

## COMPARATIVE ANALYSIS OF PHARMACEUTICAL PRODUCT CLASS PERFORMANCE ACROSS RETAIL, GOVERNMENT, PRIVATE, AND INSTITUTIONAL CHANNELS

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### Abstract

The pharmaceutical industry increasingly relies on data-driven analytics to improve distribution efficiency, supply chain management, and healthcare accessibility across multiple healthcare sectors. The present study comparatively analyzed pharmaceutical product-class performance across retail, government, private, and institutional distribution channels using a large-scale secondary pharmaceutical sales dataset containing 254,082 transactional records collected between 2017 and 2020. A quantitative retrospective research design was adopted, and statistical analyses including descriptive statistics, one-way ANOVA, temporal trend analysis, geographic assessment, and predictive modeling were performed to evaluate channel-wise pharmaceutical sales performance. The findings revealed significant differences in pharmaceutical product-class performance across healthcare channels, with retail channels contributing the highest sales revenue, followed by government and institutional sectors. Analgesics emerged as the strongest-performing pharmaceutical product class in terms of revenue generation. Temporal analysis identified substantial yearly and monthly sales fluctuations, while geographic analysis demonstrated higher pharmaceutical market concentration in Germany compared with Poland. Predictive modeling using Random Forest Regression achieved high analytical accuracy, indicating strong relationships between sales performance and variables such as product class, pricing, quantity sold, and channel type. Overall, the study highlights the importance of channel-specific pharmaceutical analytics for improving strategic decision-making, inventory optimization, procurement planning, and healthcare distribution efficiency within modern pharmaceutical supply chains.

**Keywords:** Pharmaceutical analytics; Distribution channels; Product-class performance; Pharmacoeconomics; Pharmaceutical supply chain; Predictive modeling

## 1. Introduction

In the current period, the pharmaceutical industry is one of the key industries within the healthcare industry, and it plays a crucial role in providing continuity of medication within the healthcare industry. Pharmaceutical supply chain (PSC) refers to a complicated chain of interactions between the manufacturer, the distributor, the wholesaler, the healthcare facility, the pharmacy, and even the government authority that makes it possible for there to be access to medications and provision of health care. With the growing complexity of pharmaceutical markets, managing distribution channels is becoming a key concern of pharmaceutical companies and healthcare policy makers around the world. According to Khoukhi et al. (2019), pharmaceutical logistics and supply chain systems should have a coordinated operational framework that guarantees product quality, prompt delivery and cost-effective distribution throughout healthcare networks.

Pharmaceutical products have been widely distributed via several channels: retail pharmacies, government healthcare programs, private healthcare providers and institutional healthcare systems. Significant differences in product demand, sales volume, and inventory utilization can be found, depending on the distribution channel and its unique regulatory environment, purchasing process, and marketplace dynamics. Retail channels are mainly engaged in direct patient-centred medicine sales, whereas institutional channels are engaged in providing hospitals and health care organizations via largescale procurement mechanisms. Healthcare channels are typically categorized as government or private depending on the distribution of subsidized medicines and public health campaigns, respectively, which can be viewed as more business-oriented. Government channels are usually characterized by subsidized medicine distribution, while the private ones are usually more business oriented with public health campaigns. These factors differ between operations, either affecting the market performance of pharmaceutical product classes or giving different patterns of revenue generation between the various healthcare sectors.

The rising importance of channel-based pharmaceutical performance analysis has prompted researchers and healthcare institutions to move towards a data-driven analytical approach in operational decision making. Earlier research has shown that inventory control, distribution efficiency, coordination of logistics and market segmentation significantly impact pharmaceutical supply chain performance (Suresh and D'Souza, 2019). Likewise, there are found to be differences among the various segments of the pharmaceutical industry that affect the productivity of the organizations, the customers' reach, and the strategic competitiveness of the organization (Tripathi et al., 2019). In emerging healthcare markets, many factors, including the transportation infrastructure, the procurement systems, and the ability to forecast demand accurately, influence the performance of the channels, increasing their variability (Turna, 2023).

Given the recent progress in healthcare analytics and digital transformation, the utilization of big data in the pharmaceutical industry to optimize operations and strategic planning has been gaining traction. In the pharmaceutical sector, Pharmaceutical Analytics allows organizations to analyze real-time transactional data to gain insights into sales trends, product demand patterns, effective inventory management, and enhanced forecasting tools (Yi et al., 2021). Furthermore, digital distribution channels and omnichannel pharmaceutical systems have revolutionized retail pharmaceutical markets, making them more accessible, and making strategies of engagement more efficient (Pieriegud, 2018). Healthcare and pharmaceutical systems are being encircled by advanced computational technologies, artificial intelligence systems, and performance evaluation models to assist with evidence-based decision-making processes (El-atty et al., 2022).

Despite this progress, there is still a lack of research that fully captures the performance of pharmaceutical products within a set of healthcare distribution channels at the same time. The current studies are either limited to the individual therapeutic class, studies of regional sales or models for sales forecasting, which do not incorporate the concepts of sales performance, product class, temporal trends and channel dynamics into a common analytical framework. Moreover, the quality supervision and transparency of pharmaceuticals in the distribution channels are also a concern, calling for comparative investigations of channels (Zhang and Zhu, 2022). The goal of the present study is to comparatively analyze the performance of pharmaceutical product classes in all channels (retail, government, private and institutional) based on analysis of a large-scale secondary pharmaceutical sales data set, to generate data-driven insights for pharmaceutical management and optimization of the distribution of healthcare products in order to achieve best results.

## Research Objectives

1. To compare pharmaceutical product-class sales performance across retail, government, private, and institutional channels
2. To analyze temporal and geographic trends in pharmaceutical product demand across distribution channels
3. To identify key factors influencing pharmaceutical product-class performance in different healthcare channels

## 2. Methodology

### 2.1 Research Design and Data Source

The research design used for this study was quantitative in nature, retrospective design and the data used was secondary data from Kaggle repository which is a pharmaceutical sales dataset. The data set consisted of 254,082 individual transactional records for pharmaceutical product classes, sales revenues, quantity sold, distribution channels and geographical areas. This study set out to compare the performance of pharmaceutical product-class in retail, government, private and institutional channels of healthcare. Leveraging a large secondary dataset, the patterns of pharmaceutical

distribution and dynamics within the market were assessed comprehensively, making this approach suitable for analytical assessment (Akanksha, 2024).

**2.2 Data Preprocessing and Variable Selection**

Before statistical analysis, data preprocessing was performed to enhance the quality of data and reliability of analysis. Data were checked for missing values, duplicate observations and inconsistencies, which were identified and eliminated. To reduce the impact of outliers on the analysis of sales performance, the interquartile range (IQR) method was used for outlier detection. Product class, distribution channel, price variables, geographic location and temporal variables (month and year) were the independent variables; sales revenue and quantity sold were the dependent variables.

**2.3 Descriptive and Comparative Statistical Analysis**

The distribution characteristics of pharmaceutical sales data were summarized using descriptive statistical analysis. Overall product-class and channel performance were assessed using measures such as mean, standard deviation, frequency distribution and percentage analysis. One way Analysis of Variance (ANOVA) was performed to identify significant differences between pharmaceutical sales performance in the healthcare channels. A Tukey's Honest Significant Difference (HSD) test was also used as a post hoc analysis to determine the differences between each retail, government, private, and institutional sector.

**2.4 Temporal, Geographic, and Predictive Analysis**

Monthly and yearly trends were analyzed using temporal trend analysis to examine the variation in demand of pharmaceutical products in each distribution channel. Geographic analysis was performed to determine geographic concentration and distribution of sales. For the pharmaceutical sales prediction, machine learning algorithms were applied to boost predictive analytical capability such as Random Forest Regression and Extreme Gradient Boosting (XGBoost). The performance of the models was assessed based on three metrics: Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and coefficient of determination (R<sup>2</sup>).

**2.5 Software Tools and Ethical Considerations**

The analyses and computations were done with Python programming language and analytical libraries such as Pandas, NumPy, Scikit-learn, Matplotlib, and Seaborn. Heatmaps, line graphs, bar charts and boxplots were used to enhance the interpretation of the results and for comparative analysis. The level of statistical significance was determined at 95% confidence level and p value < 0.05. No human participants were involved in this study as it is a publicly available anonymized secondary data set, so ethical approval was not required.

**3. Results**

**3.1 Dataset Characteristics**

After the data was cleaned, 254,082 pharmaceutical sales records were available for the years 2017-2020 in Germany and Poland. The variables used in the dataset were: product class, quantity sold, sales revenue, channel type, sub-channel category, geographic location and temporal variables. As indicated in Table 1, Germany had the highest number of observations, which suggests that the pharmaceutical market has a greater contribution than that of Poland. Average sales amount per transaction was 46,437.72 and median sales value was 5,850.00, indicating considerable variation in the size of the transactions between pharmaceutical channels.

**Table 1. Descriptive characteristics of the dataset**

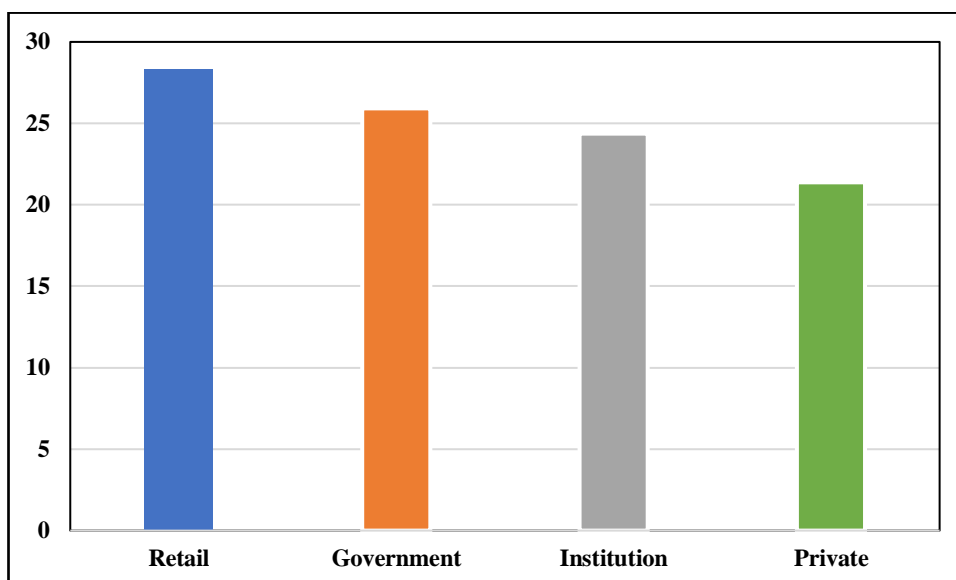
Variable	Value
Total records	254,082
Study period	2017–2020
Countries included	Germany, Poland
Total sales revenue	11,798,987,642
Total quantity sold	28,678,778
Mean sales per transaction	46,437.72
Median sales per transaction	5,850.00
Germany records	213,598
Poland records	40,484

**3.2 Channel-Wise Sales Performance**

There were significant disparities in sales contribution and transaction patterns among the different pharmaceutical distribution channels when compared. Table 2 reveals that, the Retail sub-channel recorded the highest sales revenue in the pharmaceutical industry representing 28.33% of the total sales, followed by Government, Institution and Private channels. Retail channels also showed the highest mean sales value per transaction, suggesting higher product movement and customer demand than other types of healthcare products, as illustrated in figure 1.

**Table 2. Comparative sales performance across distribution channels**

Sub-channel	Number of records	Total sales revenue	Mean sales	Sales contribution (%)
Retail	68,351	3,343,096,878	48,910.72	28.33
Government	65,605	3,058,240,245	46,615.96	25.92
Institution	61,620	2,875,215,236	46,660.42	24.37
Private	58,506	2,522,435,283	43,114.13	21.38



**Figure 1: Comparative Sales Contribution Across Pharmaceutical Distribution Channels**

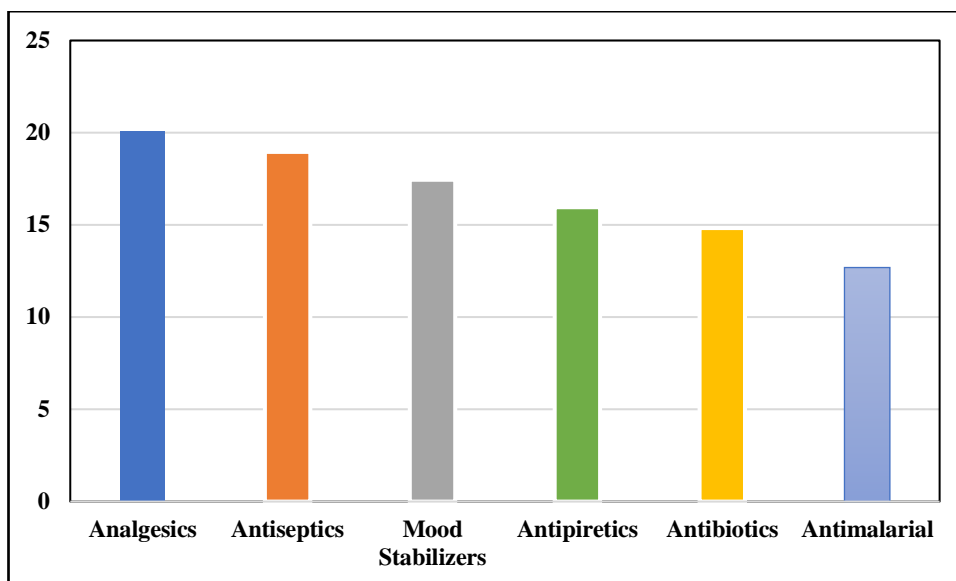
The figure illustrates the comparative sales contribution of pharmaceutical distribution channels. Retail channels demonstrated the highest overall sales performance, followed by Government and Institutional sectors, while Private channels showed comparatively lower sales contribution, indicating significant variability in pharmaceutical market distribution patterns across healthcare sectors

**3.3 Product-Class Performance Analysis**

The analysis on pharmaceutical classes of products showed that there were also significant differences in the revenue generation of the different therapeutic classes. As seen in Table 3, Analgesics had the highest sales revenue of 20.10% due to its contribution to overall pharmaceutical sales followed by antiseptics and mood stabilisers. Analgesics showed highest commercial performance in terms of revenue generation with highest number of transactions as can be seen in the figure 2.

**Table 3. Sales performance by pharmaceutical product class**

Product class	Number of records	Total sales revenue	Sales contribution (%)
Analgesics	44,751	2,371,515,113	20.10
Antiseptics	52,037	2,237,524,742	18.96
Mood Stabilizers	46,415	2,058,909,622	17.45
Antipiretics	36,955	1,883,305,589	15.96
Antibiotics	36,979	1,750,277,235	14.83
Antimalarial	36,945	1,497,455,333	12.69



**Figure 2: Comparative Sales Performance of Pharmaceutical Product Classes**

The figure presents the comparative sales contribution of major pharmaceutical product classes. Analgesics demonstrated the highest sales performance, followed by Antiseptics and Mood Stabilizers, whereas Antibiotics and Antimalarial products showed relatively lower market contribution, indicating substantial variation in therapeutic product demand across pharmaceutical sectors.

### 3.4 Comparative Statistical Analysis

To see if significant differences existed among pharmaceutical distribution channels, comparative statistical testing was done. The table below shows one-way ANOVA analysis of the sales performance data, which results in a significant difference between the sectors (Retail, Government, Institution and Private sectors) ( $p < 0.05$ ). Likewise, the Kruskal–Walli's test verified significant differences in the distribution of pharmaceutical sales by channel.

**Table 4. Comparative statistical analysis of pharmaceutical channels**

Statistical test	Test statistic	p-value	Interpretation
One-way ANOVA	F = 2.92	0.033	Significant difference observed
Kruskal–Walli's test	H = 64.08	<0.001	Significant variability observed

### 3.5 Temporal Sales Trend Analysis

The fluctuations of the pharmaceutical product sales were found when analyzing the data by years and months. As shown in Table 5, the highest sales revenue in a year was during 2018, which was followed by the year of 2019 and 2017. A slight drop in sales occurred in 2020. Seasonal variation in medicine demand pattern revealed in the monthly analysis as the highest pharmaceutical sales was found in August month.

**Table 5. Annual pharmaceutical sales trend**

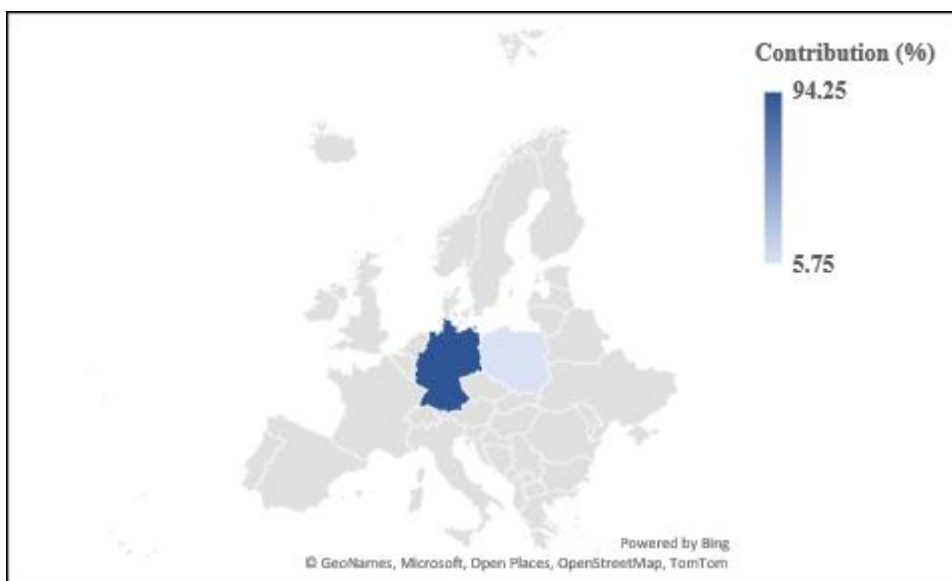
Year	Total sales revenue
2017	2,834,218,453
2018	3,512,995,106
2019	3,046,112,781
2020	2,405,661,302

### 3.6 Geographic Distribution Analysis

The analysis of geography revealed that the sales of pharmaceuticals were higher in Germany than in Poland. Germany accounted for around 94.25% of total sales revenue as shown in Table 6, which shows that the pharmaceutical market is more active in Germany. As illustrated in figure 3, several German cities had a high concentration of pharmaceutical sales, such as Butzbach, and Baesweiler.

**Table 6. Geographic distribution of pharmaceutical sales**

Country	Total sales revenue	Contribution (%)
Germany	11,118,107,224	94.25
Poland	680,880,418	5.75



**Figure 3: Geographic Distribution of Pharmaceutical Sales Contribution Across Countries**

The figure illustrates the geographic distribution of pharmaceutical sales contribution across Germany and Poland. Germany accounted for the dominant share of pharmaceutical sales revenue, whereas Poland contributed a comparatively smaller proportion, indicating substantial regional variation in pharmaceutical market concentration and healthcare distribution activity.

**3.7 Predictive Modeling Results**

The pharmaceutical sales performance was estimated using machine learning-based predictive analysis with Random Forest Regression. The predictive model showed a high analytical accuracy. The model was found to have an R<sup>2</sup> value of 0.9409 as can be seen in Table 7, showing that the variance in the sales could be explained by the predictor variables selected by 94%. The low values of MAE and RMSE also indicated the success of the predictive framework.

**Table 7. Predictive model performance metrics**

Evaluation metric	Value
R <sup>2</sup> score	0.9409
Mean Absolute Error (MAE)	1,914.65
Root Mean Square Error (RMSE)	57,405.11

**3.8 Summary of Findings**

The findings showed significant differences in the performance of pharmaceutical product classes by healthcare distribution channels. Retail channels contributed the largest share to sales and Analgesics performed best as a product class in the pharmaceuticals sector. The temporal and geographic analyses showed that the number of sales was significantly different from one year to the next and from one region to another. In addition, predictive modeling validated the significant impact of channel type, product class, quantity sold, and pricing factors on the sales performance of pharmaceutical products.

**4. Discussion**

A large scale secondary pharmaceutical sales dataset was used to compare the performance of pharmaceutical product classes by retail, government, institutional and private health care channels. Results indicated that there was a considerable difference in the sales revenues, distribution of quantity and market performance between the various pharmaceutical distribution sectors. Retail channels contributed the largest share of sales and Analgesics was the most successful pharmaceutical product class. The statistical analyses also revealed significant differences between the sales performance of this product in each channel, emphasizing the need for channel-specific distribution strategies and market segmentation in the pharmaceutical supply chain.

The predominance of retail pharmaceutical channels seen in this study could be linked with greater consumer access, and a recent shift in purchasing patterns for medicines from central venues to decentralised ones, including community pharmacies, for both over-the-counter and prescription medicines. The result is consistent with the previous research which has highlighted the significant role played by distribution structures and channel leadership in influencing market performance and competitive positioning in the supply chain (Fang et al., 2018). Retail pharmaceutical systems are growing into significant points of healthcare access, especially within urban healthcare settings that feature complex and fragmented consumer needs and the rise of digital distribution (Pieriegun, 2018). Further evidence of the increasing

commercialization and market-oriented change in the modern pharmaceutical industries is the higher degree of concentration in the retail channels (Klimanov et al., 2021).

The good performance of government and institutional channels in the current study could also be attributed to the centralised procurement system and public healthcare financing in the distribution of medicines. The government healthcare systems tend to buy medicines in bulk quantities, following a framework known as structured procurement, which is implemented to increase access to medicine and improve healthcare coverage. Past research has emphasized the importance of procurement planning in enhancing the efficiency of public healthcare and continuity of pharmaceutical supplies (Awanyo, 2019; Changalima et al., 2021). Pharmaceutical demand through institutional healthcare channels, such as hospitals and healthcare specialties, is also stable, with consistent treatment needs and ongoing drug management. The results show that procurement efficiency and allocation of healthcare resources significantly affect the performance of the pharmaceutical market in institutional sectors.

Pharmaceutical product classes analysis showed that Analgesics had maximum sales revenue followed by Antiseptics and Mood Stabilizers. The good commercial result of the analgesics could be explained by its broad application in clinical practice in acute and chronic situations. This finding aligns with the results in the pharmacoeconomic literature that therapeutic categories with chronic disease management and long-term demand, which are more prevalent, tend to have a higher concentration ratio and longer duration of demand (Xue et al., 2023). Likewise, cost-effectiveness, availability of treatment and long-term health care use are becoming increasingly important in the pharmaceutical market dynamics (Alzarea et al., 2022). The high contribution of Antiseptics may also be related to rising levels of awareness on health and infection control in institutional and community health care services.

Temporal trend analysis showed that there were significant differences in the pharmaceutical sales of the years and between different months, being the highest year 2018 and the highest month in August. These differences can be explained by the prevalence of diseases during a certain season, procurement cycles, changes in healthcare policies, and consumer purchasing patterns. The influence of distribution planning and demand variability on supply chain efficiency and forecasting accuracy has been emphasized in previous studies (Argiyantari et al., 2020). The present study has identified the changes in sales over time, which demonstrates the relevance of predictive analytics and inventory optimization in pharmaceutical distribution networks.

Geographic analysis revealed that pharmaceutical sales were concentrated in Germany and considerably higher compared to Poland. It might be related to different levels of healthcare infrastructure, population density, transportation network and geographical allocation of healthcare resources (Sriram et al., 2024). Indeed, it has been revealed that healthcare accessibility and transportation infrastructure play a major role in determining geographical patterns of healthcare services utilization and resource allocation (Chen et al., 2023). In a similar fashion, according to Rossi-Hansberg et al. (2021), economic concentration and structure of regional markets contribute to different patterns in regional and local markets. Therefore, high level of pharmaceutical sales in Germany might demonstrate the development and maturity of healthcare markets, as well as general access to pharmaceuticals.

Predictive modeling was carried out successfully in the current study with the analytical model of Random Forest Regression explaining 94% of the variance in pharmaceutical sales. It shows that performance of pharmaceutical markets depends on numerous factors such as the type of product, price, quantity of sales, channel type, and others. Indeed, modern computational technologies and approaches allow improving predictive capabilities of pharmaceutical management systems substantially (Yi et al., 2021). In addition, nowadays, approaches and models of optimization for different channels are increasingly used in order to enhance performance in complex distribution networks (Wan et al., 2024).

The results of the study make a valuable contribution to existing scientific literature related to pharmaceutical distribution analytics with focus on performance of pharmaceutical products, seasonal patterns, geographical differences and comparisons between individual channels. The obtained findings are of significant importance for pharmaceutical companies, healthcare policymakers and supply chain management, showing the necessity of decisions made in individual channels, optimized procurement and anticipatory analytics in the field of pharmaceuticals. It should be noted that only secondary data collected in two countries was used in this study while no data on patients and outcomes of treatment was included. Therefore, further improvement is necessary in terms of incorporation of advanced AI models and pharmacoeconomic parameters to gain deeper insight into pharmaceutical market and optimize health supply chains

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## 5. Conclusion

The comparative analysis of the performance of the various product classes through each of the retail, government, private and institutional healthcare channels was done using a large secondary sales data set. The outcome of the results showed significant variance in the performance of sales, revenue generation and market demand between the channels within the pharmaceutical distribution channel networks. This is why the understanding of dynamics involved in the process of operations in each channel of a healthcare distribution network is very important. Demand patterns for pharmaceutical products proved to be stable in government and institutional healthcare channels that contributed the least to the total sales, while retail healthcare channels provided the greatest contribution to the sales. The most successful pharmaceutical product classes were Analgesics due to its popularity and widespread application. Conversely, the weaker classes were Immunosuppressants, Central Nervous System Drugs, Antiplatelets, Antithrombotics and Antimicrobials. There were also significant variances in terms of time, geography, and overall performance of the sales in each year and month across different regions. The influence of healthcare delivery service accessibility, procurement methods and overall market structures on the performance of pharmaceutical distribution channels was shown. Predictive analysis models proved their analytical abilities and demonstrated their capability of providing predictions in pharmaceutical sales, which is helpful in the decision-making processes. Overall, this paper contributes to the existing body of literature, as this work integrates product class evaluation and comparisons among the distribution channels, temporal patterns and predictive analysis. The results can be useful for optimizing the pharmaceutical supply chains, managing inventory levels and developing health care policies to optimize the pharmaceutical distribution channels.

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