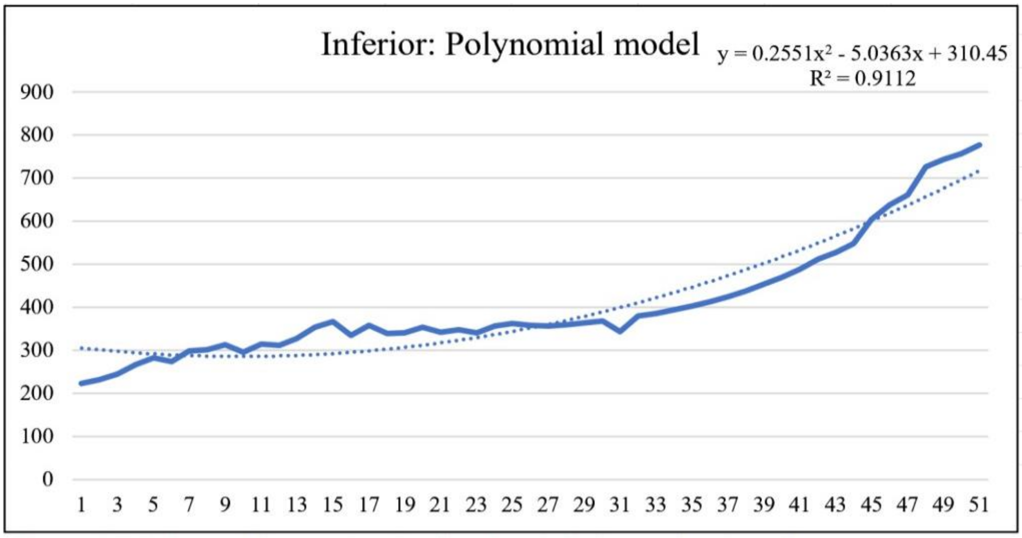

Figure 11. Polynomial approximation based on inferior goods sales volume

4. Conclusion

After meticulous calculation of each mathematical model, the result functions and R^2 values are summarized below, whichever model with the R^2 value closest to 1 could be regarded as the most precise approximation for the corresponding sales volume curve.

Table 2. Comparison of models for luxury goods

Luxury	Function	R^2
Linear	$y = -8.7176t + 463.13$	0.7247
Exponential	$y = 482.41e^{-0.03x}$	0.8786
Logarithmic	$y = -168.4\ln(x) + 739.69$	0.9702
Power	$y = 1148.8x^{-0.582}$	0.8794
Polynomial	$y = 0.3678x^2 - 27.843x + 632.07$	0.9481

In respect of luxury goods, the logarithmic model of y = -168.4ln(x) + 739.69 achieves the highest R^2 value of 0.9481, which demonstrates the demise of more expensive products during an epidemic follows a downward logarithmic curve with negative vertical stretch factor.

Table 3. Comparison of models for inferior goods

Inferior	Function	R^2
Linear	y = 8.2282t + 193.28	0.7811
Exponential	$y = 236.43e^{0.0191x}$	0.8545
Logarithmic	y = 112.88ln(x) + 69.87	0.5275
Power	$y = 167.42x^{0.2813}$	0.6196
Polynomial	$y = 0.2551x^2 - 5.0363x + 310.45$	0.9112

On the contrary, the quadratic polynomial model $y = 0.2551x^2 - 5.0363x + 310.45$ emulate other mathematical modeling assumptions by large with the best R^2 value of 0.9112, showing how the increasing trend of cheaper products in the inferior goods category fits an upward quadratic polynomial curve.

Based on mathematical analysis and approximation model, we recognize two different patterns for consumer behavior in times of the Covid-19 pandemic. When household disposable income massively decline as a result of the halted service industry, inferior goods drastically gained more popularity following a quadratic pace while luxury goods started to become ever more unaffordable. We conclude that the sales volume of two categories of beverages during the Covid-19 pandemic fit the demand elasticity model of inferior and luxury goods.

The integration of economics and data science could lay a firm foundation for effective decision-making, which enables a brand-new perspective in observing consumer behavior toward inferior and luxury products during the Covid-19 epidemic.

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