Price Elasticity Analysis and Sales Optimization in Retail Using Historical Transaction Data

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Abstract

Effective pricing is a critical factor in maximizing revenue and profitability for retail businesses. Understanding price elasticity helps retailers determine optimal price points by analyzing how demand varies with price changes. This project aims to develop a price recommendation system using historical transaction data to assess the elasticity of demand for different products and recommend pricing adjustments to increase both revenue and profitability.

Keywords: Machine Learning, Price Elasticity, Constraint Optimization.

1. Introduction

In a competitive retail environment, price elasticity[1]—the measure of demand response to price changes—plays a crucial role in setting optimal pricing strategies. Retailers often rely on trial and error to adjust prices, potentially missing opportunities to maximize revenue or inadvertently driving away demand-sensitive customers. This project focuses on developing a predictive model to analyze price elasticity across products and optimize pricing. Using transactional data, we will examine historical sales and item-level pricing to recommend price adjustments tailored to profitability and demand sensitivity.

The project will leverage price elasticity to help make informed decisions on price increases that align with revenue and profitability goals. We will also account for seasonality, trends, and external factors that may influence purchasing behavior, aiming to deliver a comprehensive solution for retail price optimization.

2. Methods

The project involved various methods like Data Collection, Exploratory Data Analysis, Calculating elasticities and finding optimal price based on recommendations.

Data Collection and Dataset

Data collection for this project required a diverse range of data, including historical sales data, pricing information, and customer demographics. The dataset[6] includes sales and inventory data for a fictitious chain of toy stores in Mexico called Maven Toys, including information about products, stores, daily transactions, and current inventory levels of each location. Additional datasets have also been created using original raw data files. Along with this price variation for each day considering discounts to calculate elasticities have also been added. For calculating

new prices some additional features such as actual product price revenue, expected revenue and profit have also been created.

Exploratory Data Analysis

Before proceeding to EDA, we did some basic checks on our dataset like finding null data, duplicates and outliers. No null data, duplicates or outliers were to be found in the dataset. Further, based on various factors such as city, store, month, etc we identified the top selling items(most units sold), top profitable items, top revenue generating items and items which were sold frequently.

Top Selling Items

Product_ID	Product_Name	Units
6	Colorbuds	104368
25	PlayDoh Can	103128
3	Barrel O' Slime	91663
8	Deck Of Cards	84034
19	Magic Sand	60598

Top Profitable Items

Product_ID	Product_Name	Profit
6	Colorbuds	806518.64
1	Action Figure	347825.31
8	Deck Of Cards	251917.38
3	Barrel O' Slime	217607.83
18	Lego Bricks	191680.99

Top Revenue Generating Items

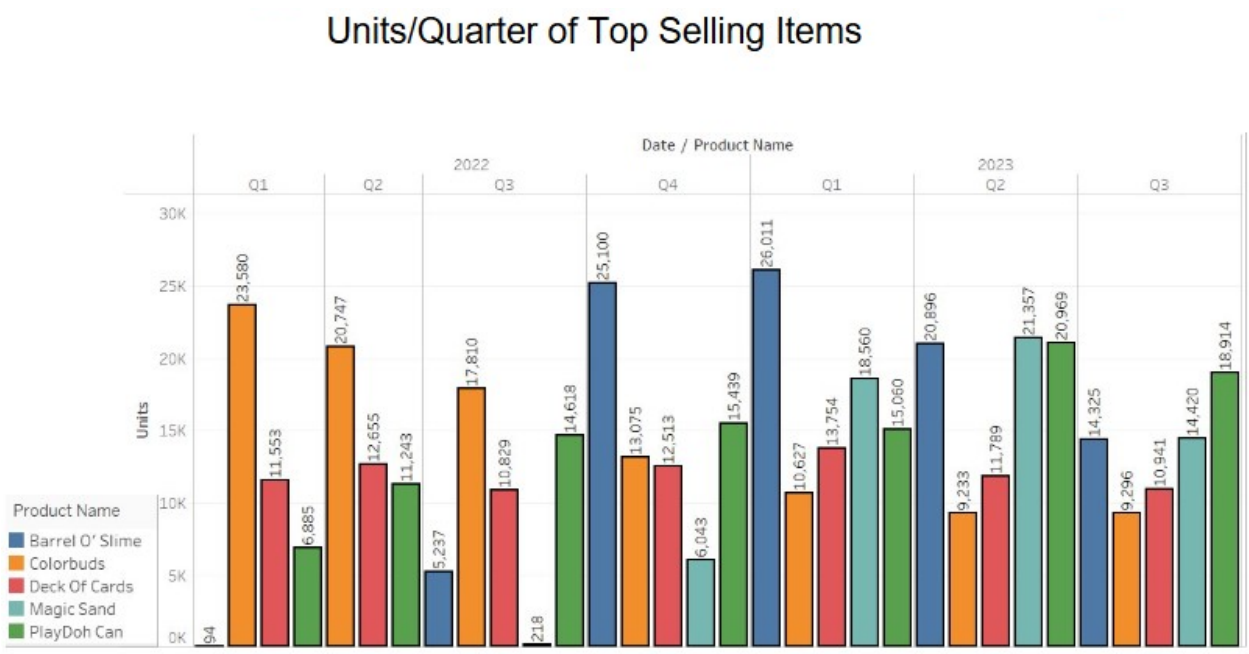
Product_ID	Product_Name	Revenue
18	Lego Bricks	2281878.62
6	Colorbuds	1553544.56
19	Magic Sand	964886.18
1	Action Figure	963467.73
30	Rubik's Cube	859579.58

Fig 1 Top selling, profitable and revenue generating items

In the above image we check the top selling items, top profitable items and top revenue generating items which are some necessary information needed for price elasticity.

	Quarter of Date						
Product Name	2022 Q1	2022 Q2	2022 Q3	2022 Q4	2023 Q1	2023 Q2	2023 Q3
Barrel O' Slime	$3.86		$3.88	$3.82	$4.35	$4.84	$4.82
Colorbuds	$14.46	$14.61	$14.52	$14.38	$15.60	$16.02	$16.00
Deck Of Cards	$6.81	$6.83	$7.28	$7.16	$7.25	$7.26	$7.26
Magic Sand			$15.47	$15.32	$15.98	$16.03	$15.94
PlayDoh Can	$2.90	$2.90	$2.89	$2.87	$3.10	$3.10	$3.09

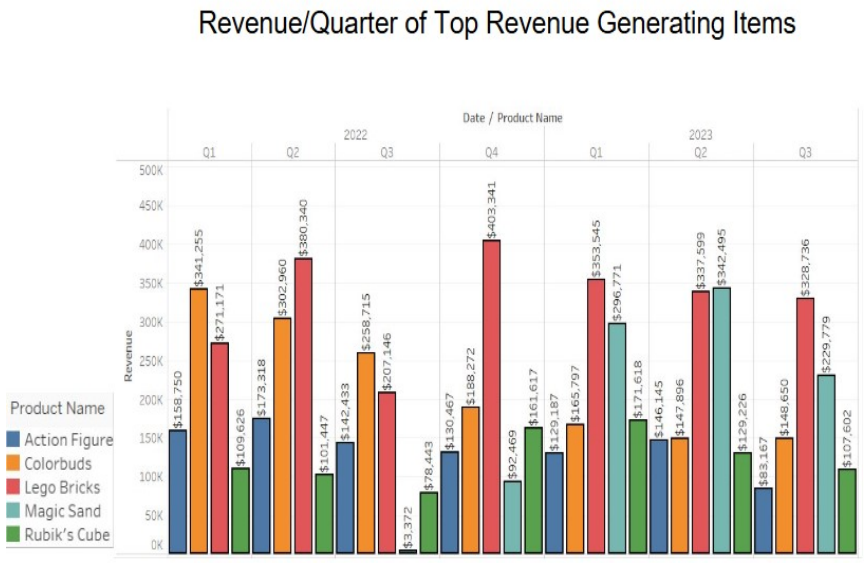
2(a)



2(b)

Fig 2 (a)Quarter on Quarter prices of top selling item, (b) Units per quarter of top selling item

From the above two images we can also find some more relevant information required for price elasticity which is that when the price of **colorbuds** is increased quarterly it affects its sale, hence further decreasing the revenue. Through this information we can understand which products we need to select so that the sale of products does not decrease hence not decreasing the revenue.



Product Name	Date						
	2022				2023		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Action Figure	$15.55	$15.60	$17.41	$17.31	$17.06	$17.04	$17.45
Colorbuds	$14.46	$14.61	$14.52	$14.38	$15.60	$16.02	$16.00
Lego Bricks	$37.93	$37.88	$38.16	$37.83	$38.36	$38.68	$38.67
Magic Sand			$15.47	$15.32	$15.98	$16.03	$15.94
Rubik's Cube	$18.45	$18.38	$18.45	$18.15	$19.41	$19.39	$19.46

Fig 3 Revenue per quarter of top revenue generating item along with Quarter on Quarter prices

Similarly, when we checked for top revenue generating items in our dataset we found out that Lego Bricks despite increase in price still generated the highest revenues among all products in most of the cases.

Approach for calculating Price Changes and Estimation.

Our approach consists of two main components: Price Elasticity Estimation and Revenue and Profit Optimization.

Price Elasticity Estimation:
Using historical transaction data, we will estimate demand elasticity by analyzing the relationship between price changes and sales quantities. To account for varying elasticity across categories, we'll first apply clustering techniques to group the dataset at various level such as store, region, city etc., allowing us to calculate elasticity within each group. Statistical and machine learning methods[2], such as linear and log-log regression, will then be used to determine elasticity coefficients, identifying which items are price-sensitive or inelastic. We will incorporate seasonality, category-specific elasticity.

Price Elasticity Formula: It measures how the quantity demanded of an item changes with a change in price. The formula is:

$$Elasticity = \%\ change\ in\ Quantity\ Demanded\ /\ \%\ change\ in\ price$$

Revenue and Profit Optimization:

With elasticity coefficients, we will develop an optimization model to recommend price adjustments that maximize revenue and/or profitability. Using mathematical programming techniques, we will balance trade-offs between price increases for revenue-maximizing items and demand sensitivity to prevent volume loss in price-sensitive items. By targeting profit maximization for products[3], we aim to create a balanced pricing strategy. Based on the calculated price elasticity, a new price is determined to maximize revenue, ensuring the new revenue exceeds the original. The log-log model is a popular method in econometrics for estimating price elasticity. Its formula is given by

$$\ln(Q)=\beta 0+\beta 1\ln(P)+\epsilon$$

Here, β1 represents the price elasticity coefficient, capturing the relationship between the price changes and quantity demanded.

Constraints / Ground rules for price changes:

1. We have only considered price increases.
2. Prices will be increased by max at either 10% or 50 cents whichever is lower.
3. We will make sure that precise ends with either 5($x.x5) or 9($x.x9) which is standard pricing around the globe.

4. Finally, we have made sure the unit sold loss considered is below 1%.

Using the above constraints and by modeling the problem with a log-log approach, we developed a revenue-optimizing Python script. This script determines the price at which the revenue for each item is maximized. If no optimal price satisfying the given conditions is identified, the script returns a price change of 0, indicating that no price modification is necessary.

3. Results and Output

As outlined in the previous section, elasticity for a product can be calculated at various levels, depending on the requirements and decisions made by the stakeholders. For our analysis, we focused on calculating elasticities at the item-store location level. To enhance accessibility and usability, we developed a user-friendly interface that allows users to calculate price elasticities at various levels. Additionally, the interface provides recommendations for the top 5 items at the selected level.

Store Location	Product Name	Product Price	Units	Elasticity	New Product Price	Delta Price Change	Revenue	New Revenue	Delta Revenue
Airport	Total	$15.38	16,292	-11.642	$472.66	$11.26	208,890	220,626	5,260
	PlayDoh Can	$3.19	1,928	-0.001	$3.55	$0.36	5,998	6,844	693
	Action Figure	$17.99	704	-0.001	$18.49	$0.50	12,049	13,017	640
	Magic Sand	$16.49	1,142	-0.033	$16.99	$0.50	18,297	19,383	552
	Animal Figures	$13.99	624	-0.001	$14.49	$0.50	8,293	9,041	497
	Dino Egg	$11.99	576	-0.001	$12.49	$0.50	6,686	7,194	349
Commercial	Total	$15.38	8,891	-8.859	$473.50	$12.10	117,992	125,725	3,752
	Barrel O' Slime	$4.99	858	-0.001	$5.49	$0.50	4,027	4,710	570
	Dino Egg	$11.99	675	-0.001	$12.49	$0.50	7,788	8,430	406
	PlayDoh Can	$3.19	977	-0.001	$3.55	$0.36	3,022	3,468	351
	Rubik's Cube	$19.99	521	-0.001	$20.49	$0.50	10,110	10,675	260
	Magic Sand	$16.49	520	-0.001	$16.99	$0.50	8,274	8,835	260
Downtown	Total	$15.40	12,616	-13.328	$552.61	$13.76	155,718	164,871	4,800
	Barrel O' Slime	$4.99	2,130	-0.001	$5.49	$0.50	10,173	11,693	1,212
	Magic Sand	$16.49	1,239	-0.001	$16.99	$0.50	19,879	21,050	619
	Splash Balls	$9.49	685	-0.122	$9.99	$0.50	6,336	6,799	299
	Dino Egg	$11.99	983	-0.867	$12.09	$0.10	11,210	11,798	260
	Animal Figures	$13.99	380	-0.095	$14.49	$0.50	5,072	5,487	259
Residential	Total	$15.40	11,777	-6.031	$554.05	$15.20	148,764	158,657	5,390
	Mini Ping Pong Set	$11.99	1,211	-0.001	$12.49	$0.50	14,111	15,125	605
	Dino Egg	$11.99	774	-0.001	$12.49	$0.50	8,809	9,667	533
	Kids Makeup Kit	$21.49	556	-0.001	$21.99	$0.50	11,442	12,226	463
	PlayDoh Can	$3.19	1,049	-0.001	$3.55	$0.36	3,251	3,724	377
	Action Figure	$17.99	485	-0.001	$18.49	$0.50	8,396	8,967	356

Table 1 Top 5 items recommended for price change in each store location.

Observations from the Table

Low Elasticity Products (Nearly Inelastic):

Most products in the table have an elasticity of around **-0.001**, meaning demand is almost unaffected by price changes. Small price increases (e.g., $0.50) translate directly to higher revenues without significant loss of unit sales.

Products with Moderate Elasticity:

Some products display moderate elasticity, where price adjustments slightly affect sales:

- **"Splash Balls" (Downtown)**:
    - Elasticity: **-0.122** (relatively more elastic).
    - Price increase: $0.50 (from $9.49 to $9.99).
    - Unit sales decreased slightly from 685 to an estimated ~680 (calculated).

Even for products with moderate elasticity, slight price increases still lead to revenue gains due to higher price points.

Products with High Unit Sales and Low Elasticity:

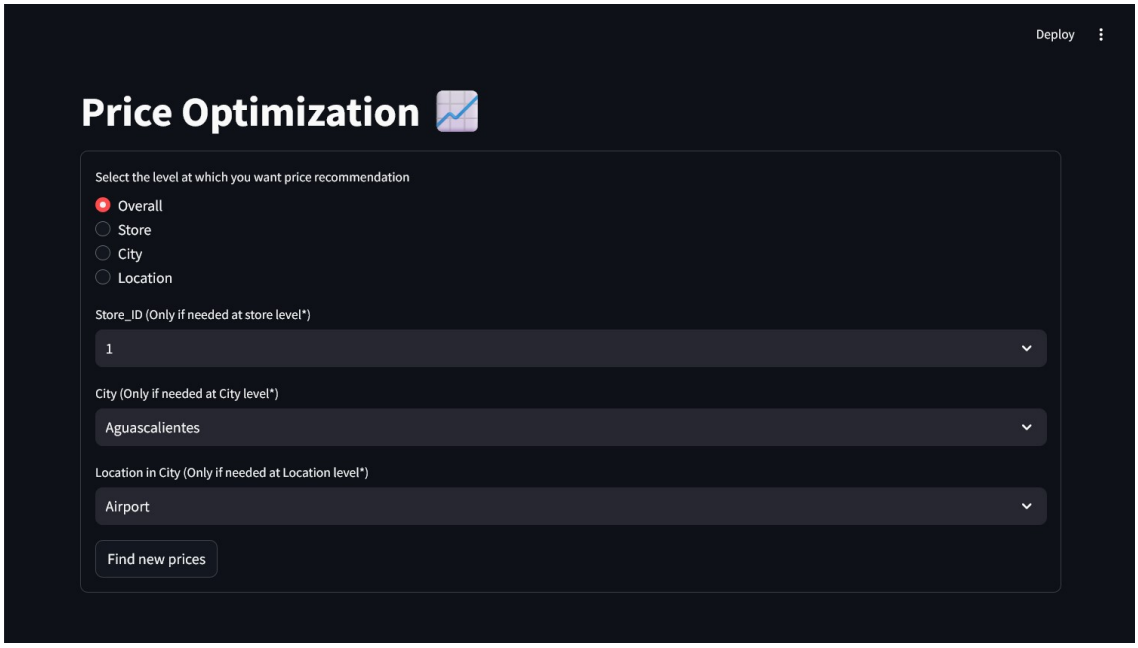
Products with high sales volume benefit significantly from price increases due to their inelastic nature:

- **"Magic Sand" (Airport)**:
    - Elasticity: -0.001.
    - Price increase: $0.50 (from $16.49 to $16.99).
    - Unit sales remain at 1,142.
    - Revenue increases from $18,838 to $19,383 (Delta Revenue: $545).

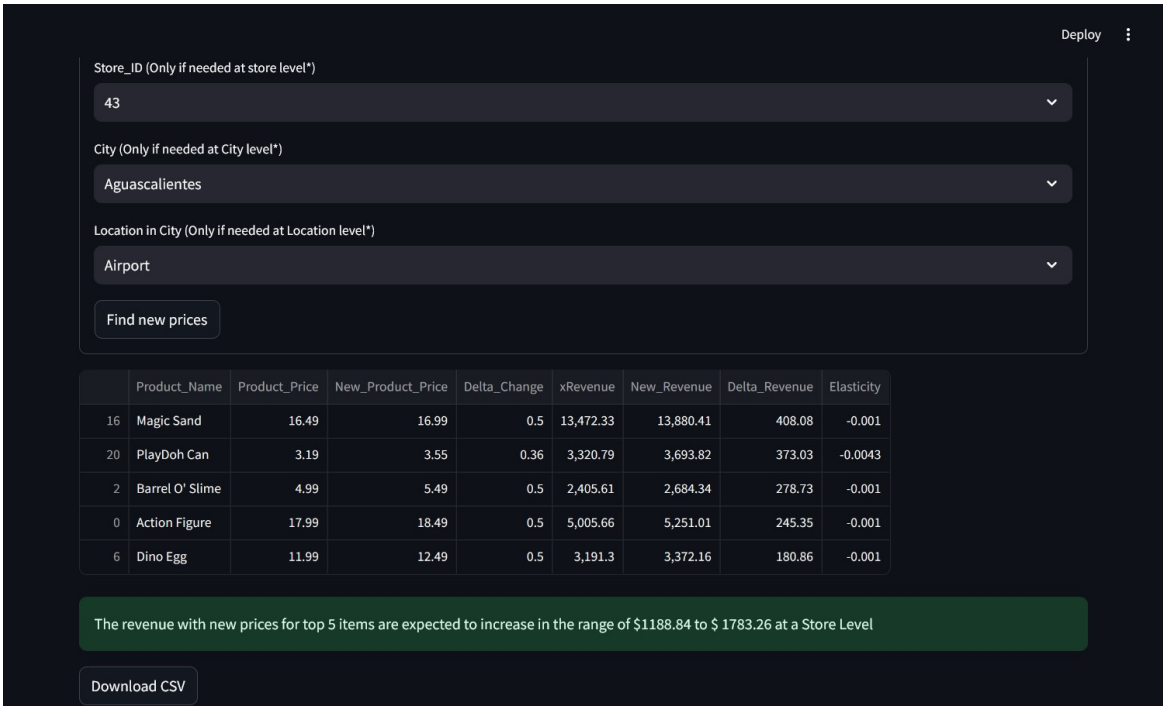
For high-volume, low-elasticity products, incremental price increases have a compounding effect on total revenue, with negligible impact on demand.

In the results and output we have observed that minor price increases are feasible without significantly impacting unit sales, as demand is inelastic for most products. Downtown and Residential locations yield higher revenue gains compared to the Commercial and Airport locations. Certain products with higher elasticity (like "Splash Balls") should be reviewed carefully for price changes to avoid reducing sales.

User Interface



4(a)



4(b)

Fig 4 User Interface (a) Input required (b) Recommendation suggested based on the input.

The user interface, developed using Streamlit and Python, enables users to specify the desired level of analysis and provide additional inputs such as store number, city, and store location. Based on these inputs, the application displays the top 5 recommended items along with the expected range of increased revenue. Additionally, it offers the option to download a CSV file containing elasticities and expected revenue increases for all items. This application showcases the real-world applicability of our work, as such tools are often developed for franchise owners, store managers, or other stakeholders to provide actionable recommendations aimed at enhancing store profitability.

4. Future scope and improvements.

The future scope for improving pricing and sales analysis focuses on leveraging additional data and advanced strategies to optimize profitability and customer satisfaction. Currently, price elasticity is calculated based on units sold and price variation, but integrating external factors such as weather conditions and age demographics can further refine the analysis. Weather conditions, for example, can significantly impact foot traffic, as fewer people may shop during extreme weather, while different age groups have varying sensitivities to price changes and purchasing behaviors. By analyzing these factors, businesses can adjust their pricing strategies in real-time to respond to these external influences. Moreover, competitor data is crucial to gain insights into market trends and adjust pricing accordingly, ensuring competitiveness in the marketplace. In terms of price optimization, businesses should look to maximize profits by not only considering elasticity but also taking into account profit margins, cost structures, and market conditions. Price reductions can be strategically implemented when required, such as

during periods of low demand or to clear excess inventory, but these should be carefully managed to avoid harming brand value. Additionally, item recommendations based on customer preferences, sales trends, and store location can help businesses tailor their product offerings to meet specific market needs, increasing sales opportunities. Similarly, inventory recommendations should be integrated to avoid overstocking or stockouts, ensuring the right products are available at the right time. Combining these insights will allow for smarter pricing decisions, more effective inventory management, and better overall customer satisfaction.

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